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Томск / Tomsk – 2016

РЕФЕРАТ

Выпускная квалификационная работа 86 с., 26 рис., 18 табл., 28 источников, 6 прил.

Ключевые слова: Гибридная системы электроснабжения, автономный потребитель, ДЭС, фотоэлектростанции

Объектом исследования является Использование возобновляемых источников энергии, как вторичного источника в гибридной системе электроснабжения поселка в Томской области

Цель работы – Определить возможность и целесообразность использования возобновляемых источников энергии, для снижения затрат на производство электрической энергии и повышения уровня жизни в поселке Лисица Томской области

Методы исследования аналитический, проектный, экспериментальный, изучение литературы

В результате исследования был проведен анализ технического и экономического потенциала возобновляемых источников энергии в Лисице, их возможность и целесообразность использования в гибридной системе электроснабжения совместно с ДЭС, произведен выбор схемы и основных компонентов, входящих в систему. В исследовании произведен расчет максимальной возможности использования фотоэлектрических панелей в составе гибридной системы без использования батарей.

Степень внедрения: Результаты исследования могут быть использованы для снижения стоимости затрат на дизельное топливо и стоимость получаемой электрической энергии в поселке Лисица Томской области

Область применения: Результаты исследования могут быть использованы как методика для оценки возможности и рациональности использования возобновляемых источников энергии в децентрализованных системах электроснабжения, с питанием от дизельных электростанций, а также как проект для установки гибридной системы электроснабжения в поселке Лисица Томской области

Экономическая значимость работы Результаты исследования могут быть использованы для снижения стоимости затрат на дизельное топливо и стоимость получаемой электрической энергии в поселке Лисица Томской области

В будущем планируется С ростом цен на дизельное топливо, привлекательность проекта будет только увеличиваться, и предложенная схема гибридной системы электроснабжения представляет собой выгодный вариант снижения общих затрат и устранения зависимости от цен на топливо

Declaration

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In Tomsk on 2nd June.2016 ……………………………………

Tomsk Polytechnic University
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Faculty of Electrical Engineering

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Thank you,
Daniel Szantai

Abstract

The master thesis focuses on the development to hybrid power system for the needs of village located in decentralized power supply. The thesis solves an important problem of decentralized energy supply by the hybrid PV-diesel system, which not includes an energy storage device.

The goal of the thesis is the creation of a technical and economical documentation of the hybrid power supply system, which provides reasoning for the installation of the system and an analysis of its effectiveness. We design the extension of real diesel generator unit with using the real data of its operating. For achieving the goal we choose the second source, specify the installed capacity, analyze the load coverage, choose the components and give a technical and economic analysis of the system. For the economic part we start with creating the analysis production of second resource and calculation the costs of investment and then using economic criteria for determine the profitability.

Key words: hybrid power supply system, autonomous consumer, rural area, diesel generators unit, PV plant

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Introduction

The absence of access to central power grid is relevant problem for many Russian regions, which have bad geographical conditions or low density of people. It is the optimal design of decentralized energy supply systems, what is one of the most important problems of modern power engineering in Russia. Price of electricity in the rural areas without electrification is several times bigger than the price for customers connected to the central grid. The reasons are in high fuel transportation costs, poor maintenance of the generating equipments and changeable load diagram leading to ineffective work conditions for generating equipments. The need in improving the performance of these systems generates an interest to hybrid power systems, which contain several types of power sources. These systems have better technical and economical characteristics, provides reliable power supply for different autonomous customers. In this context an optimal design of hybrid power systems is quite reasonable and relevant question nowadays.

The aim of this work is to contribute to solving the aforementioned problem by designing a hybrid power supply system for concrete village based on real data of consumption. It includes the creation of a technical and economical documentation of the HPS system, which provides reasoning for the installation of the system and an analysis of its effectiveness. System will be designed like the extension of diesel generator unit with using the real data of its operating. For achieving the goal is necessary to choose the second source, specify the installed capacity, analyze the load coverage, choose the components and give a technical and economic analysis of the system.

Further investigation of the importance of topic and choice for the object of research are provided in the Chapter 1. Chapter 2 presents the basic info about village mainly consumption and the technology of the production of electricity by diesel generators. Criteria and designing process of the system are described in

Chapter 3. Chapter 4 and 5 contains the analysis of potential use wind and photovoltaic energy in HPS system. The Chapters 6 and 7 contain the technical design of HPS system - sizing, choosing components and description of system. Chapter 8 includes economic analysis of system and in the Chapter 9 is describing the impact of the new system on living condition in Lisitsa.

This master thesis is part of the joint master program between Czech Technical University in Prague and Tomsk Polytechnic University, so it is based on the data of TPU and its extension in form of master thesis on the similar topic will be created in CTU.

1. Energy situation in Russian Federation

1.1. Decentralized power supply system

The special feature of Russia is its huge size, which results in the vast energy resources of all kinds, on the other hand it has a problem with connecting to the central network in far and rural areas. The problem of electrification always existed in Russia due to huge areas with the weak colonization, in which are very difficult ensure the central high voltage transmission connection. The problem of connection rural areas to the public electricity grid can be caused by technical barriers such as unsuitable geographical conditions, or by economic barriers such as economically not-approved installation. In 2010 65% of Russian regions had population less than 5 people for square kilometer and it results that 60% of the Russian territory was without electrical connection. According to the Figure.1, population of Russian Federation has asymmetric settlement. The problem with electrification affects mainly regions in Siberia, Far West and in the northeast parts of Russia. On the other hand the best electric connections have regions to the west of the Urals. However, there are problems in the central grid, not only in far region with poor colonization but also in industrialized regions, such as dense forests, mountain areas or areas, which are difficult to access. Obviously, it is not economically effective to connect villages with less than 1000 inhabitants, and with location more than 10 km from the high voltage line.

Taking to the count the geographical features of Russia, the relevant decisions are off-grid projects with the use of renewable energy power supply. In total, about 1400 small settlements with a population of approximately 20 million people (around 13% of population) are located in decentralized power supply zones of Russia. Every year 5 million tons of diesels are sent to Russian most used stand-alone power stations – diesel generators units. Only in the Tomsk region are 123 off-grid diesel stations with total consumption of fuel with annual pricing about 20 million dollars. [12]

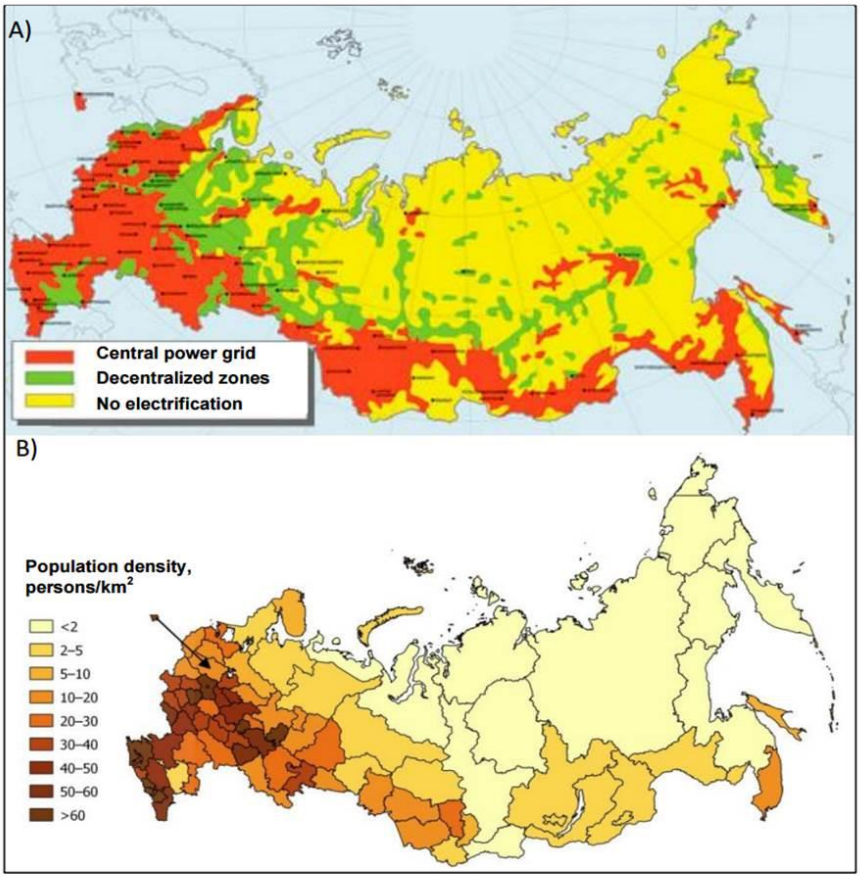

Figure 1 - Maps of electrification and population density of Russian Federation. [1]

A great number of consumers which can be supplied only from the autonomous energy supply systems and problems in the existing decentralized supply systems are leading to the urgently development and optimization of off-grid power supply systems.

1.1.1. Consequences

Absence of central high voltage connection in rural areas has impact many areas of humanity. These influences can be divided to social and economic aspects.

From social point of view, absence of central grid lead to poor living conditions, lower quality of education and the lower quality of health care. Taking into account the geographical features of Russia since 1970s these problems lead to the demographic crisis, which result in migration from rural non electrified areas to urban areas, and also from north to south.

From economical point of view, the access to electricity is useful for technological progress and industrial development of regions, this backwardness leads to high rate unemployment. The construction of central connection or off-grid power systems could to solve these problems.

1.2. Distribution energy

If in the rural areas is not economically effective being connected to central grid, the second possible solution of ensuring the electric energy requirements is conception of distributed energy. So-called distribution energy, or also off-grid energy supply systems, could be defined as systems producing energy near a point of use, with power capacity under 5 MW and connected to a local distribution network system. Distribution energy systems consumption only in Tomsk region is more than 6 million TOE per year.

Basically in Russia are used only two types of off-grid power supply systems. Firstly it is diesel or gasoline generators units, and secondly hybrid power supply systems. These systems used various types of sources, which leads to the different process of generate energy with different technologic and economic characteristics.

1.2.1. Diesel generator unit

Systems of generating electricity from gas, diesel or petrol, are remaining choice for standby and emergency solution. Diesel generator units are the most used type of autonomous energy sources in the Russian Federation. These generator sets can be divided to small portable units (8 to 30 kW) and larger units (30 kW up to 3000 kW), which can be used for villages with population less 1000 people.

The typical diesel power supplies systems are consist only by generators and local mini grid. System doesn´t need batteries, because it controls the output power from the load requirement. Diesel generators produce AC electricity, so for running electrical equipment don´t need converter. On the other hand, if in the system are used batteries, it needs to use a converter to DC.

1.2.2. Hybrid systems

The need of increase technical and economic characteristics of decentralized electricity supply systems determines interest in combination of sources. A HPS systems are systems, which combining two or more energy sources, that are operating together. These power systems, which apply energy sources of different physical nature, are universal in application, have good technical and economical characteristics, provide reliable power supply for various autonomous consumers.

Technically can include almost each type of renewable energy source, diesel, petrol or gas, but some of the types are economically non effective. The world most using combination of sources in off-grid HPS are combination between wind, photovoltaic and diesel.

There are three basic elements of the system - power sources, batteries, and the power management center. Batteries allow autonomous operations by compensating the difference between power production and use. The power management center regulates power production from each of the sources, controls power use by classifying loads, and protects the battery from service extremes.

The detail comparison of features of diesel systems and hybrid power supply systems are shown in Chapter 9 – Social aspects.

1.3. Renewable energy condition

Russia is one of the world's largest producers of energy; most of it is obtained from oil, natural gas and coal. Country is primarily focused on resources for production and export, what means it has paid a little attention to renewable energy. In the result share of electricity generated from RES in 2008 accounted for only 0.9% (8.5 TWh). Despite the fact, that Russia is currently under development in RES, behind thanks to vast expanse has well placed to exploit virtually all available renewable sources.

First of all is important to notice, that Russia is a well-established producer of hydroelectric energy, ranking fifth among the world's producers of renewable energy. Out of the 203 GW of electric generation capacity that Russia has, 139 GW comes from thermal power (oil, natural gas and coal fired plants), 44 GW[1] comes from hydroelectricity, mostly from colossal hydroelectric power stations. Russia is the second in the world for hydro potential, yet only 20% of this potential is developed. [3]

The other areas of renewable energy in Russia are still underdeveloped, although the number of natural resources on the territory of the country present considerable potential for it. According the Tab.3, we know that installed capacity of all areas of renewable energy[2] make up less than 1% of total installed capacity in Russia.

Currently, only about 300 small and micro hydropower plants with a total capacity of about 1 300 MW exist in Russia. The potential for further development is enormous, especially in the mountainous regions in the Caucasus, the Urals and the Far East.

Russia has been developing biofuel power generation since the 1960s, as one of the largest grain and increasingly rapeseed producers with a well-developed ethyl alcohol industry, Russia have a great potential in this sector.

The potential for geothermal energy is high, with theoretical resource estimates of high temperature steam, water and brine at greater than 3 GW. Currently geothermal energy is the third most commonly used form of renewable energy in Russia, after hydropower and biofuel. Biomass is estimated to have an

[1] 21.5% of total installed power capacity.
[2] Excluding hydropower station with capacity over 25 MW

overall technical potential of 35 million TOE in Russia, which, if converted to electrical power, could generate nearly 15,000 MW. This includes sewage sludge, cattle manure, and lumber waste.

Wind energy is the most dynamically developing renewable energy sector in Russia. During the recent years it has surpassed even hydro energy in terms of numbers of newly installed power facilities. Currently about 10 big and 1600 small wind parks are installed in Russia. The country has excellent potential for wind power generation and a long history of small-scale wind energy use, but has never developed large-scale commercial wind energy production. Most of its current wind production is located in agricultural areas with low population densities where connection to the main energy grid is difficult.

Table 1 - Installed capacity of renewable energy as of 01.01.2010 in Russia.[5]

Renewable energy source	Installed capacity
Bio fuel	1400,0 MW
Hydropower[3]	709,0 MW
Geothermal	76,5 MW
Biomass	23,0 MW
Wind	12,0 MW
Tidal	1,5 MW
Solar	0,05 MW
Total	2222,0 MW

Despite of a huge potential of solar energy is this sector in Russia underdevelopment. The first Russian solar plant was opened in November 2010. The highest solar potential is in the southern regions, especially in the Northern Caucasus. Russia plans to increase its solar capacity up to 150 MW by 2020.[5]

[3] Excluding hydropower station with capacity over 25 MW.

1.3.1. Reason of underdevelopment RES

There are several reasons for the underdevelopment of renewable energy in Russia.

First and mostly it is so, because of the low cost of traditional and local available energy sources. Russia is in possession of huge oil and gas reserves, which are easily accessible, and make the production of fuel and energy very cheap. In order to keep the energy prices on the Russian market low, the Russian government imposes high export duties on all commodities. The rise of energy prices can cause, that many plants, especially in the metallurgical field, would have to close down, because their main asset, the low energy prices, would be void. [5]

Another reason why the use of renewable energy in Russia is still far behind Europe and USA is the inconsistent legal base. There are only scarce government subsidies and tax incentives, and no renewable portfolio standard. Furthermore, among the population there is a weak awareness of environmental questions in general and renewable energy advantages in particular. The latter two facts also cause a low share of private investment in renewable energy projects, which along with modest state funding makes the financing of these projects very difficult

Another problem is that the electric grid and storage facilities in Russia need modernization, which is instrumental in the growth of the renewable energy sector.[5]

1.3.2. Support RES

According to the targets of edict ES-2020[4] and ES-2030[5] published by Energy Strategy of Russia, shares of renewable sources[6] in overall electricity production and consumption will be 2.5 percent by 2015 and 4.5 percent (80TWh) by 2020.

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[4] Approved in August 2003 by the government of the Russia Federation.
[5] Approved on August 27, 2009 by the government of the Russia Federation.
[6] Excluding hydropower station with capacity over 25 MW.

On 28 May 2013, the Government of the Russian Federation adopted Decree No. 449 on the Mechanism for the Promotion of Renewable Energy on the Wholesale Electricity and Capacity Market. The cornerstone of the new capacity scheme is the “Agreement for the Supply of Capacity”, which will allow renewable energy investors to benefit from regulated capacity prices for a period of 15 years. The first tender, held in September 2013, was for investment projects to build 399 MW solar power plants, which will be increase to 1.5 GW by 2020.

On November 19th 2015 Russia’s Energy Minister Alexander Novak said, that investment into renewable energy source segment in Russia will amount to 53 billion dollar by 2035. [2]

2. Cause study

2.1. Basic information

2.1.1. Location

The village Lisitsa Verkhneketsky is located in the Tomsk region, one of the federal subjects of Russian Federation, which lies in the south-east of the West Siberian Plain. The administrative center of region is the city of Tomsk. Most of the region's 316,900 square kilometers territory is inaccessible, because it is covered with taiga woods and swamps.

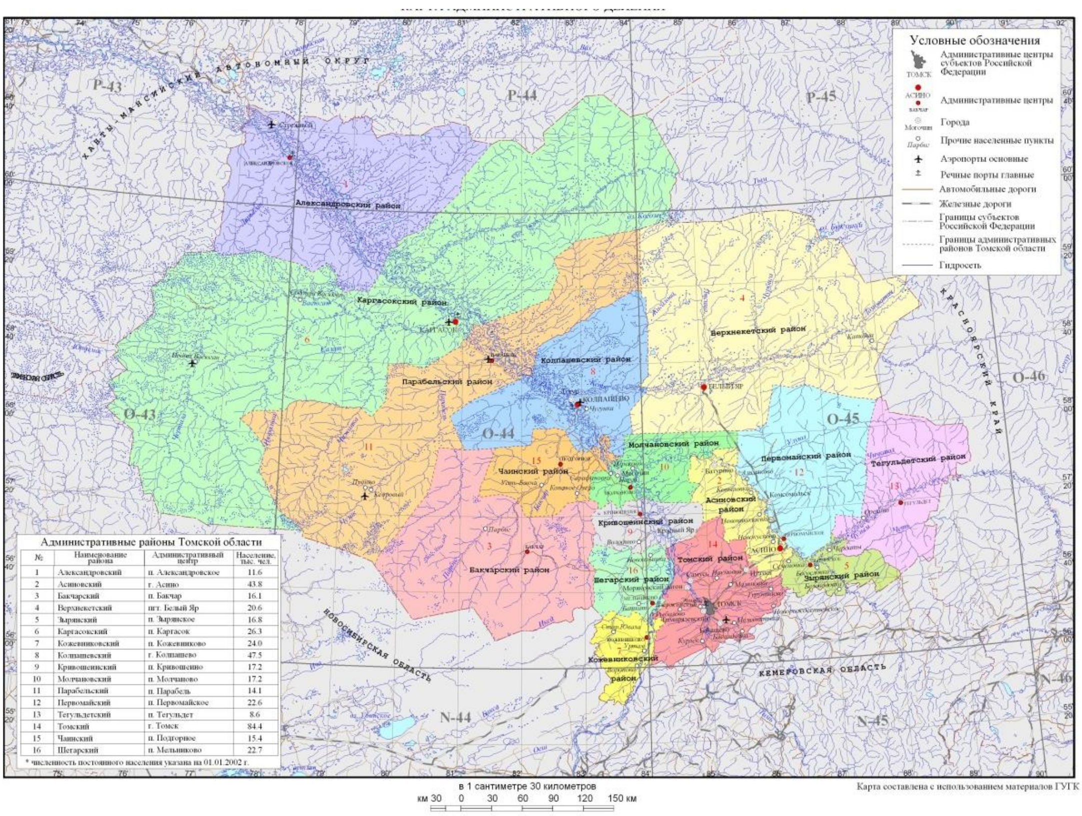

Figure 2 – Map of Tomsk region.

Village is located in Verkhneketsky District, 30 km north air line of Bely Yar, which is the administrative center of district. The district has 17,052 inhabitants (53.1 % in rural areas), which in an area of 43,349 km2 is 0.39 inhabitants per square km. In the Figure 2 is shown map of Tomsk region, district is located in the northeast of the region. In the vicinity of 30 km from the village are no permanently occupied settlements. The village is located in the densely wooded area, on the huge lowland with numerous marshes. The problems with connection is not based in wet terrain around Lisitsa but mainly in crossing across the river Ket, which separates the village from the permanently inhabited places: Bely Yar and Klyukvinka. The nearest bridge across the river is located in the village Stepanovka which is about 100 km by difficult access road, but also to the nearest point in road in this direction must be overcome 50 dense forest.

At the moment 410 inhabitants are living in the village, employed in wood processing industry, hunting or fishing. The buildings are heating by solid fuel boilers; electricity is in the village provided by diesel generators.

2.1.2. Wheatear

Before detail analysis of wind and photovoltaic condition, the average monthly temperature should be know. Its value has a significant influence on how efficiently a wind turbine and solar panel works.

The average annual temperature is -0.5 °C in region and 0.15°C in Bely Yar. Temperature is affected by continental climate with significant seasonal variations; average monthly temperatures are shown in the Figure 3. Annual rainfall is 450-590 mm and average snow depth is 60-80 cm, snow lasts 178-180 days.

Temperature is significantly influencing potential of wind, because density of the air is not a constant. Colder air is heavier and differences can be observed especially at higher wind speeds. The figure shows the power capacity of wind on one square meter depending on the wind speed and temperature.

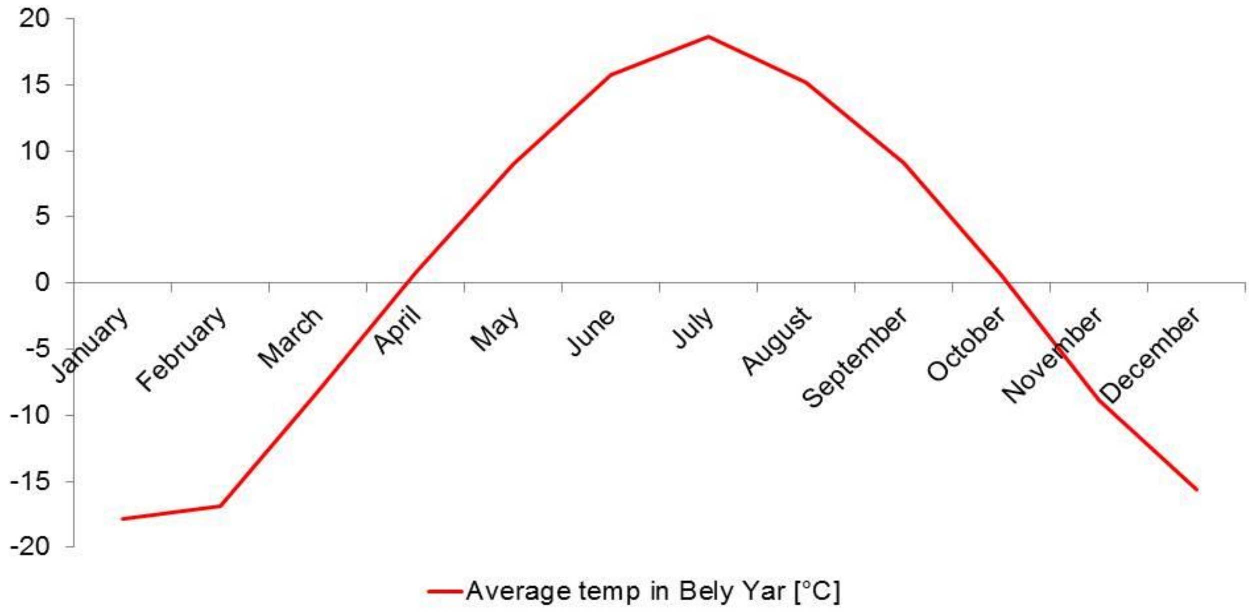

Figure 3 - Average monthly temperature in Bely Yar in the 2015.

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Table 2 – Depending of power capacity of wind on wind speed and temperature.

	Temperature		
	-20 °C	0°C	25°C
5 m/s	87 W	81 W	74 W
10 m/s	698 W	648 W	592 W
15 m/s	2354 W	2187 W	1999 W

Temperature also affects the efficiency of solar panels. Low temperatures production of solar panels increase about 20-30% more efficient.

2.1.3. Absence the high-voltage connection

Formation of the high voltage connection took in the city of Tomsk and the surrounding area, mainly in the sixties in the last century. The most active process of formation of the power system in the north-west areas of Tomsk region took place in the seventies and eighties. During this period, it built the railway Tomsk-Asino-Bely Yar and electricity customers adjacent to rail, were connected and started active development of the northern oil fields. In 1988 was built electric connection C-58,59, between cities Bely Yar and Klyukvinka. This 54.3 km long line with voltage of 110 kV is till today the nearest power line from Lisitsa. However, even for connection to this line, it is necessary to overcome 50 km thickly forested and waterlogged areas. According to the study of *Intersolar Center* construction of a transmission line with similarly long distance for Shalotch village in the Vologda region, would cost 3 800 000 dollars. Village is located, like Lisitsa, in the boggy terrain areas. It would cost some 120 000 dollars per year just to maintain it. [5]

2.2. Consumption analysis

Data about electricity output in Lisitsa in 2014 is shown in Appendix-Table.A4. Stand-alone diesel power stations produced a total 424 MWh of electricity in 2014. Own consumption of station was 17.8 MWh (4.05 % from total producing), and it increase with the amount of generated power. In this number is counted the electricity to illuminate objects, in which the generators are located, electricity used in the repairs, inspections etc. The station delivered to the grid 406 MWh, so daily average is 1.175 MWh. Total electricity consumption and segments of electricity, which is supplied to the network, are shown in Figure 4.

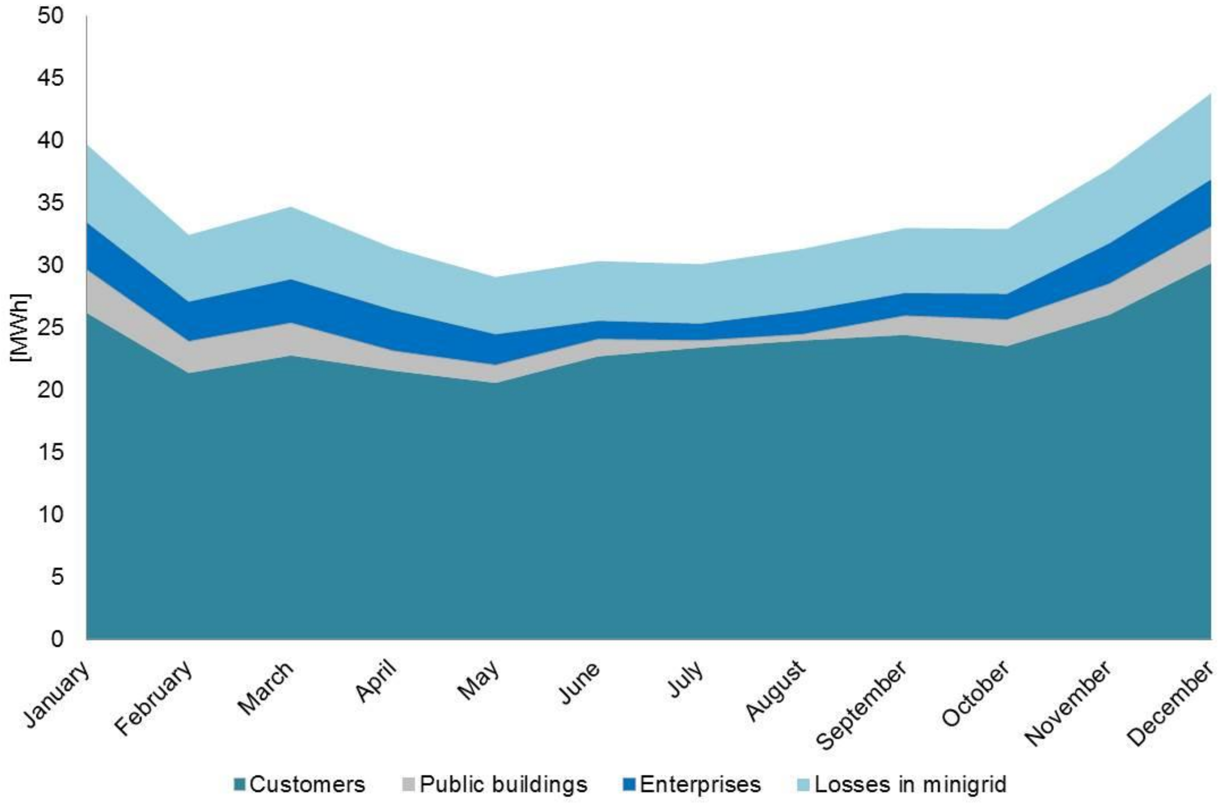

Figure 4 – Electricity of local grid in the 2015.

Significant component are the losses in the minigrid. Overall, for the year 2014 amounted 15.85% (64.5 MWh) of energy supplied to the network. The size of losses is primarily intended for the poor condition of the network, and increase with the amount of electricity in grid. From the electricity delivery to subscribers constitute major part electricity for households. Private customers subscribe up to 70% of electricity supplied to the network. Demand influences the seasons and especially duration of daily sunshine. That is why in the winter time electricity consumption rising up to 30 MWh per month. On the other hand, in May when the days are the longest consumption is only 21 MWh (68% from December's demand). Consumption of public buildings is not as high as might be expected. On average, only 1.9 MWh per month (5.5 % of the electricity network), what is 3 times less than the losses in the network. As in most rural areas the largest part of consumption public buildings from school. It is a reason, why the average consumption across the holidays is only 0.5 MWh per month. The last part of electricity consumption comes from companies. Average monthly consumption is 2.7 MWh (8 % from electricity in local grid).

2.2.1. Daily load

In the next section we´ll look at daily load in rural areas. Daily load graph is shown Figure 5. Quantity of daily consumption is influenced by the seasons, but the distribution of consumption in a day does not change significantly.

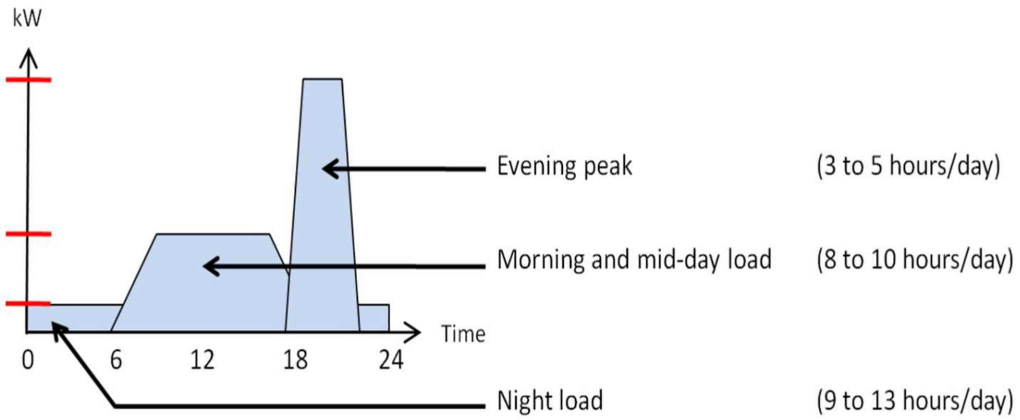

Figure 5 - Load profile in rural areas. [10]

The typical load curve for a rural village is generally composed of a prominent peak in the evening corresponding to lighting use, a morning/midday peak, and a base load. The base load is generally present in the morning, and in some cases extends to night hours. In many cases the peak load is two to five times higher than the highest power level of the base load. The energy demand in rural areas during night hours is quite limited (or non-existent in small villages) and hence the load level during the night is generally very low compared to the evening and morning peaks.

Generation systems consisting only of diesel generators are generally not run to supply a very low load over several hours because, at a low load factor, generators suffer from degradation, plus the highly inefficient fuel consumption makes this economically unviable. That is why the potential energy demand in the night is not served in small villages. The significant difference between morning and evening demand levels favours the use of two different gen-sets to better match these load levels. [10]

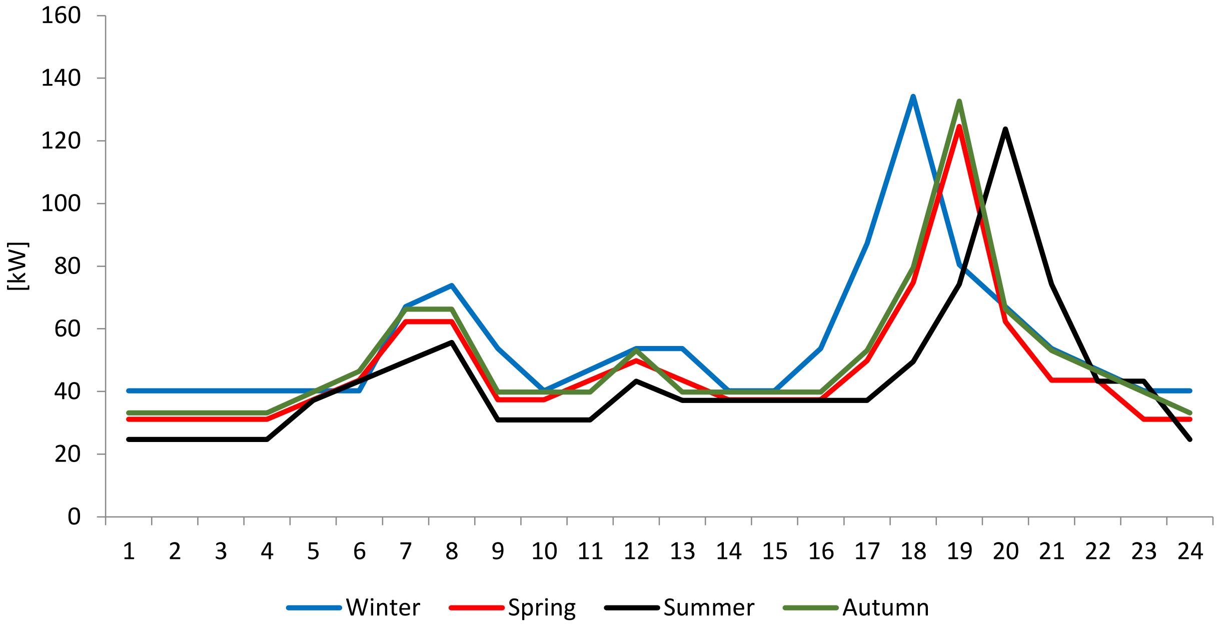

Figure 6 – Load profile in Lisitsa.

According to the typical daily consumption in rural areas and total daily consumption were compiled daily load curve in seasons. Graph of daily load is shown in the Figure 6. Detail process of calculation is shown in Appendix- Table.A5. According to this graph the characteristics of daily load in rural areas described in the previous section are correct. The daily consumption in Lisitsa also does not change during the year and is constant. Time of maximum power is the only characteristic which is changed during the season. In the summer months is peak around 21 hours and vice versa in the winter it is about 3 hours earlier. Load peak size is almost the same in the course of the year in the range from

125 to 140 kW. Derogation from the basic consumption level that is between 25-40 kW is achieved in the morning (6-8) and at the noon.

2.3. Generators

Diesel generator unit in Lisitsa includes five diesel generators with a total output 723 kW. The first generator was installed in 2003. In 2004, was installed two generators type ДГР – 224. These together cover up to 66% of total installed capacity (448 kW), on the other side together generate only 19.1 % of electricity. A fundamental disadvantage of these generators is consumption of level 6 litters per kilowatt hour and the low operating efficiency. For this reason they are used only during peak hours and at the base load are weaned. The problem is that according figure 6 is peak of daily load between 120-150 kW, so during a peak the generators operating on the level of 70-75 % nominal power. This is a reason, why these types of generators are used only like a backup.

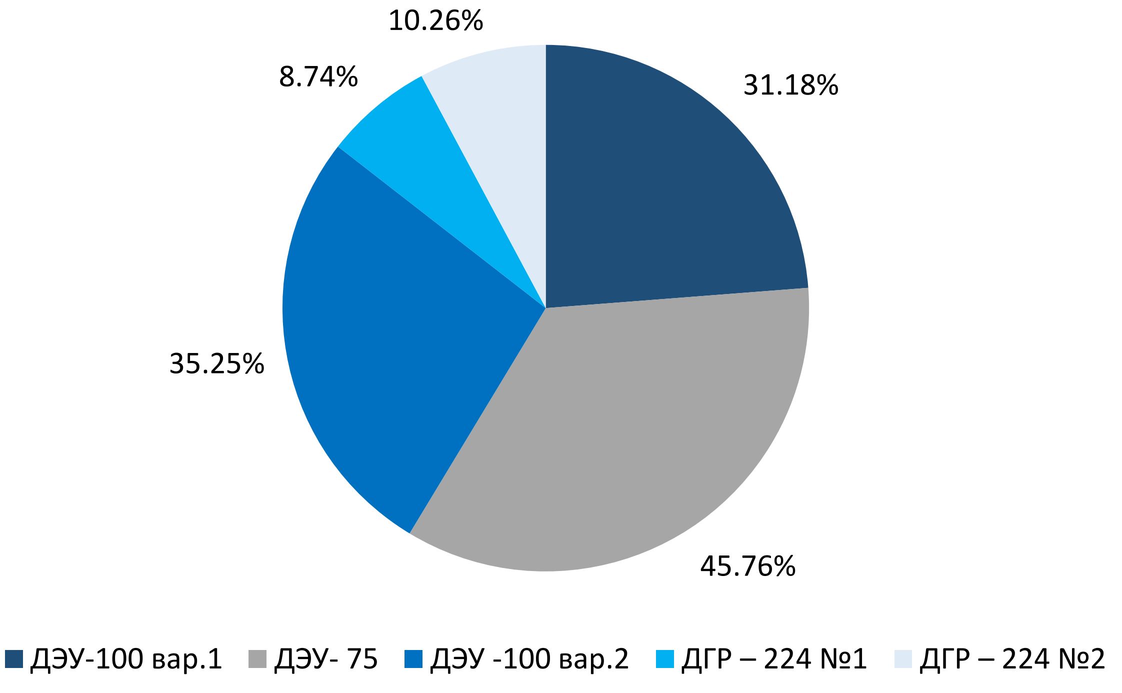

Figure 7 – The percentage of generated energy to specific diesel generators.

Lowest consumption per kilowatt hour has the smallest generators (0.23 to 0.25 liters). However total consumption represent up to 0.41 liters per kilowatt hour due to the using incorrect generators at low level of load. From Figure.6, we know that the basic level of load is between 30-40 kilowatts. The problems are generators efficiency, the generator with the least nominal power is ДЭУ-75 and this results that none of generators have optimal characteristics for operation at basic load. Operation of these generators at the level of 50% of nominal power is significantly increasing consumption of generators. Therefore, even if the project of installation HPS system would not be realized, it is recommended purchase of a new generator with nominal power at 45 kW. The generator will increase the efficiency of generation electricity and will decrease the consumption.

Percentage of generated energy of generators from a total production is shown in Figure 7.

2.4. Economic analysis

Based on the consumption and quantity of fuel was calculated the annual price of one kilowatt hour. In 2014 amounted to 52.63 rubles. Monthly trend of prices is shown in the Figure 8 and complete calculation of electricity costs in the Tab.5. The actual consumption of 0.41 litters per production of 1 kilowatt hour seems to be effective; however, the problem is the high cost of transport of fuel.

Costs for purchases of fuel were in 2014 only 24.07 % of the total cost (approximately 5.55 million rubles). In calculation was used the retail price of fuel, because was not possible to found relevant the wholesale prices in such a remote region.

The total annual cost to transport of fuel is amounted to 17 million rubles. The costs are so high for two basic reasons. Firstly, there is no way by which could be transported such huge quantity of fuels after the Earth surface. The second problem is the location of the village, which are around 60 kilometres as the crow flies from the nearest town. It must be added that, the calculation of consumption helicopter is approximate. Consumption in these machines is measured in litters per hour of flight, because the distance range greatly affects weather conditions. The high transport prices may be significantly reduced with the use of renewable energy, which use local resources.

Table 3 – Calculation of cost for electricity.

Item	Price	
Annual consumption	174399	liters
Price for 1 liter of diesel[7]	34.3	RUB/liter
Total price for diesel	5580766	RUB
Weigh of diesel	146495	kg
Max. payload on external sling[8]	20000	kg
Annual number of transports	7	times
Distance	62	km
Total fly distance	454	km
Cruise speed	255	km/h
Fuel burn	3750	l/hour
Fuel with empty payload	2250	l/hour
Estimate consumption	1470	l/100km
For one year	534276	l
Price for transport	17096841	RUB
Cost for storage[9]	500000	RUB
Operating cost	500000	RUB
Total annual cost for fuel	23177607	RUB
Average price for kilowatt hour	52.63	RUB/kWh

In the calculation were not included the depreciation of diesel generators, which total acquisition cost was 7 million rubles. The total annual cost in 2014 reached the level of 23,177,607 rubles. Per inhabitant it is 50,200 rubles per year.

[7] Cost for liter of diesel from day 11.5.2016. Free available at: [26].
[8] For calculation was used type MI-26 ACMI Transport Helicopter. Parameters freely available at:[27]
[9] Cost for storage and operating cost was estimated based on total fuel consumption.

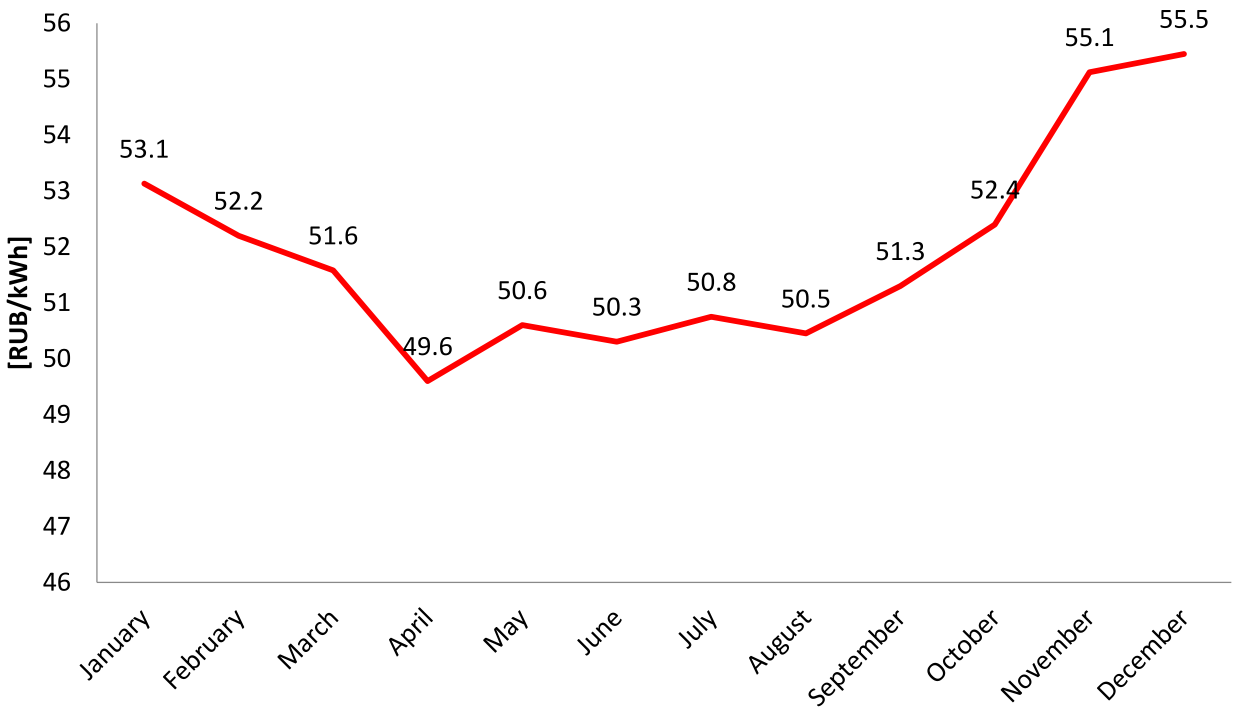

Figure 8 – Monthly cost for one kilowatt hour.

3. Power hybrid supply system

3.1. Design

Based on the SWOT analysis, hybrid stand-alone systems have generally better technical and economical features compare with autonomous power supply station generated energy from the fossil fuels. The proper decisions in the questions of choosing resources and construction of hybrid system are a primary task in design the HPS since it should take into account technical, economic, environmental aspects.

Generally the process of designing of HPS systems include following main tasks:

- initial analysis and selection of resources included onto the system,
- the choice of location,
- sizing of the system and choosing the components,
- final analysis of project.

The main problem in designing the stand-alone hybrid power supply systems is the uncertainty in quantity of electricity, generated by RES. Therefore in the first phase of project must be created analysis of conditions of potential sources (weather and geographical conditions of specific region) and consumption analysis of potential consumers.

After choosing the resource with the highest potential is the next task the determination of an optimal ratio between installed capacities of power sources included into the system. This must be made by taking into account climate and geographical conditions, character of consumption and technical character of system. In this case the main tasks are: agreement of consumption and generation processes, determination of rational load modes, and creation of automatic control systems. The structure of power system significantly influences performance of designing power system and contains many primary tasks being considered in the beginning of power construction project, such as production costs, reliability.

After system configuration is necessary to choose the concrete system components. The uncertainty of RES requires also an introduction of back-up sources or batteries into the system and control system of HPS. Final analysis is the last part of the design the system. Optimization of operating mode comes after the installation of the power supply system.

3.2. Criteria

The determination of main criteria depends on the entity which decides. Project of hybrid power supply system in Lisitsa is primary projected for village inhabitants, but important factor will be also interest of private investors. For inhabitants especially the price on electricity, the number of possible interruptions and the simplicity of power supply play the most significant role. If we consider the private investor, such aspects as a system's performance, installation costs, payback period and risk of the project should be taken into account. For government authorities are the most important the increase of employment and of welfare in the region and environmental issues related to the project.

In the previous chapter was revealed a major weakness of the diesel generator unit. It is not efficacy of generation electricity, but the cost of fuel and its transport. Therefore, the most important prerequisite for a hybrid system is generating energy from local resource which will lead to reduce the transport cost of fuel. This is a reason why the hybrid system must use renewable energy source.

Another important factor is that the combination diesel with other fossil fuels will not be technically, economically or environmentally conveniently. In the evaluation of the feasibility of the project will be an important overall potential of resource. It would not be relevantly to install HPS system in which the secondary source will not even able to generate 10% of total consumption. HPS system should improve the living standards. System downtime it is not be greater than 1 hour 46 minutes per week (reliability of 99%).

In economic terms, it will be important to reduce the cost per kilowatt hour. The total payback period should not exceed 10 years and the maximum total investment in the project should not exceed 50% of the total annual cost of electricity, which is about 10 million rubles.

The precise wording of the criteria is shown in Table 4.

Table 4 – Criteria of power hybrid supply system in Lisitsa.

Type of criteria	Criteria
Technical	C1. One of the sources used in the system must be RES. C2. System must use local resources. C3. Both of resources must be able to generate 10% of annual consumption (40.7 MWh per one year). C4. Installed capacity of the both generators must be 100kW. C5. Reliability will be 99% (average duration of outage 1 hour 46 minutes per week). C6. Battery must be able to cover 25% of daily consumption.
Economical	C7. Total investment cost cannot be more than 5 million rubles. C8. Payback time of the investment must be less than 10 years. C9. The HPS must decrease the price of electricity in minimum about 20% in 5 years period.
Other aspects	C10. The system must improve livelihoods. C11. Installation time must be less than one year. C12. The HPS must decrease GNG emissions.

3.3. Possible solutions

Some sources of renewable energy may be excluded from the system designing without a thorough analysis of the potential. It is doing based on geographic characteristics such as location and terrain.

3.3.1. Potential of biomass energy

So, first of all, it is necessary to consider the volume and location of biological resources. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: thermal, chemical, and biochemical methods. Different technologies of processing in biomass energy are available dependent on its type. According to the type of sources of biomass are distinguished the following groups:

- peat;
- wood and products of it;
- agricultural waste and high-yielding plants;
- waste of human activity.

Decentralized energy areas in Russia tend to have large resources of forest and peat, many times greater than other types of biomass. Volume of the possible number of annually produced wood is not limited to felling. In the process of forest care, sanitation and other cutting it is possible to produce 2 million cube meters. Thus it is a significant energy source, inexhaustible source, environmentally-friendly, and in this respect, incomparable with oil or gas. Peat is one of the most common solid combustible fossils, too. Russian Federation has possesses the largest reserved of peat and Tomsk Region specially has the second largest reserves of peat in Russian Federation. By 1994 in its territory were identified and accounted 1340 peat deposits in virtually areas. Thus, such types of biofuel as wood and peat are common in Russia and in many cases are considered as primary energy source, making up traditional power base of decentralized energy areas. The main advantages of these energy resources are independence of their potential on the season, available energy transformation technologies, and low production cost of electricity. [15]

The problem is that the use of local biomass resources is capital-intensive. For burning in boilers it should reach a degree of moisture (16-20) and so fuel for the achievement it must be dried. That means in addition to liner cargoes for the supply of fuel (wood or wood products), in the total cost is necessary include also the cost of building the appliance. It should be also noted that energy density of biomass is much lower than that of coal and oil, so its transportation over long distances for energy production is not economically profitable. On that basis is divided to the technologies, which convert the energy from biomass directly or from biofuel. Biofuel is resulting from the processing of biomass, to achieve a higher calorific value and designed for transport and subsequent use.

Secondly, the combination of biomass or biofuel with diesel generators are among the least used HPS systems. There are several reasons, but the most important are that both generators can provide constant power. Diesel generators and biomass boilers are the deterministic source of energy, which does not depend on the season or time of day, but they can adjust the output power based on the consumption. This is not a bad property but it causes that both these types of generators combine exclusively with stochastic energy sources, because are able to close the gap fluctuations in their performance.

The most common type HPS system with using the biomass is in combination with photovoltaic and wind power. Based on the above-mentioned fact, in the construction of HPS system in the Lisitsa will be primary use wind or photovoltaics energy.

3.3.2. Potential of hydropower energy

Hydropower potential in Lisitsa is almost zero. The northern areas of Tomsk region are large swamps which, moreover, after seven months in a year are freezing. On the use of water power is need to reach a certain level of falls and the quantity of water in the river, what in the backwaters is not reached. In the construction of HPS system will not use hydropower energy.

4. Wind potential

Wind is one of the most using energy sources in the hybrid power supply system. Especially in a combination with PV energy or diesel generator units can create very efficient autonomous system. Options of using are significantly limited, because wind is a stochastic energy source. The fact that it cannot be effectively predicting future values is a reason, why it must be combined with more constant energy source.

On the other hand combination with PV can be very profitable, because wind turbine generally creates higher output during the winter and spring, whereas the solar panels produce peak output during the summer. With the effective combination of these two sources can be providing a constant electrical output throughout the year.

As the wind power is proportional to the cubic wind speed, it is crucial to have detailed knowledge of the site-specific wind characteristics. Even small errors in estimation of wind speed can have large effects on the energy yield, but also lead to poor choices for turbine and site. An average wind speed is not sufficient. Site-specific wind characteristics pertinent to wind turbines include:

- long-term fluctuations;
- short-term fluctuation(turbulence);
- wind speed;
- wind speed distribution;
- distribution of wind direction. [13]

4.1. Wind condition in Tomsk region

The average annual wind velocity in the Tomsk area is around 3.2 m/s. The prevailing wind directions are southerly and south-westerly. The highest monthly average wind velocity is observed in the spring months, the lowest in June and July with a velocity 2.5 m/s and also in the winter. The maximum wind velocity in the area can reach around 30 m/s with southwesterly winds. Seasonally, the highest velocity is noted in the spring and autumn, rarely in the summer. In the winter months the maximum wind velocity does not exceed 15 m/s. [24] Characteristics are affected by continental climate with the big see distance (the nearest big water surface is Baikal - 1850 km) and considerable distance from mountains (the nearest Altai - 1000 km).

These parameters suggest, that Tomsk region is not ideal for the construction of wind power plants. For effective utilization of wind energy it needs to have average annual wind speed at least 3.5 m/s. It is limit, where low wind turbines start to generate the first watts of power.

Figure 9 - Average annual wind specific power map [W/m²]. [10] *[15]*

[10] The calculation of wind potential correspondent to height equal 10 meters.

Positive is that, there are large differences between particular cities in region. In the Figure 9 is shown average annual wind specific power map of Tomsk region. Wind flow specific power is integrated wind energy performance per area unit of flow cross section. According the map region can be divided by two areas: flood of the river Ob and river Ket, where the average annual specific power is between 150-200 W/m^2. However in the rest territory specific power characteristics do not exceed 100 W/m^2. [15]

Village Lisitsa Verkhneketsky (red point in the Figure.9) is on the edge of effective distribution energy from wind. Village is located around 45 km north from river Ket, near the city Bely Yar, where is according map specific power equal to 140 W/m^2.

4.2. Wind condition in Lisitsa

4.2.1. Long-term fluctuation

One of the first steps in detailed determining, if a wind energy system is profitable is find how much wind energy is available. To obtain reliable data for analysis of the territory is necessary to use large amount of measurements for a sufficiently long time. The annual energy yield from wind can also vary from year to year, caused by many factors including variations in solar intensity and other large-scale effects. Empirical evidence shows that these annual variations are much more distinct than for solar irradiance and can vary as much as 30 %. According to longitudinal data is possible to say, if the metrics show the trend or an anomaly caused by annual variations.

Unfortunately, in the village Lisitsa meteorological station was installed at the beginning of 2015, therefore before detailed analysis of the measured values needs to be finding at long-term trends in this area. It is reason, why for long-term analysis was used data from Bely Yar, the nearest city with relevant data.

The average wind velocity from the year 2015 is 3.12 m/s, what is almost the average for last 6 years, so annual wind velocity correspond to the long-term values, are reliable and can be used for detail analysis. It cannot be observed upward or downward trend over the last half dozen years, annual average wind velocity in this period was between 2.9 to 3.5 meters per second.

4.2.2. Wind speed and wind gust

Data from meteorological station in Lisitsa (more appendixes Tab.A1 and Tab.A2) was measured by an anemometer, which is placed only 2.12 meters above the ground. It is known that wind speed in a removal process from underlying surface increases and air flow becomes steadier. Approximately wind speed at the altitude h can be estimated by formula:

$$V_h = V_v \times \left(\frac{h}{h_v}\right)^{\alpha}$$

where, V_h is wind speed at the altitude h, V_v is wind speed at the altitude of vane, h_v is vane height, α is factor dependent on average wind speed at the altitude of vane[11]. [15]

With this formula was data transforming from 2.12 to 12 meters.[12] All another graphs and calculations will be corresponding in this height.

One of the basic indicators determining potential of wind power supply is an average monthly and annual wind velocity. Long-term average annual wind speed was discussed in the preceding section. In Lisitsa Verkhovensky in height equal 12 meters is average wind speed 4.06 m/s. For small wind power plants usually need the average annual wind speed in 12 meters at least 4 meters per second.

From detailed analysis in the Figure 10 we know, that monthly wind velocity is unevenly. The highest values reach in spring, on the other hand in winter, when

[11] Coefficient α was changed according wind velocity on 2.12 meters (interval 0.13-0.2).
[12] 12 meters was chosen like limit height in which can be install both micro and small wind turbines.

energy demand is the highest - wind potential is limited. It should be noted that in the winter months, the average monthly wind speed compared to the highest measured value decrease of 45%.

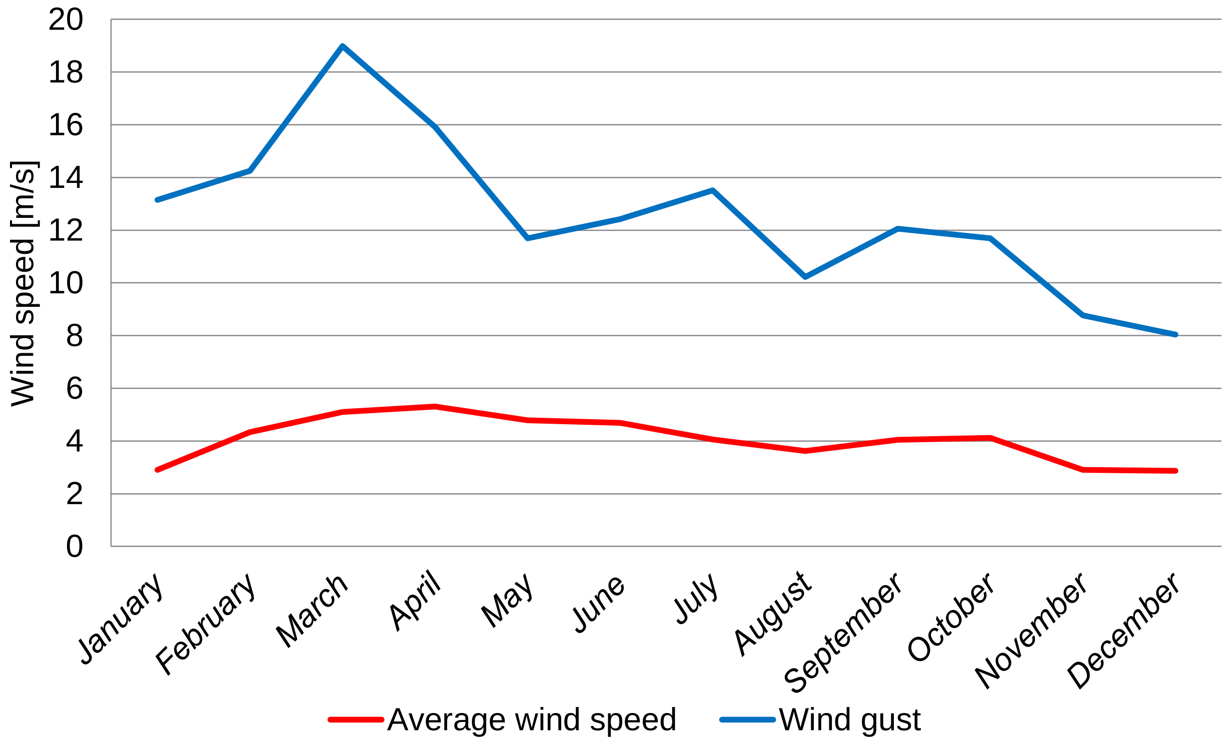

Figure 10 - Wind speed and wind gust - 2015th Lisitsa Verkhneketsky.

A wind gust is a sudden, brief increase in the reported when the peak wind speed reaches at least 8 m/s and the variation in wind speed between the peaks and lulls is at least about 4.5 meters per second.[13] The duration of a gust is usually less than 20 seconds. Gusts at the ground are caused by either turbulence due to friction, wind shear or by solar heating of the ground. These three mechanisms can force the wind to quickly change speed as well as direction. [25] Sites with high average wind speeds tend to suffer less from turbulence. In the case of friction, gusts are generated when wind blows around, trees or other obstacles. This type of gustiness is generally largest near tall buildings and alley ways and least over large water bodies. But air over water can still be gusty. This can be caused by wind shear. A

[13] Definition is valid for the wind speed measured at 10 meters height.

wind shear is a change in the wind over a distance. This can be a change in wind direction, wind speed or both.

High winds are known to cause damage, depending upon their strength. One of the main characteristics of wind its high temporal variations, where wind speeds can double or triple within seconds. Wind power is depend on the cube of the wind speed, if wind speed increase about 2-3 m/s, wind power increase 8 or 27 times. [13]

Turbulence is bad for wind turbines especially for three reasons. It reduced production of energy, increased wear and tear shorten lifetime of the turbine and increased dynamic loads on the blades. Classic HAWT must be in strong winds either electronically or mechanically braked. Otherwise at extreme speed limit threatens to overcome the strength of the material used. However VAWT do not need to brake because the upper limit of the wind speed is not limited, or is very high.

According to obtained data, the power of wind gust in Lisitsa is relatively low. The values less than 20 m/s are on the level in which small and medium sized wind turbines achieve optimal performance.

4.2.3. Distribution of wind energy

Distribution of wind directions[14] is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. These graphs can be thought of as a wheel with spokes spaced, at 45 degrees and for each spoke the wind speed is calculated separately. The design and location of a wind farm and wind turbines is sensitive to of the shape of wind direction graph.

Deformation of the graph is caused by two reasons. The first are macro-climatic situation, while the latter is shape of terrains and obstacles near the place of

[14] Called also wind rose.

installation. It means inhomogeneous landscapes, steep cliffs or mountain tops or regions with many obstacles (such as buildings, chimneys of factories etc.).

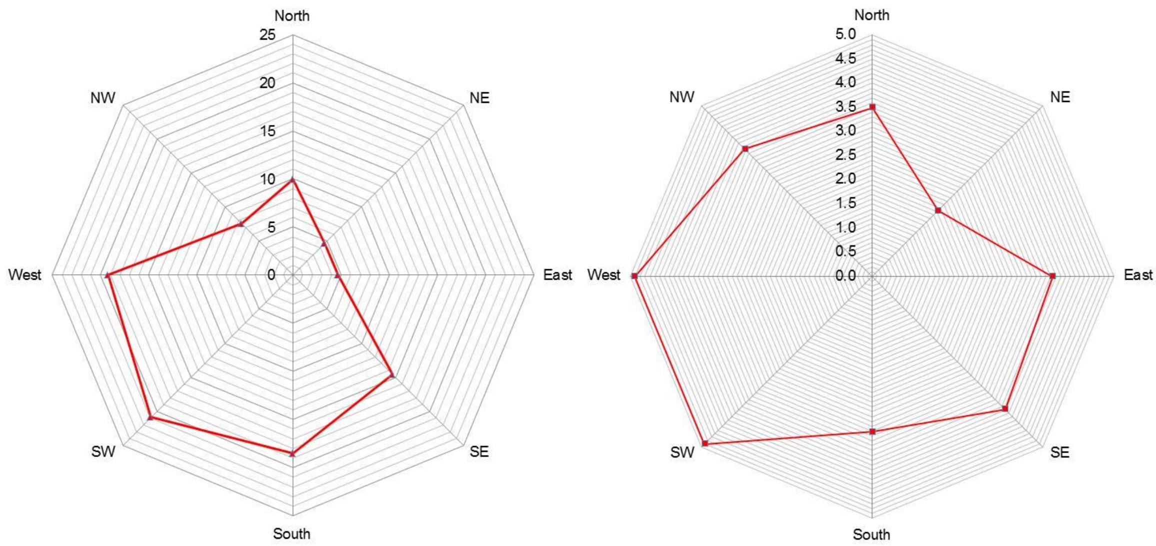

Figure 11 - In the left graph is measure the time wind blows in each direction [%] and in the right average wind speed across all directions [m/s].

The design of a wind farm is sensitive to the shape of the wind direction graph. In some areas, particularly in areas where the wind is driven by thermal effects, the wind can be very unidirectional. In this type of site, the wind farms tend to be arranged in tightly packed rows, perpendicular to the wind, with large spaces downwind. [14]

Left graph in the Figure 11 shows the duration for which the wind comes from this sector for village Lisitsa. Values are consistent with the results of the study from under which the prevailing wind direction in the Tomsk region is South (in Lisitsa 18.5%) and Southwest (20.9%). [3] A strong presence has also Western wind direction which blows 18% of the time. The bigger differences can be seen in the right graph in which are shown the average wind speed across all direction. Average wind velocity with West and Southwest direction are 4.9 m/s. Each other direction has average speed less than 4 m/s.

Combine both measurements by multiplying the time with the cubic speed for each sector individually to get the distribution of energy across all directions. In the Figure 12 we can see that 64.9 % from wind energy will be creating from wind with west and south-west direction.

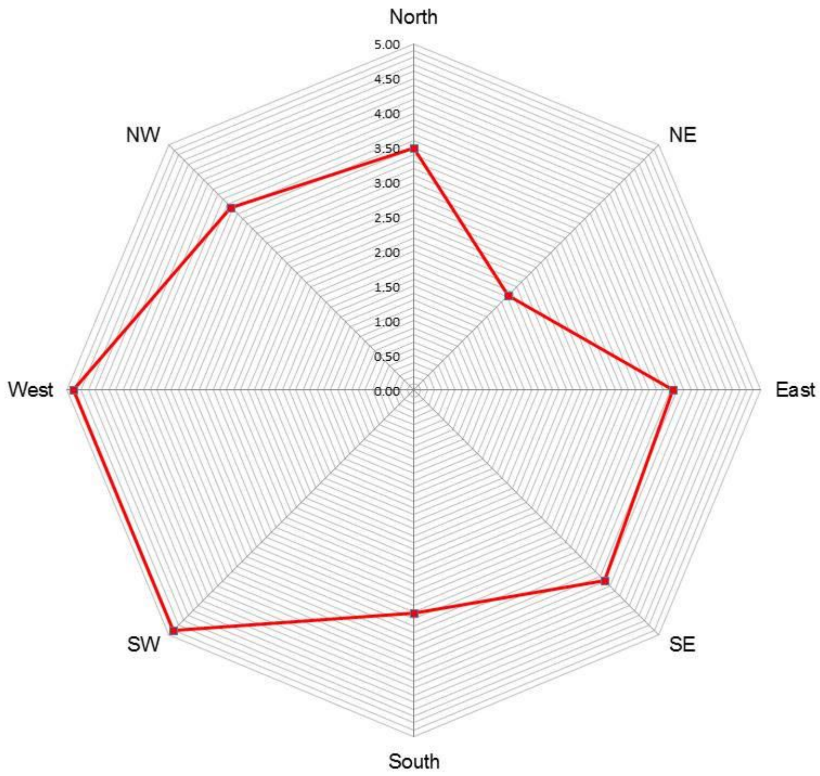

Figure 12 - Distribution of energy across all directions [%].

4.2.4. Wind distribution function

The description above focused on the wind speed and wind rose. The other important parameter determining the output of a wind turbine is the wind speed distribution. This distribution describes the amount of time on a particular site that the wind speed is between different levels. This distribution is important since it is the combination of the wind speed distribution and the power curve of the proposed turbine which together determine the energy production. [14]

In the Figure 13, the actual wind speed distribution in Lisitsa is shown, as well as a Weibull fit to the distribution. The Weibull distribution is a mathematical expression, which provides a good approximation to many measured wind speed distributions. The Weibull distribution is therefore frequently used to characterize a site. Such a distribution is described by two parameters: the Weibull scale, parameter which is closely related to the mean wind speed, and the shape parameter, which is a measurement of the width of the distribution. This approach is useful since it allows both the wind speed and its distribution to be described in a concise fashion. However, as can be seen from the figure, care must be taken in using a Weibull fit. For many sites it may provide a good likeness to the actual wind speed distribution, but there are some sites where differences may be significant. [14]

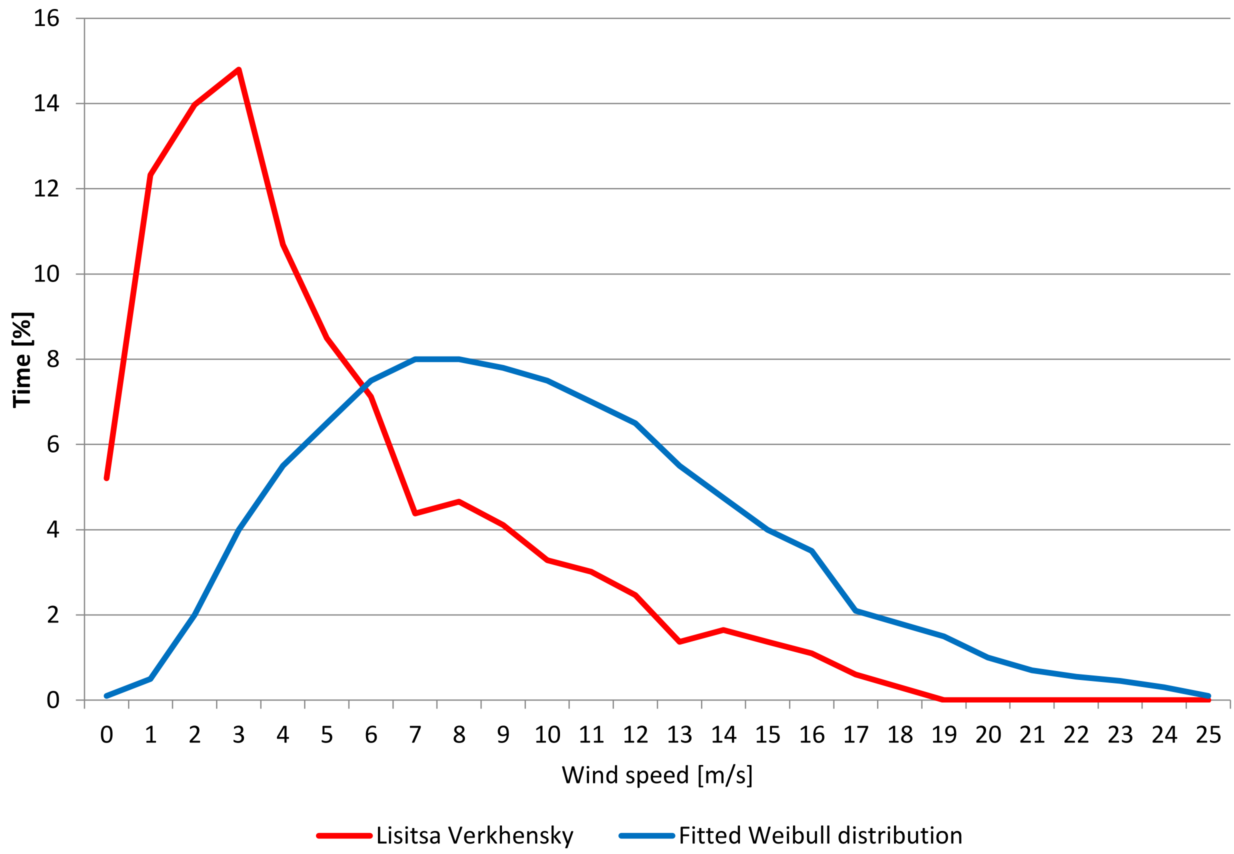

Figure 13 - Wind speed distribution function.

This function is important since it is the combination of the wind speed distribution and the power curve of the proposed turbine which together determine the energy production. In the graph is clear that compared with Weibull function is distribution function from Lisitsa significantly deformed. Most represented are the wind speed in the range of 3-4 m/s, in the 45% of times are wind velocity less like 5 m/s. Another significant problem is range of values. The highest wind speed in the 2015 was 19 m/s, and only 13.2% of total time was wind speed more than 10 m/s.

4.3. Wind turbines

Based on the annual wind speed and the wind distribution function, we know that in Lisitsa can be installed only small and micro wind turbines. On the other hand, to be able to meet the criterion C3 and ensure annual minimum of 40.7 MWh of electricity will have to choice between turbines with an installed capacity of at least 2 kW. For calculation of potential energy, we selected the following types of wind turbines:

- Сапсан-5000 [7]
- MicroArt - Low wind generator 2.5/3.5 kW [8]
- MicroArt - Low wind generator 5/7 kW [9]

Turbines were selected based on availability, installation cost and especially on performance characteristics. Detail parameters of turbines are shown in the Table 5.

According distribution function was calculated the values of potential annual electricity energy for all 3 types of wind turbines. The values are in the range 8-15 MWh depending on installed capacity of turbines. To meet the criteria C3 for production at least 10% of total consumption of electricity would need to use at least three turbines of the type *Low wind generator 5/7kW* or five turbines *Low Wind 2.5/3kW*. Theoretically it is possible to meet the criterion C7 without being overrun of the maximum possible investment in the project, but the problem will be with storage the energy.

Table 5 – Technical specification of wind turbines.

	Low wind generator 5/7 kW	Low wind generator 2,5/3,5 kW	Сапсан-5000
Rated power	5000 W	2500 W	5000 W
Max power	7000 W	3500 W	6000 W
Rotor	6 m	3.8 m	2.5 m
Number of blade	3		
Rated speed	8 m/s	10 m/s	10 m/s
Working wind speed	3-30 m/s	2.5-25 m/s	3-45 m/s
Max. wind speed	50 m/s		
Operating voltage	48V		48-56V
Annual production	3.5 - 10 MWh	3 - 8.5 MWh	3 - 11 MWh
Optimal mast height	12 meters		
Working temperature	-30°C; 50°C	-40°C; 50°C	-30°C; 50°C
Generator	With permanent magnet, 3-phase alternating current		
Type of blades	polyester resin reinforced with glass fiber		
Type	Horizontal rotation of the rotor across the wind		
Braking method	automatic brake, folding tail	electromagnetic brake	
Manufacturer	MircoArt		Сапсан-энергия
Price	299 000 RUB	140 000 RUB	319000 RUB

4.4. Conclusion

Daily historical data from weather database can provide a basic understanding of wind patterns, however due to the sensitivity and variability of wind, no calculation can replace real measurements at the site itself. Climate data, including wind patterns, mostly comes from small meteorological stations located on the edge of town and measuring the rate at low altitudes. It is often the case that the wind patterns measured at these places are very different than the wind patterns of nearby sites. However, by understanding basic concepts of air movements, you can adjust the wind data to better suit the site location and simulate more accurate scenarios.

Table 6 - Annual energy capture and price for kWh generated by wind turbine.

		Low wind 2.5/3.5 kW		Сапсан 5000		Low wind 5/7kW	
Wind speed [m/s]	Distribution function of wind [%]	Power in wind speed [W]	Output [Wh]	Power in wind speed [W]	Output [Wh]	Power in wind speed [W]	Output [Wh]
0	5.21	0	0	0	0	0	0
1	12.33	31	91.73	3	271.41	0	0
2	13.97	60	201.21	26	674.73	0	0
3	14.79	300	1065.21	38	3782.21	500	1775.34
4	10.68	550	1410.41	126	3616.83	700	1795.07
5	8.49	950	1936.44	362	3947.15	1200	2446.03
6	7.12	1250	2136.99	625	3653.37	2000	3419.18
7	4.38	1480	1557.04	992	1638.09	2700	2840.55
8	4.66	1920	2146.19	1481	2399.03	3480	3889.97
9	4.11	2200	2169.86	2109	2140.14	4200	4142.47
10	3.29	2350	1854.25	2894	1463.08	5000	3945.21
11	3.01	2680	1938.41	3851	1402.03	5700	4122.74
12	2.47	2900	1716.16	5000	1015.59	6500	3846.58
13	1.37	3200	1052.05	6357	345.88	7000	2301.37
14	1.64	3350	1321.64	6200	521.42	6000	2367.12
15	1.37	3485	1145.75	5550	376.69	5300	1742.47
16	1.10	3300	867.95	4920	228.28	5100	1341.37
17	0.60	3090	444.96	4400	64.07	5000	720.00
18	0.30	2750	198.00	4150	14.26	5000	360.00
19	0.00	2600	0	3750	0	5000	0
Total output		22.96	kWh/day	27.55	kWh/day	41.06	kWh/day
		8.38	MWh/year	10.06	MWh/year	14.99	MWh/year
Percent of consumption		1.81%		2.37%		3.53%	
Price		140000	RUB	319000	RUB	299000	RUB
Installation cost		150000	RUB	215000	RUB	195000	RUB
Operating cost (5years period)[15]		100000	RUB	140000	RUB	140000	RUB
Total cost		408000	RUB	544000	RUB	524000	RUB
Price of generating electricity years period)		46.53	RUB/kWh	77.76	RUB/kWh	43,7	RUB/kWh

[15] Operating cost was estimated according install capacity.

Average wind speed in Lisitsa was 4.06 m/s in the year 2015. It predicted low potential to use wind energy in hybrid power supply system. This basic indicator suggests, that installation wind turbines may, under certain conditions, be profitable. The most important elements of which considered in the assessment of wind potential is consumption. The daily consumption of energy at the level of 1.114 MWh determines capacity of turbines, which can be effectively used in hybrid power supply system. For effective completion of diesel generator units is needed to use turbine with install power of at least 2 kW, but optimally 10 kW. These turbines need only to start rotation speed on the level of 3 m/s and for optimum performance 10-12 m/s. However according by the distribution function we know that these levels of velocity are reaching only in 15.2% from all the time.

Even though that according technical view could be used turbines with install power around 3-5 kW, this solution is not economically profitable. In the Table.6 is calculated the profitability of three types of turbines at the different levels of wind speed. The wind turbine costs represent only 30 %-35 % of the total cost of a small wind electric system. It is necessary buy other components of wind energy system, such as inverters and batteries, as well as initial cost and labour. The cost of the energy produced by wind turbines over the 5 years period has been estimated to vary 43-45 rubles per one kilowatt hour. Total costs will reach more than 7 million (maximum investment will exceed by 50%) and the price per kilowatt hour will decrease about 9 rubles, which is 17%.

Factor which decided that wind energy cannot be effectively used in HPS system was the price per kilowatt hour. However the system in combination Wind-DG cannot meet also the criteria C5, C7, C8. Investment will be more than 5 million rubles, reliability will be less than 99% and the estimated payback period is 17 years.

5. Photovoltaic condition

Such as wind energy also the biggest negative of solar energy is an intermittent of energy, which means that it is not available all the time. Unfortunately the Sun's bounty can be harvested only during daylight hours and some energy must be stored for use during the hours of darkness or energy must be providing from another source. In both on-grid and off-grid situations, solar PV has considerable merits, sometimes in combination with other energy sources.

Solar energy resources of the territory are directly influenced by follow geographic and climatic characteristics:

- daylight duration;
- values of irradiation;
- potential photovoltaic energy;
- azimuth and latitude of panels.

The most common indicator used for prediction the effective installation of solar panel is the value of potential solar energy. This characteristic determines average annual quantity of photovoltaic energy falling on the earth, but does not show a number of micro-climate features, which may have certain influence of them.

The parameter is used for two possible adaptations of results. The first compares the monthly amount of solar energy within a year, while the latter compares annual values of potential energy in different locations.[17]

According potential solar energy map shown in the Figure 14, Tomsk region can be divided by three areas. Southwest part of the region, with total average annual radiation on horizontal surface makes 1100-1200 kWh/m^2. These conditions ensure stable operation of solar plants. Central part of region with total average value of energy resource a year makes 1000-1100 kWh/m^2, which basically meets the requirements of small and medium sized solar plants operating. North-east part has potential of solar energy resource equal 900-1000 kWh/m^2. In this area, conditions for use of large and medium-sized solar plants are unfavorable.[16] According the location of village Lisitsa (red point in the Fig. 14) can be expected, that annual potential solar energy for horizontal position of panels will be in interval 1050-1150 kWh/m^2. [15]

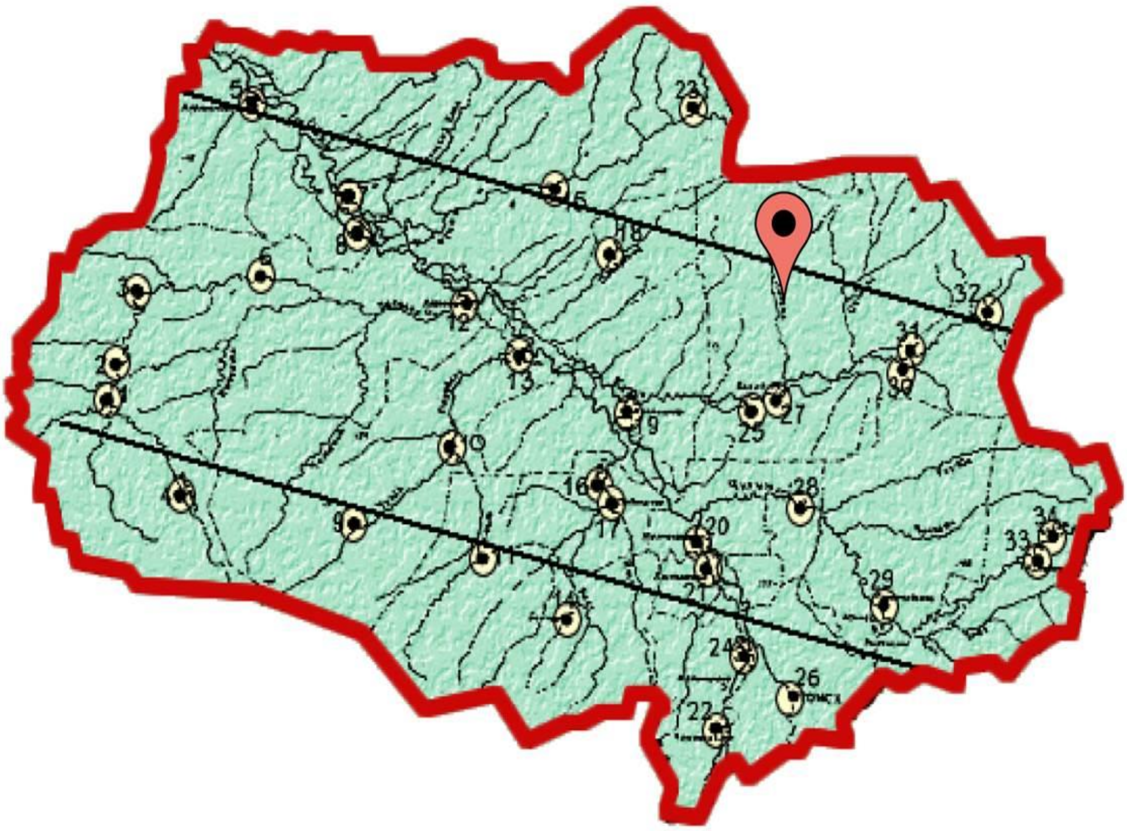

Figure 14 – Map of potential annual solar energy in Tomsk region [kWh/m^2]. [15]

5.1. Solar energy in Lisitsa

5.1.1. Daily sunshine duration

Daily sunshine duration is a climatological indicator, measuring duration of sunshine in given period for a given location on Earth. It is a general indicator of

[16] Estimates of solar energy resources are obtained for horizontally placed receiving surface of a solar panel.

cloudiness of a location, and thus differs from insolation, which measures the total energy delivered by sunlight over a given period. Belong to basic and the most important parameter which determines quantity of electric energy generation from solar units.

If the Sun were to be above the horizon 50% of the time, apparent maximal daytime duration would be 4 380 hours. However, there are physical and astronomical effects that change that picture. Namely, atmospheric refraction allows the Sun to be still visible even when it physically sets below the horizon. [18] Sunshine duration is usually expressed in average hours per day, or total hours for year. The first measure indicates the general sunniness of a location compared with other places, while the latter allows for comparison of sunshine in various seasons in the same location.

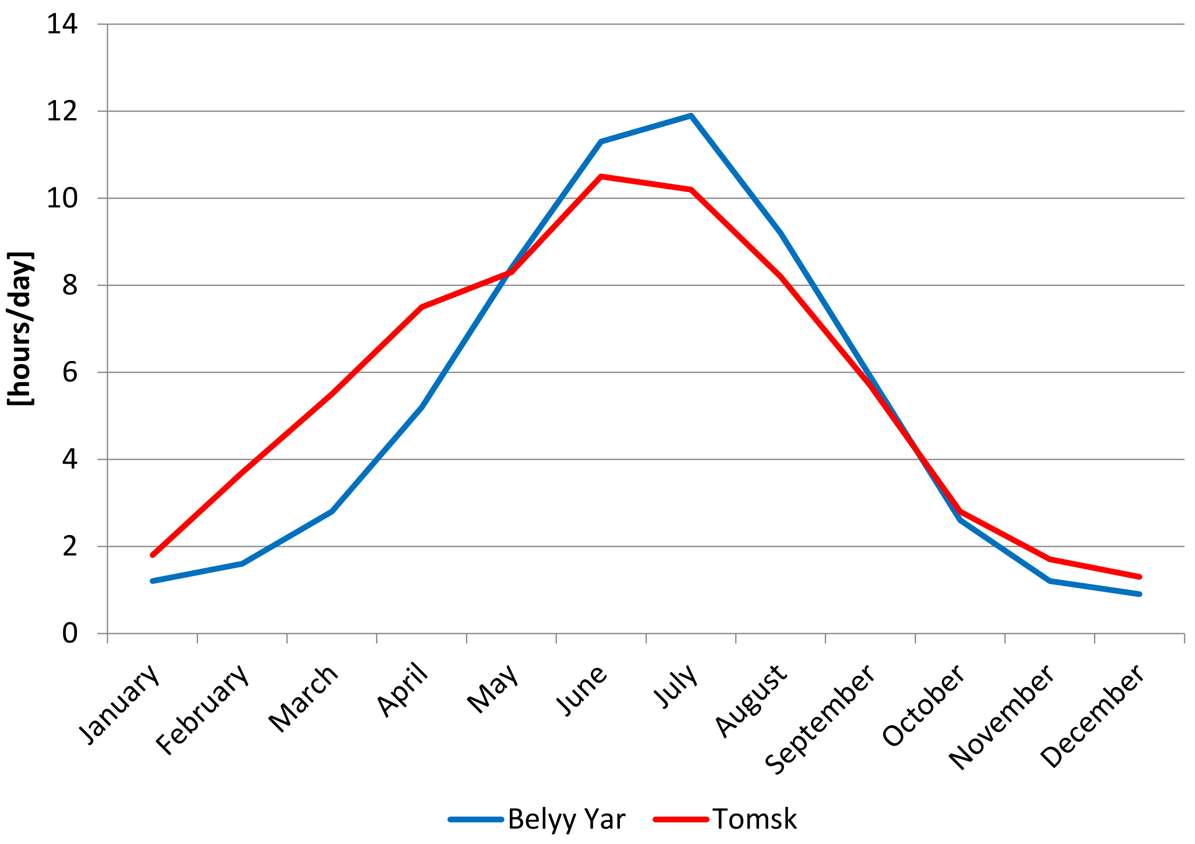

Figure 15 - Daily sunshine per year 2015 in Belyy Yar and Tomsk.

Tomsk region normally gets between 1850 and 2050 hours of sunshine each year. In the north area is the shortest daily sunshine duration, and direction on the south is the amount of hours increasing. According Figure 15 is shown the range of difference between places. In the Tomsk is annual amount of sunshine 2046 hour and in Bely Yar[17] only 1899 hours (7.5 % decreases). Bely Yar is only about 160 kilometers further north.

The sunniest months in the region are June and July. During these months, sunshine duration averages are between 11 and 12.5 hours per day over most of the region. The extreme south gets most sunshine, averaging over 13.5 hours a day in early summer. January, February and December is the dullest month, with an average daily sunshine ranging from about 1 hour in the north and central part of region to almost 2-2.5 hours in the south of region. Over the year as a whole, most areas get an average of between 5 and 5.75 hours of sunshine each day.

Duration of daily sunshine specifies the time interval in which we can expect the solar energy in the quantity, in which can be effectively transformed into electricity. However, for determining an amount received energy is necessary to know other parameters, which significantly influence the quantity of energy falling on the earth's surface.

5.1.2. Azimuth and latitude

The global radiation at ground level is composed beam radiation which comes straight from the sun and diffuses radiation which has undergone scattering during its passage through the atmosphere. Theoretically is an insolation of one kilowatt per square meter known as the maximum of incident energy, however because the sun and the Earth is in constant motion the value will be all the time changed. Most of the time the energy is significantly below this value because it depends on the angle of incidence of the Sun's rays with the ground, increasing during the day from a very

[17] Bely Yar is in this section instead of Lisitsa, like the nearest city with relevant long-term data.

low value at dawn as the Sun rises to a peak at noon and falling again as the Sun sets.

For this moment, every estimates of solar energy resource was obtained for horizontally placed receiving surface of a solar panel. The efficiency of solar plants depends also on its position on the Earth, its orientation and it also varies continuously with time as well as weather conditions. The orientation of the solar collector or the photovoltaic array with respect to the position of the Sun is a major determinant in the efficiency of the solar power system, because the amount of energy captured is directly proportional to the area of the Sun's energy front intercepted by the collector.[17]

The best orientation of solar power panels in Tomsk region is with orientation of their receiving surfaces to the south at an angle of 42-44 degrees.[18] . Efficiency of panels with these parameters will increase about 20-25% compared to horizontal panels.

5.1.3. Radiation

Total solar irradiance is defined as the amount of radiant energy emitted by the Sun over all wavelengths, not just visible light, falling each second on a 1 square meter perpendicular plane outside Earth's atmosphere at a given distance from the Sun.

The amount of solar energy that actually passes through the atmosphere and strikes a given area on the Earth over a specific time varies with latitude and with the seasons as well as the weather and is known as the irradiance.[19]When the Sun is directly overhead the insulation, that is the incident energy arriving on a surface on the ground perpendicular to the Sun's rays, is typically 1000 Watts per square meter.

[18] Optimal position of panels in the Tomsk region is calculated from software: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?lang=en&map=africa
[19] Incident solar radiation sometimes called also insolation.

This is due to the absorption of the Sun's energy by the Earth's atmosphere which dissipates about 25% to 30% of the radiant energy. [17]

For determine the intensity of solar radiation incident on the earth's surface was used Photovoltaic Geographical Information system, which for calculations uses geographical location of object. Annual value of irradiance in Lisitsa was measured 299 W/m^2. The values are in the interval between 214.6 W/m^2 in December to 393 in May. Small differences between winter and summer periods are due to weather conditions in Lisitsa, especially in the fact that the sunniest day is in winter. Specific values for individual months are shown in Appendix-Table 16.

The quantity of direct and diffuse radiation determines the values of parameters DNI and D/G. Direct normal irradiation is the component of solar irradiation that reaches a surface of the Earth on a straight line from the sun, without any atmospheric losses due to scattering or absorption. It is measured in watts per square meter. On the other hand D/G is ratio of diffuse to global irradiation. In the Tomsk region is annual DNI index between 2700-2900 Wh/m^2 per day. D/G ratio is in the latitude of Tomsk region in interval 0.5-0.7 throughout the year.[20]

5.2. Conclusion

Complete calculation of efficiency of solar panels and the total energy production is shown in the Table 16. Although the low temperature positively affects the efficiency of solar panels the highest monthly efficiency of solar module is 15%. It is affected mainly by the low level of radiation; from the level of 1000 W/m2 (optimal- efficiency around 21% for monocrystalline) in average every decrease by 100 W/m^2 reducing the efficiency about 0.9%.

In this level of efficiency is annual production of energy about 185 kWh per square meter. To cover 10% of consumption would be necessary to install approximately 225 square meters of solar panels, which means installed capacity on

[20] Detailed values of DNI and D/G index from village Lisitsa is shown in the Table 16.

the level 29.778 kWp. For this capacity, the estimate investment in the project will be around 6 million rubles. Another positive is that photovoltaic panels would be able to generate energy only at the price around 30 rubles per kilowatt hour (calculated for a period of five years).

6. System dimensions

After determining the values of radiation, the optimal angle, the daily sunshine duration and other characteristics is necessary to design a system, which will optimally transform photovoltaic energy to electricity. The most important is the selection of solar panels.

6.1. Solar panels

Parameter that most influences the selection of the type of solar panels is value of irradiance. A relative normalized irradiance-dependent efficiency of photovoltaic modules is recommended as an objective means of quantifying their behaviour under variable irradiance conditions. It allows users to decouple the irradiance dependent behaviour of photovoltaic modules from their temperature dependence. This criterion is shown to have a broad applicability in diagnostics by manufacturers and users of photovoltaic module's data sheets. In the Figure 16 is graphically presented values of the relative normalized irradiance-dependent efficiency.[21] The highest efficiency at the values of radiation to 600 W/m2 is reaching monocrystalline silicon modules. [6]

According to the aforementioned study was from among the available photovoltaic panels selected type PANDA 60 Cell Series 2. This monocrystalline silicon panel has high efficiency even at low levels of radiation. Under irradiation of 200 W/m2 has a module effectivity of 97% (relative to STC). This feature allows delivering a greater amount of electricity during the winter months and enables also

[21] All research is freely available at [17].

use this panel even at such low levels irradiance as measured in Lisitsa. Technical characteristics of panel are shown in Table 7. [20]

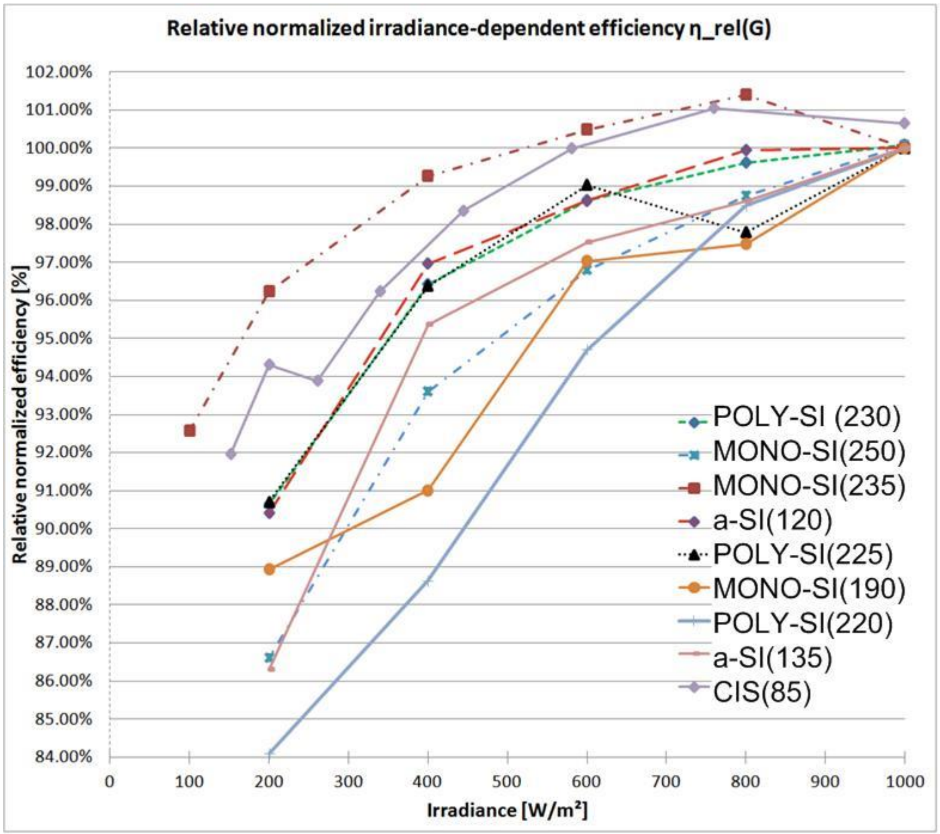

Figure 16 - Irradiance-dependent normalized relative efficiency graph of modules.[6]

Table 7 – Technical specification of solar panel. [20]

Parameter	Panda cell 60 series 2.
Maximum power	270Wp (rated power output)
I_{sc}	9.35A (short-circuit current)
V_{oc}	38.1V (open-circuit voltage)
I_{mpp}	8.74A (current at maximum power)
V_{mpp}	29.7V (voltage at maximum power)
Modules Efficiency	16.50%
Maximum System Voltage	1000V
Background Coloration	White
Frame Color	Silver
Connections	MC4 / IP67 (110cm cables / 4mm)
Dimensions	1650x990x40mm
Weight	18.5 kg

Product Warranty	10 years
Performance Warranty	10 years for 92%; 25 years for 82% of rated power

6.2. System dimensions

As mentioned in the section about hybrid systems, systems using stochastic energy sources must contain storage, which would be able to compensate for fluctuations in energy production from RES. The problem with the HPS system Lisitsa is the installed capacities of PV plants that do not allow profitably use batteries. If the batteries should be able to keep half the daily consumption, must have total capacity 55 kWh. The costs of such batteries are around 5 million rubles, what would have doubled the total cost of a hybrid system. Based on this fact the batteries in Lisitsa will not be used and the first limit condition of total PV plant output is that at no time will generate more electricity than actual load is.

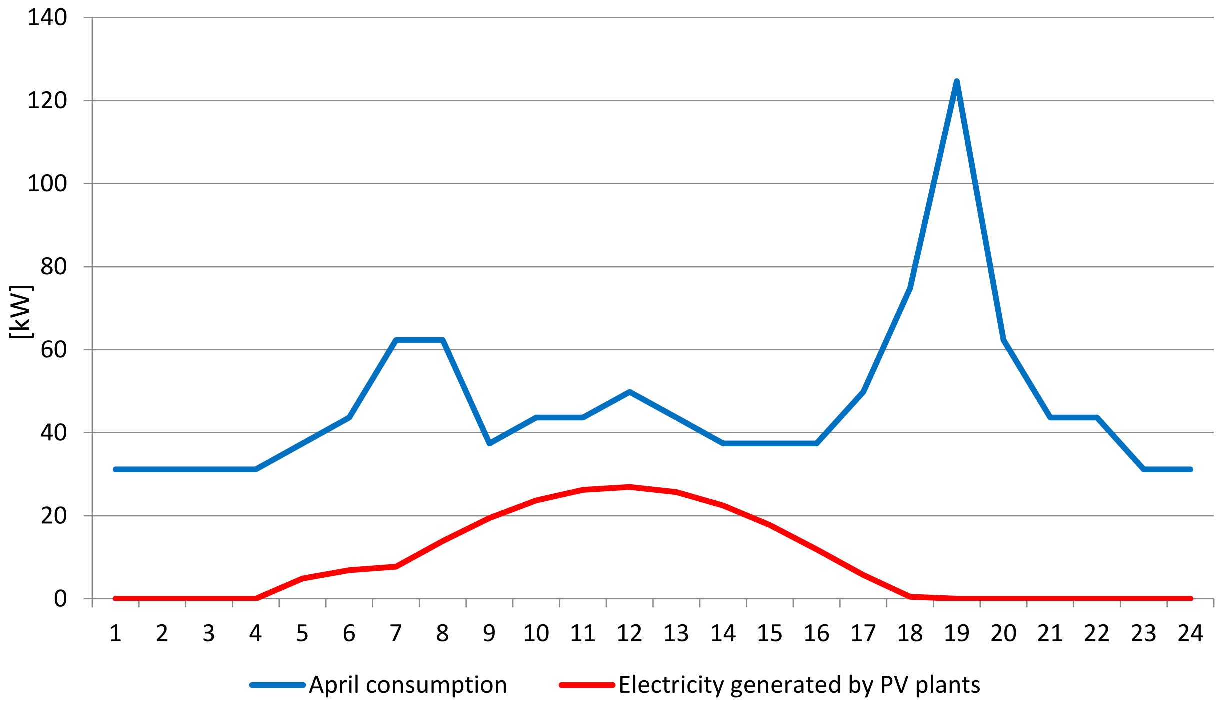

Figure 17 – Comparison of April consumption with production of PV plants with installed capacity 2.47 kW.

The second limiting conditions are that for reliability of system it is necessary continuous operation of at least one diesel generator. It is necessary due to fluctuations in the network as well as short-term interruptions in production of PV plant. The diesel generator has critical operating point at level of 40% from the nominal power. It had been significant limiting factor if the smallest diesel generator would have the nominal power at 75 kilowatts. The advantage is the installation of a 40 kilowatts diesel generator, which was recommended in Chapter.3. In the HPS system will be this generator using during parallel running the diesel unit and the PV plant, in the case of PV output will be greater than 25 kW. System will be sized so that at any moment generator generates more than 17.5 kW.

In Figure.17 is shown the daily load diagram in April, which is a month during which there is the highest value of radiation and PV plant will deliver the highest power. The graph also displays the daily power output diagram of photovoltaic plant with a total installed capacity of 22.23 kilowatt peak during the April day with clear sky. It is the highest possible installed capacity in which the production of the diesel generator is least 17.5 kW. This installed capacity is equal to an area of 179 square meters. The hybrid power supply system will be used 99 photovoltaic panels type - Panda cell 60 series 2.

7. System design

7.1. Diesel generators unit

Pursuant to Section 2.4 we know, that generator unit includes the measuring of the output load (M1 in Figure 21) and gen-set controller, which based on this data is configuring of outputs power and frequency of each single diesel generators. Genset controller monitors the parameters of individual generators to avoid overheating, overvoltage or other negative electrical effects. This configuration is not necessary to modify, it is necessary only to add new generator (type ДЭУ-40), that have different operating characteristics than other generators, but does not affect the configuration of controller.

Operation of the diesel generators system will be affected only in the case that photovoltaic plant starts to generate electricity. In this case the electrical measuring of output PV plant (equipment M2- in Fig. 19) sends a signal to genset controller, in which will be the output parameters, such as voltage, active and reactive power, current, frequency and so on. Based on these parameters the controller adjusts production of diesel generators, so that the conditions of minigrid will be fulfilled.

7.1.1. Generator АД-40

This generator was selected based on the recommendations of Section 3.3. It solves the problem with low efficiency electricity generation for base load. Generator is able to generate 40 kW (maximum basic load) and secondly it was chosen with order to maximize installed capacity of photovoltaic power stations (in accordance with Chapter 6). Type АД-40 was selected based on price, availability and seamlessly integration into the diesel unit. Its characteristics are shown in Appendix-Table A6.

7.2. Photovoltaic

7.2.1. Panels connection

Of the three basic ways of engaging photovoltaic panels (parallel, serial, and serial-parallel) has been chosen connection in 9 blocks with 11 parallel connected panels. In fact, due to minimize the negative impact of shadow effect is the most common type of connections series-parallel, however it is a three basic reason why was chosen serial connection.

The first is effort to maximize the installed capacity, 99 panels is problematic divided into blocks in which would be used a series-parallel connection. For using this connection is necessary to omit several panels.

The second point is the absence of space where can be PV plants installed. Since this is a hybrid system and mini grid is connected to the fixed point on the building in which is installed diesel unit also solar plants must be near the building. Serial connection allowed to installation blocks in different places. On the roof of the building can accommodate the only 50 panels.

The third point is that 11 panel have total power capacity 2970 Wp what is the ideal level for selecting an inverter that will not have to be oversized. The problem is not even voltage equal to 419 V. Selected inverter takes the maximum input voltage 500V, which in theory will permit the addition of another 2 panels in series.

7.2.2. Inverters

For each block was used DC-AC inverter ISG1l from Eaton. This type of inverter best meet the conditions set by the type of panels and type of panel’s connection. Maximum input voltage is 500 volts and current 13 ampere. Maximum input power is 3180 W, but the optimum level of input is between 2200-2600 W. Given to the character of distribution photovoltaic energy (see Appendix-Figure 26) it determines the higher average efficiency of inverter, because the levels of radiation 1000 watts per square meter are achieved only in 55-60 days per year. It determines that the input power higher like 2800 W will be achieved in only 16-17% of days, while output in the range of 2.2 to 2.6 kW will be delivered in 45% of days. Output voltage of the inverter is 230 V and connection is intended to connection on one phase. Detailed inverter parameters are shown in Table 8.

In the Russian Federation price ranges from 205 to 220 thousand rubles. Total costs of inverters represent 2.15 million rubles.

Table 8 – Parameters of invertors used in PV plant. [21]

	Type	ISG1l-2800/1
Input	*Max DC power*	*3180W*
	Max DC voltage	*500 VDC*
	MPP voltage range	*150-450 VDC*
	Max input current	*13 ADC*
Output	*Output power*	*2800W*
	Max. output power	*3000W*
	Operating voltage	*190-256 VAC*
	Operating frequency	*50 Hz*
	Power connection	*1-phase*
Mechanical parameters	*Max. efficiency*	*>96%*
	Euro efficiency	*>95%*
	Overvoltage category	*III.*
	Operating temperature	*-30;55*
	Comm. Interface	*RS232*
	Display	*LCD/16 characters*
	Price	*215000 RUB*

7.2.3. Overvoltage protection

Electronic and electrical devices are designed to operate at a certain maximum supply voltage, and considerable damage can be caused by voltage that is higher than that for which the devices are rated. When the voltage in a circuit or part of it is raised above its upper design limit, this is known as overvoltage. The conditions may be hazardous. Depending on its duration, the overvoltage event can be transient a voltage spike or permanent, leading to a power surge.

For connecting PV panels was chosen fuse isolator PCF-10DC. The detailed parameter of this equipment is shown in the Figure 19.

Type of disconnector	*PCF-10DC*
Rated voltage	*800 V DC.*
Rated current	*max. 25A*
Max. fuse link power dissipation	*3W*
Cross section of connecting wire	*0.5-10 mm2*
Utilization category	*DC-20B*
Price	*638 RUB*

Figure 18 – PCF-10DC [16]

SPUM PV-600 is surge arrester type 2 IEC 61643-1. Installed at the boundary of LPZ 1-2, which ensures potential equalization positive and negative busbars of photovoltaic systems and elimination of transient overvoltage that originate during atmospheric discharges or switching processes. Particular varistor sectors connected between terminals L +, L- and PE are fitted internal disconnectors which are activated when a fault (overheating) varistors.

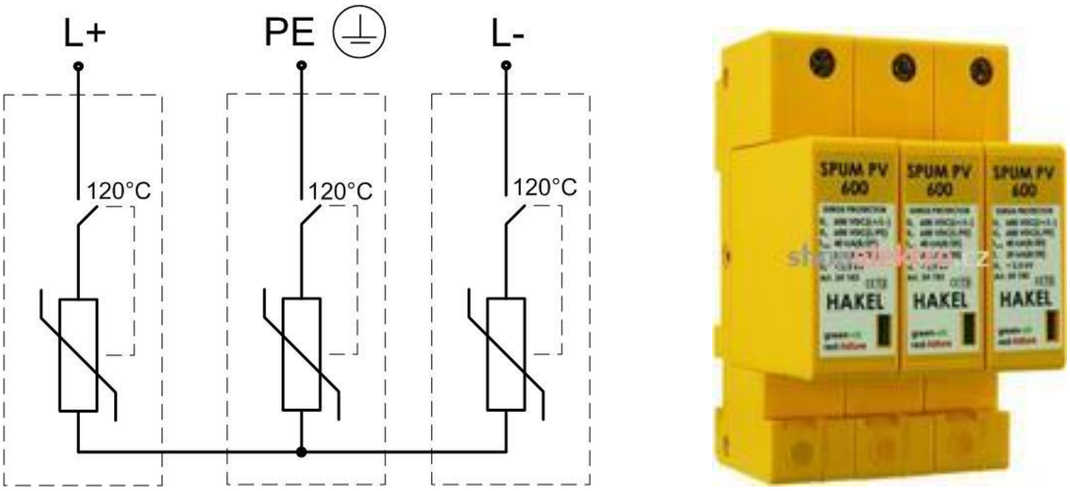

Figure 19 – SPUM [19]

Maximum continuous operating voltage is 600 volts. Maximum leakage current is 40 kA and maximal voltage protection at the level of 2.5 kV. Operating temperature is from minus 40°C to 65°C. Price for SPUM PV-600 is 7054 rubles and for PCF-10DC is 458 rubles. Total cost for components in overvoltage protection are 67 608 rubles. [19]

7.2.4. Monitoring relay

DPC02 is a 3-phase or 3-phase plus neutral line voltage monitoring relays designed by Carlo Gavazzi. It is designed for phase sequence, phase loss, over and under voltage (separately adjustable set points), over and under frequency with built-in time delay function. Supply ranges from 208 to 690 VAC covered by four multivoltage relays. Monitoring system is shown in the Figure. 20; construction is designed for application in generator sets and systems using renewable energy.

Figure 20 – DPC-02 [11]

General characteristics are:

- TRMS 3-phase over and under voltage, phase sequence, phase loss and asymmetry monitoring relay;
- Detect when all 3 phases are present and have the correct sequence;
- Detect if all the 3-phase-phase or phase-neutral voltages are within the set limits;
- Detect if asymmetry is below set value;
- Separately adjustable setpoints;
- Separately adjustable delay functions (0.1 to 30 s);
- LED indication for relays, alarm and power supply ON;
- Output: 2 x 8A relay SPDT NE.

Actual price for equipment is in the Europe 360 euros in rubles around 26 660. [11]

7.2.5. Cables

Drakaflex-Sun Betax solar cables are specifically designed and manufactured for use in solar applications. They satisfy with their reliability, excellent life-cycle and optimal physical qualities. All cables are tested and certified according to established international testing methods and meet the highest demands. These cables satisfy with their outstanding product qualities. The used materials are flame-retardant, do not contain halogen components and do not generate corrosive gases in case of fire, but only a little smoke. The used materials do not contain attractants for martens and are resistant against ammonia. The jacket is separated from the insulation and therefore easier to strip off. The cables are compatible with all major connector systems. [22]

Type of cables Drakaflex will be used for connecting solar panels and inverters. The rated voltage is 1000 volts direct current and cross section is 4 square millimeters. Temperature range is minus 45 Celsius degrees and plus 90.

For connecting other components will be used cable type CYKY-J 3x2.5. The nominal voltage of this type of cable is 750 volts, temperature range is minus 30 and plus 70 Celsius degrees and current load is 22 amperes. [23] For connection monitoring relay and contactor will be used cable type CYKY-J 5x10 with nominal voltage 750 volts and current load of 80 amperes. [24]

It is difficult to estimate the cost of cabling. The length between the solar panels can be diametrically different, such as length between panels and combine box. The total costs of cables were estimated at 610,000 rubles.

7.3. Electrical scheme

Based on the selected connection of solar panels and components of the system, was created electrical scheme of hybrid power supply system. It is divided into three following parts:

- photovoltaic part;
- diesel generators unit;
- output part of system.

The first two parts consist from already installed components. The last part of the system described in the previous sections.

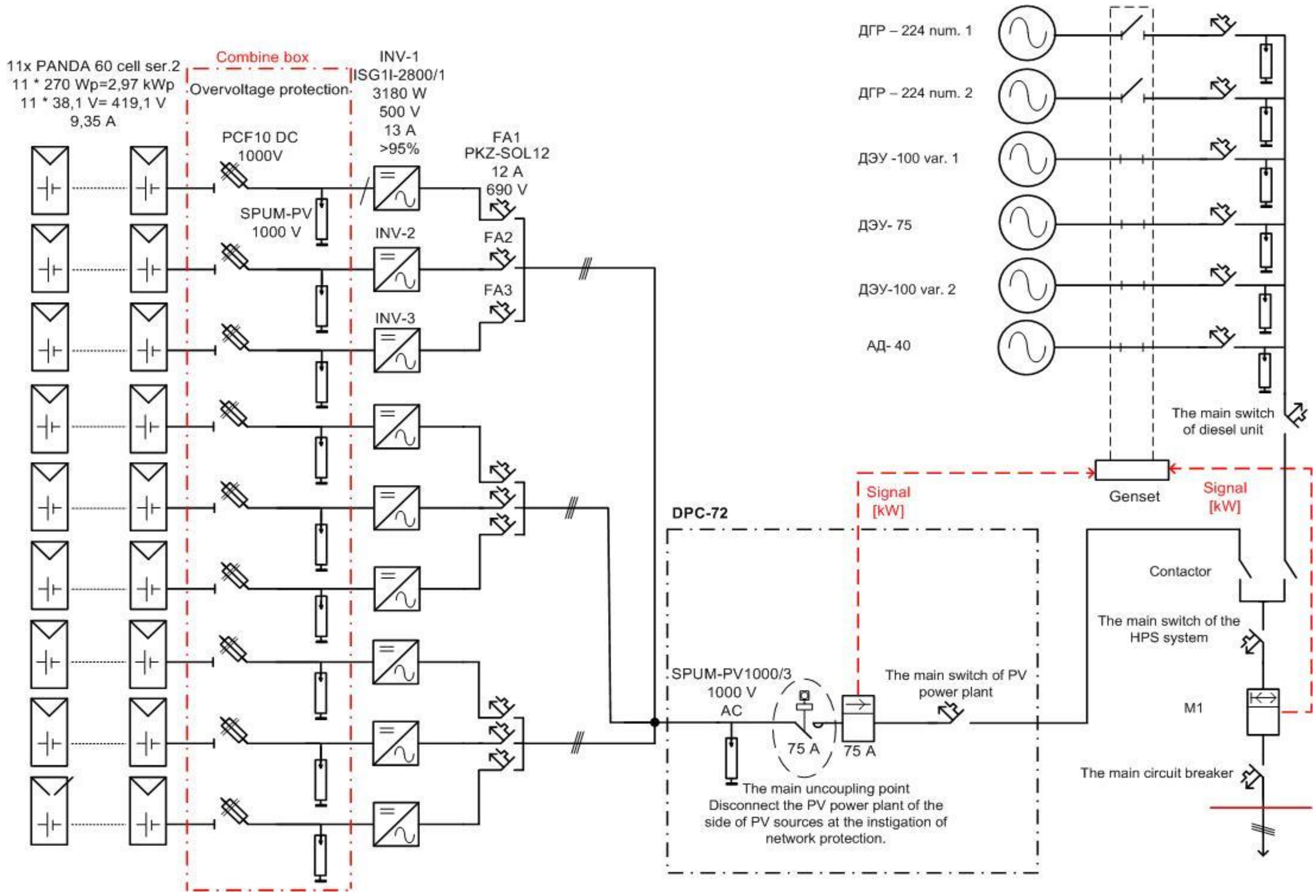

Figure 21 – Electrical scheme of the PV-diesel hybrid power supply system.

8. Financial analysis

8.1. HPS production

One of the main conditions for the HPS system was annual quantity of generating energy. In the criterion C3 was defined the minimal quantity of power produced by secondary sources to 10% of consumption.

Designed hybrid system is not fulfilled this condition, because the annual production of PV plant is 33.15 MWh, which represents 8.42% of total consumption. Non-performance is caused, because the system from economical point of view does not include the battery and all the time must be running at least one generator (see Chapter.6).

Monthly amount of generating electricity from PV plant and from diesel generators unit is shown in the Figure 22.

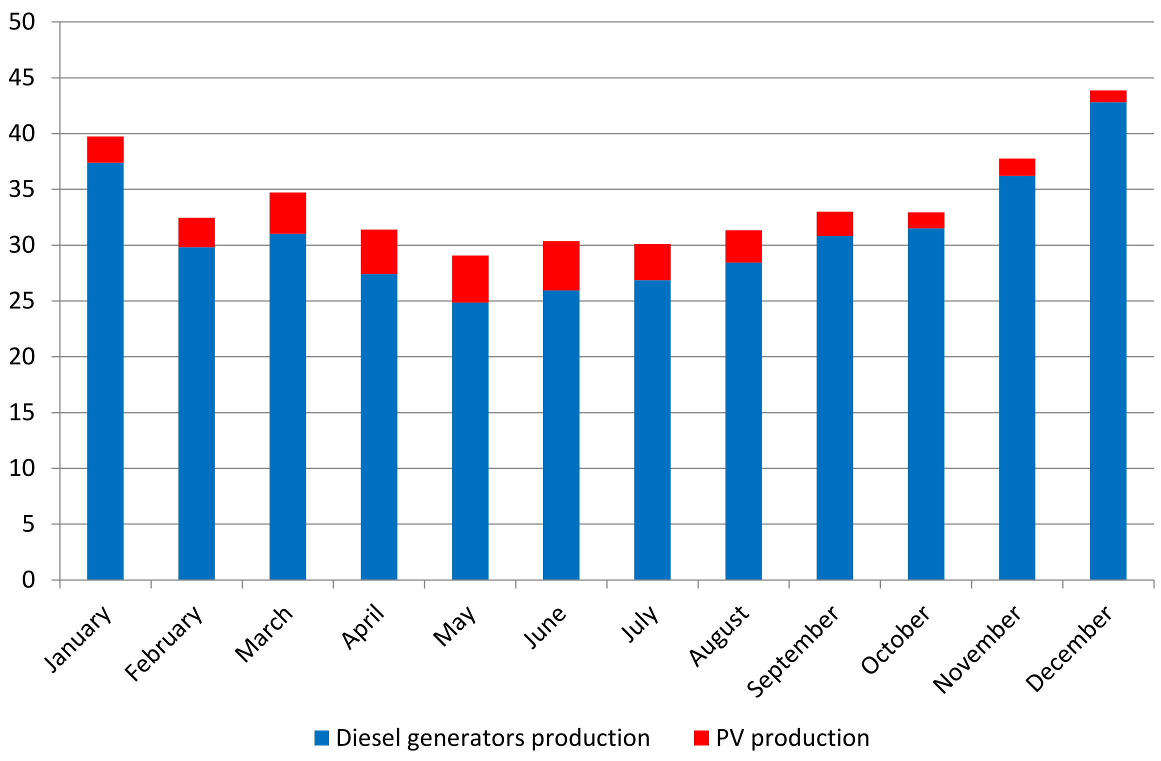

Figure 22 – Monthly quantities of generating electricity by PV-diesel HPS system

8.2. Costs

Rural electrification agencies as well as many operators of small diesel minigrids are aware that hybridization can help to provide a better service and reduce production costs compared with single-source systems. The cost of solar panels has been steadily decreasing and this trend favours a broad deployment of PV hybrid systems.

Data collected on recent systems installed in Africa and Asia show that the typical real installed cost of a complete PV-diesel hybrid system is in the range of 5 500 to 9 000 EUR for kilowatt peak with variations according to system size and location. Diesel gen-sets are widespread in developing countries and products and services for those are readily available. On the contrary, solar PV distributors and installers with a significant market base and experience are far fewer, implying increased costs for that part of the system and some variations according to the country considered. Despite variations due to system size and location, the cost structure of a photovoltaic and diesel hybrid system typically follows the breakdown shown in the pie chart. [10]

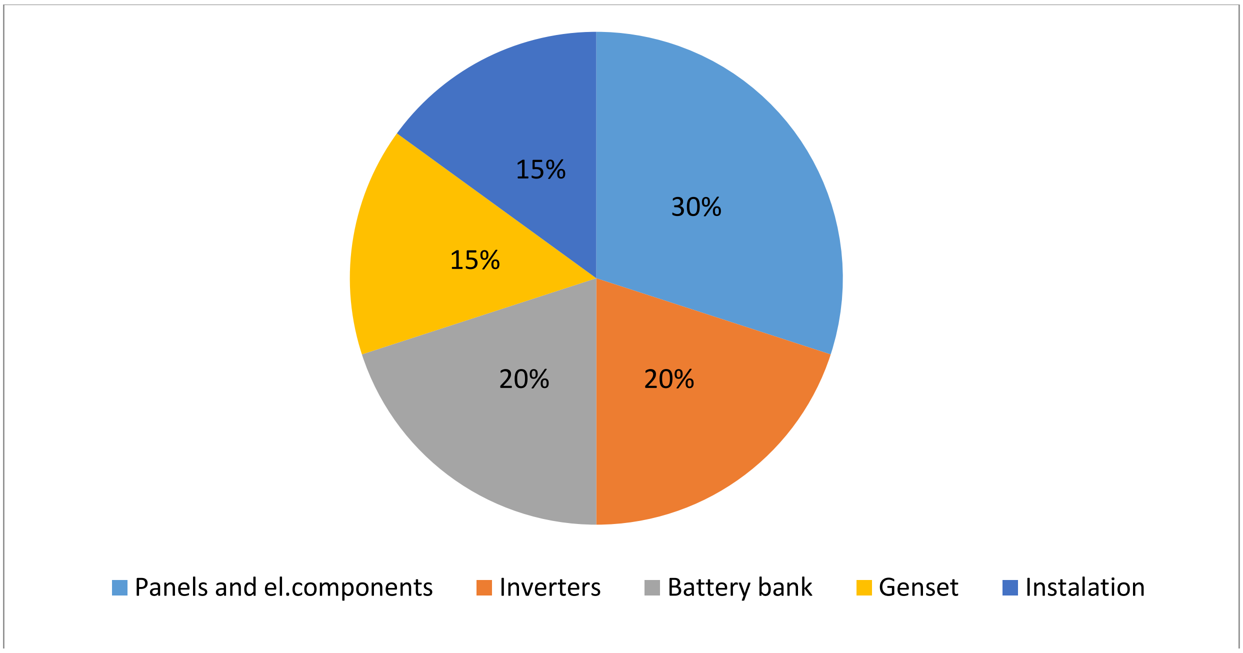

Figure 23 – Cost structure of typical HPS system combining PV and diesel. [10]

The total cost per install kW in HPS system in Lisitsa are 245137 rubles. In the calculations are not counted the cost of diesel generators unit, because unit was installed before initiating proposals and its running is no changed. A secondary source has been designed to adapt to running generator unit. The only item which was counted as expenses was diesel generator АД-40 without which it would be impossible to construct hybrid system.

Price per kWh are decreased also the fact that the system does not use any energy storage as is typical in the systems using renewable sources. Achieving this was through the correct system dimensioning. It reduces the total cost by about 20%.

Table 9 – Cost for hybrid system.

Equipment	Price for one		Quantity	Total cost	
	euro	ruble		euro	ruble
Panda-60 Cell Ser.2	229 €	17083	99	22671 €	1691257
ISG1l-2800/1	2949 €	220000	9	26541 €	1980000
PCF-10DC	7.99 €	596	9	71.91 €	5364.486
SPUM PV-600	95 €	7087	9	855 €	63783
DG АД 40-T400	5000 €	373351	1	5000 €	373351
DPC-02	360 €	26856	1	360 €	26856
PKZ-SOL 12	63 €	4699	9	567 €	42298
Cables				8176 €	610 000
Transport				16085 €	1200000
Installation				8800 €	656480
Total cost				90167 €	6726499

Cost distribution is shown in Table 9. The cost of solar panels is 1.5 million rubles, what is 28% of total investment. The high item is also cost for inverters, for which is used 30% of the budget. Problematic was estimated the costs of transportation and installation. For transport is for the better comparison used the same type of helicopter, as for calculating transport cost in Chapter 2. Installation costs were based on the value from study, under which the cost of installing 1 kW represents 30,000 rubles.

The total costs of hybrid system are 6.726 million rubles, which exceeds by 34 % the maximum investment limit defined in the criterion C7. The reasons for exceeding are estimates the values, which could not be determined specifically. In the estimate were used the maximum possible values, so in the case of realization of the project real costs cannot exceed the estimates cost. Secondly, in defining the criteria was not counted the cost of a new diesel generator.

8.3. Price of electricity

Basic assumption for calculating investment effectiveness is that all the energy generated by solar power plant will be consumed. Solar power plant for five years will produce 5.32 MWh of electricity per year. Price per kilowatt hour is subsequently calculated using the following formula:

$$Price = \frac{Investnent + Period\ .\ Operating\ costs}{Period\ .\ Annual\ production} \quad [RUB/kWh]$$

Cost of 1 kWh in the period of 5 years is 41.03 rubles. This item has been counted operating costs which are estimated at 25,000 rubles a year. C9 criterion that has been met, since lowering the initial price per kilowatt hour by 21.2 % and for each kilowatt hour generated by solar power plant will be spared 11.03 rubles.

The proposed system optimizes operating a diesel generator unit. A newly installed generator has an optimal installed capacity on the work at basic load (between 30-40 kW). Its use at night will increase efficiency and reduce total consumption. Estimates suggest that its using should reduce consumption per generated kilowatt hour from 0.41 liter to 0.38 liter. This optimization would reduce the cost of electricity from 52 rubles to 50 rubles per kilowatt.

Moreover, this optimization does not depending on the installation of the photovoltaic power plant and can lead an immediate reduction in fuel costs with almost zero investment cost. Generator alone costs 373351 rubles and return on investment is less than half a year. This period may be further reduced and value significantly depending on the time of use of the generator.

8.4. Payback period

Payback period is the time in which the initial cash outflow of an investment is expected to be recovered from the cash inflows generated by the investment. It is one of the simplest investment appraisal techniques. The formula to calculate payback period of a project depends on whether the cash flow per period from the project is even or uneven. In case they are even, the formula to calculate payback period is:

$$Payback\ period\ = \frac{Initial\ investment}{Cash\ inflow\ per\ period} \quad [RUB]$$

In Table 10, it is showing a specific calculation of economic indicators. According to the accumulated cash flow, we can see the payback period is three years and two months. Unfortunately, Payback period does not take into account the time value of money which is a serious drawback since it can lead to wrong decisions. A variation of payback method that attempts to remove this drawback is called discounted payback period method.

The discount rate refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. [4]

Discount rate is the rate of interest which a central bank charges on the loans and advances to a commercial bank. The bank rate is known by a number of different terms depending on the country and has changed over time in some countries as the mechanism used to manage the rate have changed.[4]

Table 10 –Cash flow.

Year	Invest. [Rub.]	Opportunity cost [Rub.]	CF [Rub.]	Cumulative CF [Rub.]	Cumulative DCF [Rub.]
0	-6726499			-6726499	-6726499
1	-25000	1744722	1729722	-5006777	-5134164
2	-25000	1727275	1712275	-3304503	-3674738
3	-25000	1710002	1695002	-1619501	-2337129
4	-25000	1692902	1677902	48401	-1111172
5	-25000	1675973	1660973	1699374	12452.82
6	-25000	1659213	1644213	3333587	1042284
7	-25000	1642621	1627621	4951208	1986151
8	-25000	1626195	1611195	6552403	2851226
9	-25000	1609933	1594933	8137336	3644087
10	-25000	1593834	1578834	9706169	4370761

Due to the instability of energy prices (especially oil) and large fluctuations in the exchange rate of rubles, was elected discount on the level 8%. Discounted cash flow is shown in the Table 10.

Payback period is three years and four months; discounted payback period is four years and three months. These values are shown also in Figure 24.

8.5. Net present value

Net present value (NPV) is a popular measure of profitability used in corporate budgeting to assess a given project's potential return on investment.

Because of the time value of the dollar, NPV takes into account the compounding of the discount rate over the duration of the project.

The NPV of a project or investment reflects the degree to which cash inflow, or revenue, equals or exceeds the amount of investment capital required to fund it. When assessing multiple projects, businesses use NPV as a way of comparing their relative profitability to ensure that only the most lucrative ventures are pursued. A higher NPV indicates that the project or investment is more profitable. [4]

To calculate NPV, the estimated cash outflow and inflow for each period must be established, as well as the expected discount rate. Though the exact figures can only be known after completion, fair estimates can be made by looking at the performance of similar projects or investments.

$$NPV = \sum_{t=1}^{T} \frac{Ct}{(1+r)^\wedge t} - Inv. \quad \text{[RUB]}$$

For economic efficiency of hybrid power supply system was chosen 10 periods. It was difficult to determine lifetime of system but in the most of hybrid systems is biggest problem lifetime of batteries. HPS system in Lisitsa have determined lifetime around 20 years. With small decreasing of efficiency of solar panels and with needs to replace the battery back. Decreasing of solar panels is estimated to 1% in one year.

Value of NPV you can see in the Figure 24, it is presents by the value of commutative discount cash flow after 10 years. So 10 years after installation of HPS system, it earns about 437,071 rubles more than the same investment in the government bonds at a rate of 8% p.a.

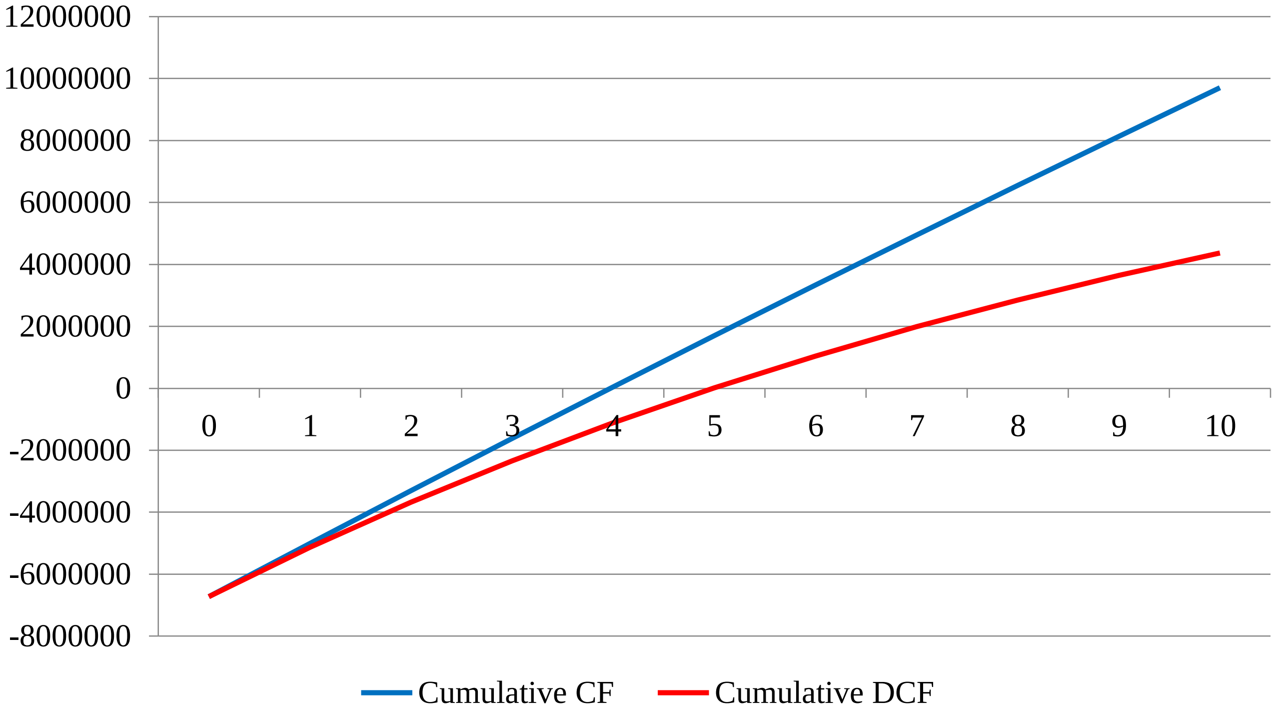

Figure 24 – Comparison of cash flow and discount cumulative cash flow

8.6. Internal rate of return

The internal rate of return (IRR) on a project is the rate of return at which the projects NPV equals zero. At this point, a project's cash flows are equal to the project's costs. Similar to how management must establish a maximum payback period, management must also set what is known as a hurdle rate, the minimum rate of return a company will accept for a project. [4]

$$NPV = \sum_{t=1}^{T} \frac{CFt}{(1+IRR)^t} = 0$$

$$IRR = 21.15\ \%$$

9. Social responsibility

In comparison with diesel generator unit has hybrid system a much more positive impact on living standards of population in rural areas. Main features of diesel generators units and hybrid power supply systems are shown in the Table 13 and Table 14.

The main advantages of diesel systems are installation costs, which, in comparison with the hybrid system are lower. Among the positives include the ability to generate constant power throughout the entire period of operation, what lead that in systems are not used batteries. These systems are also not dependent on external factors such as geographic location and terrain and can be installed virtually anywhere.

Table 11 - SWOT analysis of stand-alone diesel power supply system.

Strengths	Weaknesses
acquisition costs installation and removal guaranteed power output (constantly) AC electricity (don’t need converter) regardless of location	low efficiency of production operating costs (staffing, oil, etc.) fuel cost transportation costs of fuel air pollution and GHG effect limited use of local energy resources price for one kWh
Opportunities	**Threats**
combination with RES use batteries (need DC converter)	growth price of diesel aging of diesel power systems in Russia problems with transportation of fuel quality of power supply (repair, revision, etc.)

The main weaknesses of stand-alone diesel generator units are low technical and economic efficiency of production, high fuel prices and high transportation costs. Another problem is that some districts face frequent disruptions in fuel supplies due to bad weather transport conditions. All of the above factors lead to high cost of electricity, which is more than half a dollar per one kilowatt hour. Such conditions results to elimination electricity consumption by population, companies and government institutions.

Another negative fact is huge depending on the price of diesel. At the time of writing this work, the price of oil attacks ten year minimums. Graph of oil prices in last 20 years on the London stock exchange is shown in Figure 25. It is the fact that the price of fuel in the world and in Russia is closely linked and therefore given the expected increase in fuel prices will be linear grows the cost of running diesel units. With annual consumption of 175 000 liters, if price of diesel will increase by 5 rubles per liter, then the total cost of electricity in Lisitsa will increase about 1.2 million rubles (after counting the cost for fuel transport). Therefore, the use of local resources to future is necessary.

Figure 25 – Price for barrel of oil in London stock exchange (1990-2015). [28]

System generating energy from a single source may also have big problems with the stability-making power. Especially if system is not using battery to compensate fluctuations of load and is dependent on regular long transports fuel.

Features of hybrid power supply systems are shown in Table 12. Combinations of multiple sources can greatly reducing the threats, which have stand-alone diesel generator units. The system is not so heavily dependent on fuel costs and transportation, because they are used in smaller quantities. System also increases the efficiency and reduces the cost per kWh, because produces energy from renewable sources. The disadvantages are the high initial costs and necessity detailed analysis of usability RES.

Table 12 - SWOT analysis of the hybrid power supply system for autonomous customer

Strengths	Weaknesses
efficiency of production operating cost fuel cost transportation cost use local energy resources green energy quality of power supply	acquisition costs installation and removal intermittent energy resource (RES) need converter need battery depends by locality
Opportunities	**Threats**
combination more types of RES	growth price of diesel aging of diesel power systems in Russia

.

The greatest drawback is the need for a thorough analysis of the potential of renewable resources on the basis of which some locality may flagged as inappropriate for use of the hybrid system.

Conclusion

The problem of energy supply for the decentralized customers is not a trivial problem. There are not only technological, but also economic, social, ecological and many other boundaries and restrictions. This work combines those boundaries and comprises a deep technical analysis with extensive and modern economic evaluation.

According the analysis of current process of generating electricity we can see how ineffective can be a diesel unit in case that they are oversized. Price for electricity increased not only for low efficiency of diesel generators, but also because of enormous costs for transporting of fuel. Price on the level of 50 rubles per kilowatt hour is the main reason, which limits the quantity of electricity consumed by households as well as the company. The first output of labour is the recommendation for purchase new diesel generator that would work more effectively at the basic load.

The greatest potential for exploitation from renewable energy resources has photovoltaic and despite the fact that Lisitsa is located in the northernmost area of Tomsk region. Optimization of production was achieved by selecting a solar panel that achieves 15-16% efficiency even at low radiation levels. The biggest problem in the design of the system was the right sizing. (nadimenzovanie) Daily consumption of 1.1 MWh did not allow the use of batteries. Even in case it would be able to store only 25% of daily consumption, purchase of battery will increase total investment costs threefold. The system was therefore sizing so that neither under ideal weather and the greatest level of radiation the production will be only 60% of consumption. Selecting the components was not technically challenging, it was necessary to modify the setting genset controller.

From economic point of view, project has a quick payback period and high net present value. This is mainly due to costs for transport of fuel which will reduced.

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Appendix

Table A1 - Wind velocity and direction in Lisitsa Verkhneketsky (Feb-June.2015, Jan.2016).

Day	January	February	March	April	May	June
1	SW 1m/s	W 2m/s	W 3m/s	N 4m/s	W 5m/s	W 4m/s
2	0m/s	W 1m/s	W 2m/s	NW 2m/s	W 5m/s	NW 4m/s
3	SW 2m/s	SW 2m/s	W 3m/s	-	W 7m/s	N 6m/s
4	W 1 m/s	SW 3m/s	-	N 4m/s	NW 4m/s	N 1m/s
5	NE 2m/s	SE 2m/s	N 2m/s	NW 3m/s	S 2m/s	NW 3m/s
6	NE 2m/s	W 1m/s	N 3m/s	N 3m/s	E 3m/s	N 2m/s
7	NE 1m/s	W 3m/s	N 3m/s	N 1m/s	E 4m/s	NE 2m/s
8	0m/s	S 5m/s	N 3m/s	NE 4m/s	SE 2m/s	SE 4m/s
9	SW 3m/s	-	S 3m/s	W 5m/s	S 2m/s	SE 4m/s
10	0m/s	SW 4m/s	SE 3m/s	S 2m/s	SW 4m/s	SW 4m/s
11	N 1m/s	S 4m/s	SW 3m/s	SW 3m/s	SW 4m/s	W 6m/s
12	W 2m/s	SE 4m/s	W 4m/s	W 4m/s	-	W 5m/s
13	W 2m/s	SW 5m/s	S 5m/s	SW 4m/s	SW 4m/s	SE 1m/s
14	W 2m/s	SW 5m/s	W 3m/s	W 5m/s	W 3m/s	E 3m/s
15	NW 3m/s	SW 3m/s	SW 3m/s	S 1m/s	NW 4m/s	S 3m/s
16	NE 2m/s	SE 3m/s	W 3m/s	W 3m/s	N 3m/s	S 4m/s
17	N 3m/s	SW 1m/s	SW 4m/s	W 5m/s	E 4m/s	N 2m/s
18	NE 2m/s	W 3m/s	SW 6m/s	S 3m/s	S 2m/s	S 2m/s
19	S 4m/s	SW 3m/s	NW 4m/s	SE 4m/s	SW 2m/s	S 2m/s
20	SW 2m/s	S 3m/s	S 2m/s	S 3m/s	NW 4m/s	N 4m/s
21	SW 3m/s	E 2m/s	SW 5m/s	W 3m/s	SE 5m/s	N 6m/s
22	SW 4m/s	SE 2m/s	S 3m/s	SE 2m/s	SW 4m/s	N 2m/s
23	SE 1m/s	S 2m/s	S 4m/s	S 2m/s	SW 3m/s	NW 4m/s
24	SE 1m/s	SE 3m/s	S 3m/s	SW 5m/s	W 4m/s	NE 1m/s
25	NE 3m/s	NE 1m/s	W 4m/s	SW 5m/s	SE 2m/s	NW 5m/s
26	E 3m/s	W 2m/s	S 3m/s	SW 6m/s	N 3m/s	NW 2m/s
27	NW 2m/s	SW 4m/s	W 6m/s	SE 3m/s	W 4m/s	SW 1m/s
28	NW 2m/s	N 5m/s	W 3m/s	W 8m/s	SW 3m/s	SW 2m/s
29	W 2m/s	SW 3m/s	-	W 5m/s	N 2m/s	W 3m/s
30	SW 3m/s		W 5m/s	SW 2m/s	W 3m/s	W 3m/s
31	W 2m/s		NW 2m/s		SE 2m/s	

Table A2 - Wind velocity and direction in Lisitsa Verkhneketsky (July-December.2015).

Day	July	August	September	October	November	December
1	SW 2m/s	W 2m/s	SE 2m/s	-	W 2m/s	S 1m/s
2	W 3m/s	N 5m/s	SE 3m/s	-	W 1m/s	SW 1m/s
3	SE 3m/s	W 4m/s	E 3m/s	-	SE 3m/s	0m/s
4	SW 2m/s	N 4m/s	W 4m/s	-	SE 3m/s	0m/s
5	W 3m/s	S 2m/s	W 3m/s	-	E 2m/s	SE 2m/s
6	SW 2m/s	SW 6m/s	W 2m/s	-	SE 3m/s	SW 2m/s
7	SE 2m/s	SE 2m/s	SW 2m/s	-	SE 4m/s	S 1m/s
8	SE 3m/s	NW 1m/s	S 3m/s	SE 2m/s	S 3m/s	SE 3m/s
9	SW 3m/s	SW 2m/s	S 2m/s	E 3m/s	S 3m/s	S 3m/s
10	E 1m/s	N 1m/s	SW 5m/s	W 2m/s	SW 1m/s	S 4m/s
11	SE 2m/s	SE 1m/s	S 3m/s	NW 2m/s	0m/s	S 2m/s
12	S 3m/s	N 2m/s	N 3m/s	S 4m/s	N 1m/s	S 3m/s
13	S 3m/s	NW 1m/s	W 3m/s	SE 2m/s	N 1m/s	W 5m/s
14	S 2m/s	NW 2m/s	W 4m/s	SW 3m/s	NE 1m/s	S 3m/s
15	SW 4m/s	W 3m/s	W 3m/s	W 3m/s	N 1m/s	SW 3m/s
16	W 4m/s	S 2m/s	NE 2m/s	SE 4m/s	N 1m/s	SW 1m/s
17	SW 3m/s	S 3m/s	-	NW 3m/s	NW 1m/s	S 3m/s
18	SE 2m/s	NE 1m/s	-	SE 4m/s	W 1m/s	SW 3m/s
19	SE 3m/s	E 2m/s	-	SW 1m/s	N 1m/s	SE 1m/s
20	SW 4m/s	SW 4m/s	-	N 1m/s	N 2m/s	SW 2m/s
21	SW 5m/s	W 2m/s	-	N 2m/s	N 2m/s	S 1m/s
22	NE 2m/s	W 3m/s	W 3m/s	NE 1m/s	SE 1m/s	SE 1m/s
23	NE 1m/s	S 3m/s	NE 4m/s	W 1m/s	SE 4m/s	E 2m/s
24	SW 3m/s	SW 4m/s	NW 2m/s	S 3m/s	SE 4m/s	E 1m/s
25	S 3m/s	E 2m/s	N 3m/s	S 3m/s	NW 1m/s	0 m/s
26	NW 3m/s	S 1m/s	W 2m/s	NW 1m/s	S 2m/s	E 1m/s
27	SE 2m/s	S 4m/s	SW 1m/s	S 4m/s	SW 2m/s	S 3m/s
28	SW 2m/s	SW 4m/s	-	S 3m/s	SE 3m/s	S 1m/s
29	S 2m/s	S 2m/s	NW 3m/s	SE 3m/s	SE 2m/s	SE 2m/s
30	SW 3m/s	SW 5m/s	-	E 9m/s	W 4m/s	SW 4m/s
31	W 5m/s	S 2m/s				SW 1m/s

Table A3 – Calculation of photovoltaic potential in Lisitsa.

		[unit]	January	February	March	April	May	June	July	August	September	October	November	December	Year	Average
Average hours of sunshine	Belyy Yar	[hours/day]	1.20	1.60	2.80	5.20	8.40	11.30	11.90	9.20	5.90	2.60	1.20	0.90		5.18
		[hours/month]	37.20	46.40	86.80	156.00	260.40	339.00	368.90	285.20	177.00	80.60	36.00	27.90	1901.40	
	Tomsk	[hours/day]	1.80	3.70	5.50	7.50	8.30	10.50	10.20	8.20	5.70	2.80	1.70	1.30		5.60
		[hours/month]	55.80	107.30	170.50	225.00	257.30	315.00	316.20	254.20	171.00	86.80	51.00	40.30	2050.40	
D/G		[-]	0.59	0.51	0.54	0.61	0.56	0.47	0.49	0.51	0.59	0.67	0.66	0.68		
DNI		[Wh/m^2]	1030	2310	3660	2940	4030	5110	4800	3860	2280	1220	950	627		2740
Angle		[°]	79	71	58	37	26	21	25	36	48	61	74	80		43
Weather	Clear sky	[days]	22	14	12	11	9	13	7	8	7	6	13	13		
	Real sky	[days]	5	5	5	7	8	9	8	6	8	8	4	6		
	Diffuse sky	[days]	4	10	16	12	14	8	16	17	15	17	13	12		
Irradiance	Clear sky	[W/m^2]	493.703	605.485	647.311	666.40	499.95	458.69	458.51	508.35	550.938	589.589	534.689	465.17		543.03
	Real sky	[W/m^2]	148.925	273.428	381.40	291.49	322.28	313.54	319.64	313.11	244.408	165.820	144.517	106.73		252.11
	Diffuse sky	[W/m^2]	39.222	82.628	152.26	150.36	164.40	137.24	143.30	135.98	110.244	73.846	49.965	29.56		105.75
	Total	[W/m^2]	358.16	330.84	364.11	348.24	336.37	393.40	293.24	281.65	239.52	183.85	255.28	214.60		299.94
Total photovoltaic energy	Clear sky	[$Wh/m^2/day$]	3209.07	5146.63	7120.42	8198.18	7999.26	8027.08	7794.62	7371.16	6611.27	5601.10	3742.83	2558.46	73380	decrease:
	Real sky	[$Wh/m^2/day$]	968.02	2324.14	4195.40	3935.13	5156.43	5486.87	5433.84	4540.22	2932.90	1575.29	1011.62	587.07	38146	48.0%
	Diffuse sky	[$Wh/m^2/day$]	254.94	702.34	1674.93	2029.91	2630.40	2401.69	2436.17	1971.75	1322.94	701.54	349.76	162.61	16638	77.3%
	Total	[kWh/m^2]	76.46	90.70	121.91	133.56	150.07	155.53	137.01	119.73	87.98	58.14	57.25	38.73	1127.05	
	Average	[$Wh/m^2/day$]	2466.44	3127.48	3932.43	4451.96	4840.98	5184.21	4419.74	3862.27	2932.54	1875.33	1908.34	1249.47		3322.61
Temperature		[°C]	-17.8	-16.9	-8.2	0.8	9	15.8	18.7	15.2	9.1	0.6	-8.9	-15.6		0.15
Efficiency	Irradiance 1000W/m^2		21.78%	21.69%	20.97%	20.42%	19.66%	19.14%	18.93%	19.22%	19.66%	20.30%	21.05%	21.55%		20.36%
	Irradiance 300W/m^2		16.65%	16.34%	15.88%	15.21%	14.35%	14.29%	13.28%	13.47%	13.58%	13.77%	15.09%	15.27%		14.76%
Electricity in grid		[MWh]	39.75	32.46	34.73	31.40	29.08	30.36	30.11	31.34	33.01	32.93	37.75	43.87		
Generate energy	For 1 m^2	[kWh/day]	0.41	0.51	0.69	0.72	0.69	0.82	0.59	0.52	0.41	0.26	0.29	0.19		0.51
		[kWh]	12.73	14.82	20.76	21.61	21.54	24.71	18.19	16.13	12.16	8.01	8.64	5.91	185.20	
	For 225 m^2	[kWh]	2863.55	3333.81	4671.36	4861.19	4845.72	5559.60	4092.66	3629.60	2736.53	1801.28	1944.08	1330.51	41669.89	
Electricity in grid		[kWh]	39750	32460	34730	31400	29080	30360	30110	31340	33010	32930	37750	43870		
Percent of consumption		[%]	7.20%	10.27%	13.45%	15.48%	16.66%	18.31%	13.59%	11.58%	8.29%	5.47%	5.15%	3.03%		10.24%

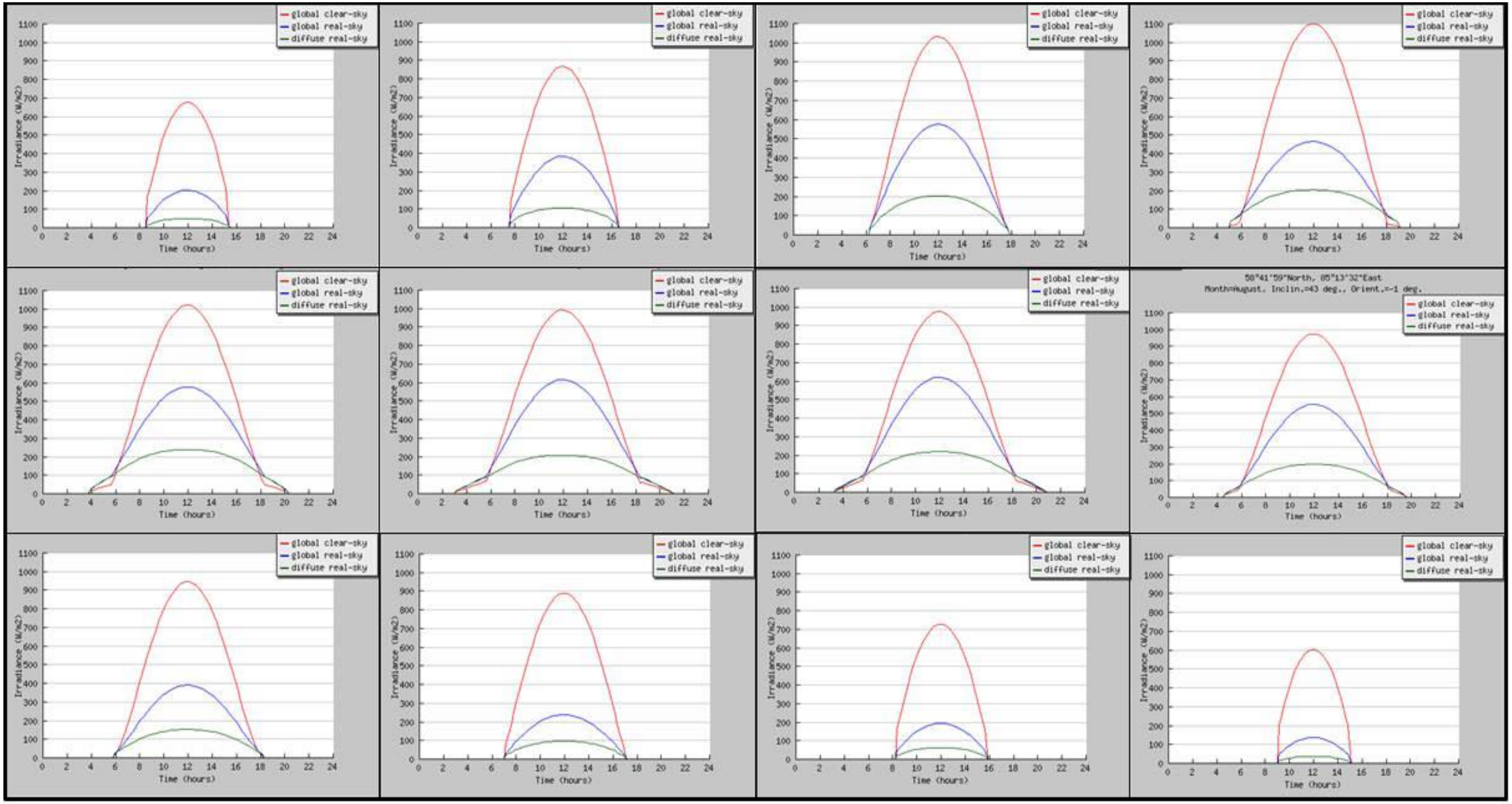

Figure 26 – Photovoltaic radiation daily profile for three types of cloudiness in Lisitsa.

Table A4 – Consumption analysis in Lisitsa

	Electricity consumption analysis-real numbers						
Month	*Electricity supply for public buildings [MWh]*	*Electricity supply for people [MWh]*	*Electricity supply for enterprises [MWh]*	*Electricity losses [MWh]*	*Electricity supply in grid [MWh]*	*Own needs [MWh]*	*Power output DG [MWh]*
January	*3.41*	*26.26*	*3.84*	*6.24*	*39.75*	*1.66*	*41.41*
February	*2.48*	*21.43*	*3.22*	*5.33*	*32.46*	*1.42*	*33.88*
March	*2.55*	*22.83*	*3.56*	*5.79*	*34.73*	*1.54*	*36.27*
April	*1.53*	*21.61*	*3.32*	*4.94*	*31.40*	*1.32*	*32.72*
May	*1.37*	*20.63*	*2.52*	*4.56*	*29.08*	*1.22*	*30.30*
June	*1.32*	*22.76*	*1.52*	*4.76*	*30.36*	*1.27*	*31.63*
July	*0.51*	*23.46*	*1.41*	*4.73*	*30.11*	*1.26*	*31.37*
August	*0.43*	*24.04*	*1.93*	*4.94*	*31.34*	*1.32*	*32.66*
September	*1.48*	*24.48*	*1.87*	*5.18*	*33.01*	*1.38*	*34.39*
October	*2.06*	*23.59*	*2.11*	*5.17*	*32.93*	*1.38*	*34.31*
November	*2.43*	*26.10*	*3.29*	*5.93*	*37.75*	*1.58*	*39.33*
December	*2.87*	*30.26*	*3.85*	*6.89*	*43.87*	*1.84*	*45.71*
Year	*22.44*	*287.45*	*32.44*	*64.46*	*406.79*	*17.18*	*423.97*
Monthly average	*1.87*	*23.95*	*2.70*	*5.37*	*33.90*	*1.43*	*35.33*
Percent from total electricity in grid	*5.52%*	*70.66%*	*7.97%*	*15.85%*	*100.00%*	*-*	*-*
Percent from total electricity output	*5.29%*	*67.80%*	*7.65%*	*15.20%*	*-*	*4.05%*	*100.00%*

Table A4 – Consumption analysis in Lisitsa

	Electricity consumption analysis- absolute numbers					*Fuel consumption*		
Month	*Public buildings to power output*	*People to power output*	*Enterprises to power output*	*Loses in grid to power output*	*Own consumption to power output*	*Fuel Consumption [gr./kWh]*	*Fuel consumption [l/kWh]*	*Total fuel [l]*
January	*8.23%*	*63.41%*	*9.27%*	*15.07%*	*4.02%*	*343.5*	*0.409*	*16935*
February	*7.32%*	*63.25%*	*9.50%*	*15.73%*	*4.19%*	*342.0*	*0.407*	*13794*
March	*7.03%*	*62.94%*	*9.81%*	*15.96%*	*4.26%*	*339.0*	*0.404*	*14640*
April	*4.68%*	*66.06%*	*10.15%*	*15.10%*	*4.02%*	*329.0*	*0.392*	*12814*
May	*4.52%*	*68.09%*	*8.32%*	*15.05%*	*4.02%*	*340.0*	*0.405*	*12262*
June	*4.17%*	*71.96%*	*4.81%*	*15.05%*	*4.02%*	*338.0*	*0.402*	*12727*
July	*1.63%*	*74.78%*	*4.49%*	*15.08%*	*4.02%*	*341.0*	*0.406*	*12734*
August	*1.32%*	*73.62%*	*5.91%*	*15.13%*	*4.03%*	*338.9*	*0.403*	*13176*
September	*4.30%*	*71.18%*	*5.44%*	*15.06%*	*4.01%*	*338.0*	*0.402*	*13837*
October	*6.00%*	*68.76%*	*6.15%*	*15.07%*	*4.02%*	*339.5*	*0.404*	*13866*
November	*6.18%*	*66.36%*	*8.36%*	*15.08%*	*4.02%*	*370.4*	*0.441*	*17342*
December	*6.28%*	*66.20%*	*8.42%*	*15.07%*	*4.02%*	*372.6*	*0.444*	*20272*
Year	-	-	-	-	-	-	-	*174399*
Monthly average	*5.14%*	*68.05%*	*7.55%*	*15.20%*	*4.05%*	*344.3*	*0.410*	*14533*

Table A5 – Daily consumption calculation

Rated active power	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Winter	30	30	30	30	30	30	50	55	40	30	35	40	40	30	30	40	65	100	60	50	40	35	30	30
Spring	25	25	25	25	30	35	50	50	30	30	35	40	35	30	30	30	40	60	100	50	35	35	25	25
Summer	20	20	20	20	30	35	40	45	25	25	25	35	30	30	30	30	30	40	60	100	60	35	35	20
Autumn	25	25	25	25	30	35	50	50	30	30	30	40	30	30	30	30	40	60	100	50	40	35	30	25
Real number	kW																							
Winter	40.3	40.3	40.3	40.3	40.3	40.3	67.1	73.8	53.7	40.3	47.0	53.7	53.7	40.3	40.3	53.7	87.2	134.2	80.5	67.1	53.7	47.0	40.3	40.3
Spring	31.2	31.2	31.2	31.2	37.4	43.6	62.3	62.3	37.4	37.4	43.6	49.9	43.6	37.4	37.4	37.4	49.9	74.8	124.6	62.3	43.6	43.6	31.2	31.2
Summer	24.8	24.8	24.8	24.8	37.1	43.3	49.5	55.7	30.9	30.9	30.9	43.3	37.1	37.1	37.1	37.1	37.1	49.5	74.3	123.8	74.3	43.3	43.3	24.8
Autumn	33.2	33.2	33.2	33.2	39.8	46.4	66.3	66.3	39.8	39.8	39.8	53.1	39.8	39.8	39.8	39.8	53.1	79.6	132.6	66.3	53.1	46.4	39.8	33.2

Table A6 – Diesel generator characteristics [18]

Generator	AD-40
Nominal power	40kW/50kVA
Nominal voltage	400V
Frequency	50Hz
Nominal current	72A
Consumption	17 liters
Operating speed	1500 1/min