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A REVIEW TO WIND ENERGY UTILIZATION IN NORTH-WEST RUSSIA

Bachelor's Thesis 2013

## ABSTRACT

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A Review to Wind Energy Utilization in North-West  
Russia

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The problem of using renewable energy sources is studied in this thesis work. The attention is concentrated on the feasibilities of using the wind energy in the North-West Russia and on some problems which can appear. Some of them are the place of a possible wind farm, laws of new sources connection, and the protection of the electrical grid.

The aim of the work was to realize the possibility of inserting new energy resources into the Russian electrical grid and the importance of using renewables. An answer was sought to the question why the country network had no changes for a long time and what factors are preventing the changes.

The study was carried out with the help of technical encyclopedias and energy companies official websites. Some information was retrieved through the conversation with specialists from the largest Russian energy companies.

The idea of inserting new energy resources in the Russian economy looks very promising. Naturally, some investments and time are needed. In the next few years the problem of renewables will become very actual and then this work will be very useful.

## TABLE OF CONTENTS

1	INTRODUCTION	6
2	ELECTRIC POWER GENERATING	7
2.1	Fossil fuels	7
2.1.1	The elementary composition of the solid and liquid fuels	7
2.1.2	Nonrenewable energy sources	9
2.1.3	Approximate prices for the fossil fuels	9
2.2	Renewable energy sources	10
2.2.1	Solar energy	10
2.2.2	Geothermal and hydro energy	12
2.2.3	Wind energy	13
2.2.4	Solid waste and biomass	13
2.2.5	Fuel cells	14
2.3	Types of power plants	14
2.3.1	Steam turbines	14
2.3.2	Thermal power plants	15
2.3.3	Nuclear power plants	16
2.3.4	Water power plants	17
2.4	Day and night time load	18
2.5	Rational use of energy	19
3	POWER SUPPLY IN NORTH-WEST RUSSIA	21
3.1	Total energy production in Leningrad region	21
3.2	Lack of energy	22
3.3	Electricity transfer networks and Vyborg DC link	23
3.4	Technical concepts of connecting wind power to electrical network	24
3.5	Internal electrical network of a wind power park	27
4	ELECTRICITY TRADE MECHANISMS OF RUSSIA	29
4.1	Owners of the grid	29
4.2	Grid of North-West Russia	31
4.3	The transfer prices and the electricity prices	33

4.3.1	Electricity market	34
4.3.2	Electricity prices in North-West Russia	35
4.4	Comparison of EU and Russian regulations	36
4.5	Economic benefits of wind farms	40
4.5.1	Economic benefits of existing wind farms	40
4.5.2	Methods of rising economy of wind farms	41
5	WIND ENERGY BASICS	43
5.1	Power from wind	43
5.2	Wind power potential	45
5.3	Vertical wind generators	47
5.3.1	Orthogonal wind turbines	47
5.3.2	Wind turbines with Savonius rotor	48
5.3.3	Wind turbines with a Darrieus rotor	49
5.3.4	Wind turbines with a Helicoid rotor	50
5.3.5	Multibladed wind turbines	51
5.4	Horizontal-axis wind generators	52
5.5	Present wind farms in Russia	55
6	GRID CONNECTION	58
6.1	Operation of wind turbines	58
6.1.1	Faults	60
6.1.2	Determining the state of system components	61
6.2	Devices used for grid connections	61
6.2.1	Transformers	62
6.2.2	Switches and axial devices	63
6.3	Grid protection	64
6.3.1	Short-circuit current	64
6.3.2	Islanding and auto recloser	65
6.4	Voltage control	65
6.5	Grid effects	67

6.5.1	Wind turbines power quality	67
6.5.2	Output behavior of wind power plants	68
6.5.3	Voltage and frequency response	69
6.5.4	Harmonics and methods to reduce them	70
6.6	Grid connection rules	72
7	CONCLUSIONS	75
	REFERENCES	76

## 1 INTRODUCTION

Energy is a decisive sector for the development of the Russian economy, because without its progress the development in the country is not possible. Heat energy takes the principal place in the energy balance of Russia, which accounts for about 40 % of the fuel produced in the country. The part of energy of the fossil fuels in the fuel and energy balance (FEB) of the country is 25 %. Of particular interest to the individual regions is the use of renewable energy sources, such as the use of wind. The share of wind power in the Russian fuel and energy balance cannot be more than 1 - 2 %, even with the present intensity of its development. This energy source, as an autonomous one, is certainly promising. To increase the gross output with maximum use of all kinds of energy saving, it is necessary to increase the production of electricity.

For many years, Russian energy was based on the use of organic fuels to convert heat into electrical energy by using steam turbines. At the moment this technology and the level of improvement of these facilities behind the world, and this gap is to overcome. Increasing of the energy capacity of Russia should be mainly implemented due to the production of electricity through the use of organic fuels. One of the most significant problems in the long term period is the technical re-build of existing power plants, extending the life of power plant facilities. In recent years, because of the financial crisis, there is a constant increase in the volume of equipment that has reached its economic life, which leads to a lack of efficiency of the electricity generation and reduction the reliability of electricity supply. It is necessary to modernize the energy sector.

Prospective development of the main power grid of Russia has to ensure its stable and reliable operation under the conditions of market power and electricity. In order to eliminate technical constraints to the development of competition in the market, special attention has to be paid to the development of backbone electric grids, increasing their branching and bandwidth and reconstruction. The development of electric power industry in the future will depend on the rate of growth of the economy, the implementation of structural reforms in the sector, aimed at creating a competitive market economy that will improve the efficiency and investment attractiveness of energy. This thesis aims at giving an overview of the status of power supply in North-West Russia.

## 2 ELECTRIC POWER GENERATING

A definition of energy in a dictionary (Glossary.ru) says that: "Energy is a scalar physical quantity that is a common measure of the various forms of motion and transition measure of the movement of matter from one form to another." The energy resources are material objects, in which the energy is concentrated. Energy resources are divided into renewable and non-renewable. The former are those that continuously regenerates by nature (water, wind), and the later are the previously accumulated in nature, but in the current geological conditions are not forming (coal, oil, gas). The energy extracted directly from the nature (fuel, water, wind, geothermal, nuclear), is called the primary. The energy obtained after the conversion of primary energy in special plants, is called secondary. (Physicalsystems, 2013)

### 2.1 Fossil fuels

Any substance capable of combustion to pick out significant amount of heat may be called a fuel. According to the definition given by Mendeleev (quoted in Bystritskyi, 2005, 34) "fuel is a combustible matter, deliberately burned to produce heat." The practical feasibility of fuel is determined by the quantitative inventory, production facilities, the rate of combustion, calorific value, the possibility of long-term storage and harmless combustion products for people and equipment. Chemical energy release is the process of an oxidation reaction of fuel and oxidant. (Bystritskyi, 2005, 34)

#### 2.1.1 The elementary composition of the solid and liquid fuels

The fuel in the form in which it comes to be burned in the furnaces or combustion engines is called the working. In general, the content of solid or liquid fuel includes carbon C, hydrogen H, oxygen O, nitrogen N, sulfur S and non-combustible mineral impurities – ash A and moisture W.

For the working fuel mass the equation is obvious:

$$C^p + H^p + O^p + N^p + S^p + A^p + W^p = 100 \% \text{ (Equation 2.1)}$$

Characteristics of the fuel composition, according to the working masses, are very unstable, as it can vary greatly depending on the method of its production, transportation

and storage. The moisture contained in the fuel, together with ash, called a ballast of fuel. The ballast significantly reduces the value of the fuel, reducing its calorific value. Moisture is harmful in the fuel because, firstly, heat is consumed for its evaporation when combustion, and secondly, it reduces the relative amount of combustible material in the fuel. The presence of ash not only reduces the heat of combustion, but makes process of combustion in the furnace and its operation more difficult. (Bystritskyi, 2005, 86)

The approximate composition and thermal performance of a combustible fuel mass are presented in table 1:

Table 1. Composition and thermal performance of different fuels (Bystritskyi, 2005, 88)

Fuel	Composition of combustible fuel mass, %					Incombustible materials, V, %	Lowest heating value, MJ/kg
	C <sup>P</sup>	S <sup>P</sup>	H <sup>P</sup>	O <sup>P</sup>	N <sup>P</sup>		
Wood	51	-	6,1	42,2	0,6	85	19
Peat	58	0,3	6	33,6	2,5	70	8,12
Lignite	64 - 78	0,3 - 6	3,8 – 6,3	15,26	0,6 – 1,6	40 - 60	27
Coal	75 - 90	0,5 - 6	4 - 6	2 - 13	1- 2,7	9 - 50	33
Oil	85	0,05	14,9	0,05	-	0	43
Natural gas	95	-	3,8	0,4	0,9	-	36,7

According to table 1, it is possible to sum up that oil and natural gas are the best fuels for combustion because of the high heating value and low amount of emissions.

### 2.1.2 Nonrenewable energy sources

It is difficult to calculate how many years oil reserves will be enough. If current trends continue, the annual consumption of oil in the world by 2018 will reach 3 billion tons. Even assuming that the using reserves will increase substantially, geologists have come to the conclusion that by 2030, 80 % of the world's oil reserves will be exhausted.

Coal reserves are easier to estimate. Three quarters of the world's reserves (approximately 10 000 000 000 000 t.) are situated in the countries of the former Soviet Union, the U.S. and China. Although there is much more coal in the world than oil and natural gas, its reserves are not unlimited. In the 1990s the global consumption of coal was more than 2.3 billion tons per year. Differently from the oil, coal consumption has increased significantly, not only in developing countries but also in industrialized ones. According to current forecasts, coal reserves should last for another 420 years. However, if the consumption will grow at their current pace, there will not be enough coal reserves even for the next 200 years.

In 1995, more or less authentic global uranium reserves were estimated at 1.5 million tons. Additional resources were estimated at 0.9 million tons. The largest known sources of uranium are found in North America, Australia, Brazil and South Africa. It is believed that the countries of the former Soviet Union have large amounts of uranium. In 1995, the number of operating nuclear reactors around the world reached 400 (in 1970 - only 66), and their total capacity was about 300 000 MW. In the U.S. only 55 new nuclear power plants planned and under construction, and 113 other projects were canceled. (Encyclopedia of Kol'er, 2000)

### 2.1.3 Approximate prices for the fossil fuels

The prices for some fossil fuels are presented in table 2. Two countries are shown for comparing.

Table 2 Fossil fuels prices (Volgograd consumer, 2013)

Country	Natural gas, €/MWh	fuel oil (crude oil), €/liter	oil, €/liter
Russia	7.3	0.24	0.81
Finland	26.65	0.63	1.64

The prices explain why traditional energy production, by burning fossil fuels, is still so popular in Russia. In addition, we know that the amount of fuel still storing in Earth crust is not forever. The problem of finding new alternative sources of energy is already present.

## 2.2 Renewable energy sources

Renewable or regenerative energy ("green energy") is the energy from sources that are on a human scale could be called inexhaustible. The basic principle of the use of renewable energy is its removing from occurring in the environment processes and providing it for technical uses.

### 2.2.1 Solar energy

Solar energy has two main advantages. Firstly, there is a lot of it and it relates to renewable energy resources: the duration the sun existence is estimated at about 5 000 000 000 years. Secondly, its use does not result in harmful environmental effects. However, the use of solar energy is bothered by a number of difficulties. Although the total amount of this energy is huge, it is scattered without control. To obtain large amounts of energy collecting large areas are required. In addition, there is the problem of instability of energy supply: the sun does not always shine. Even in the desert, where cloudless weather is the predominant, night follows day. Consequently, collectors of solar energy are required. Finally, many using methods of solar energy do not yet have been tested, and their economic viability is not proven. You can specify three main areas of solar energy:

- for heating (including hot water) and air conditioning

- for the direct conversion into electricity by means of solar photovoltaic cells
- for large-scale electricity production from thermal cycling.( Encyclopedia of Kol'er, 2000)

### 2.2.2 Geothermal and hydro energy

Geothermal energy, i.e. the heat of the Earth's interior, is already used in a number of countries, such as Iceland, Russia, Italy and New Zealand. The crust thickness of 32-35 km is much thinner than the layer lying beneath it - the mantle, extending about 2 900 km to the hot liquid core. The mantle is a source gases-rich fiery liquid rock (magma), which are erupted by the active volcanoes. Heat mainly appears due to the radioactive decay of substances in the earth's core. Temperature and the amount of heat are so great that it causes the melting of mantle rocks. Hot rocks can create thermal "bags" which are heated under the surface. After a contact with them, water is heated and even converted to steam. Because such "bags" are usually sealed, hot water and steam are often under high pressure and temperature of them exceeds the boiling point of water at the surface. The largest geothermal resources are concentrated in the volcanic areas and the borders of the cortical plates. The main disadvantage of geothermal energy is that its resources are localized and limited, although surveys do not show the presence of significant deposits of hot rocks or the possibility of drilling wells to the mantle. A significant contribution of this resource in the energy sector can be expected only in the local geographic areas.

Hydropower provides nearly a third of the electricity used in the world. Norway, where the electric power per person is more than anywhere else, lives almost totally with hydroelectric power. In water power plants and pumped storage power plants the potential energy of the water is used, accumulated by dams. At the base of the dam located turbine rotated by the water (which is supplied to them under normal pressure) and the rotating rotor generators of electric current. There are really large power plants. Two large hydropower plants in Russia are widely known: Krasnoyarsk (6000 MW) and Bratsk (4100 MW). The largest water power plant in the United States is Grand Coulee, the full capacity 6480 MW. In 1995, hydroelectricity accounted for about 7 % of the electricity generated in the world. Hydropower - one of the cheapest and cleanest energy resources. It is renewable in the sense that the reservoirs are fulfilled with river and rain water. The question remains to be open about the feasibility of building hydroelectric power stations on the plains.

There are tidal power plants, which use differences of water levels, which are formed during high tide and low tide. To do this, the low coastal basin is separated by a dam,

which delays the tidal water at low tide. The water is then released, and it turns the turbine. Tidal power plants can be a valuable local energy help, but there are not many suitable places in the world for their construction, so they cannot change the overall energy situation. (Encyclopedia of Kol'er, 2000)

### 2.2.3 Wind energy

Wind energy is the energy sector, specializing in the conversion of kinetic energy of air masses in the atmosphere to electrical, mechanical, thermal, or in any other form of energy that is convenient for use in the economy. Such a transformation can be carried out by such units as the wind generator (for power), windmill (for conversion into mechanical energy), sail (for use in transport), and others. Wind energy is a renewable form of energy, as it is a consequence of solar activity. Wind power is a booming industry, so at the end of 2010 the total installed capacity of all the wind turbines in the world was 196.6 GW. In the same year, the amount of electrical energy produced by wind turbines in the world was 430 terawatt-hours (2.5 % of the electrical energy produced by mankind). Some countries are particularly rapidly developing wind energy. In 2011 in Denmark wind power produced was accounted in 28 % of all electricity, in Portugal – 19 %, Ireland – 14 %, Spain – 16 %, in Germany – 8 %. In May 2009, 80 countries used wind power on a commercial basis. (Encyclopedia of Kol'er, 2000)

### 2.2.4 Solid waste and biomass

Approximately half of the solid waste is water. That is easy to collect only 15 % of waste. The best result that can provide solid waste is approximately 3 % of energy corresponding to oil and 6 % to natural gas. Consequently, without radical improvements in the organization of solid waste collection, people are unlikely to provide a major contribution of the production of electricity. Biomass - wood and organic waste accounts for about 14 % of the total energy consumption in the world. Biomass - a common household fuel in many developing countries. There have been proposals to grow plants (including timber) as a source of energy. Fast-growing aquatic plants are capable of producing up to 190 tons of dry matter per hectare per year. Such products can be burned as fuel or started the distillation to produce liquid and gaseous hydrocarbons. In Brazil, sugar cane was used for the production of alcohol fuels to replace gasoline. The cost is slightly higher than the cost of conventional fossil fuels. With proper management of such energy, source can be recharged. More research is need-

ed, especially in growing crops and their cost-effectiveness, taking into account the costs of collecting, transporting and grinding. (Encyclopedia of Kol'er, 2000)

### 2.2.5 Fuel cells

A fuel cell is an electrochemical device like an electrochemical cell, but differs in the material. For the electrochemical reaction are fed into it from the outside - in contrast to the limited amount of energy stored in a galvanic cell or battery. Fuel cells carry out the conversion of chemical energy into electricity, avoiding inefficient combustion processes following with heavy losses. This is an electrochemical device that generates electricity as a result of high-performance "cold" combustion of fuel directly. (Encyclopedia of Kol'er, 2000)

## 2.3 Types of power plants

Kinds of power plants that can be chosen, when natural energy is converted into electrical. For these purposes special facilities were developed - power plants. There are many types of power plants such as:

- thermal power plants
- water power plants
- nuclear power plants
- solar power plants
- geothermal power plants
- diesel power plants
- tidal power plants
- wind farms.

### 2.3.1 Steam turbines

A steam turbine - is continuously operating thermal unit, which is the working body of water and steam. A steam turbine process converts the potential energy of compressed and high temperature steam into kinetic energy of rotation of the turbine rotor. It includes a steam turbine and auxiliary equipment. Steam turbine plants are used to drive turbine generators in thermal and nuclear power plants.

In the power plant the mechanical energy converts into electrical energy by using an electrical generator. A schematic diagram of the steam turbine which drives an electric generator is shown in Figure1. There is steam from the boiler unit (1), where it receives heat from the combustion of the fuel supplied to the turbine (2), and expanding there, it does mechanical work, turning the electric generator rotor (3). After exiting the turbine, the steam enters the condenser (4) where it is condensation. Condensates of exhausted steam worked in the turbine pass through a preheater (6) to the deaerator (7) with a condensate pump (5). A feed pump (8) takes the water from the deaerator through the heater (9) in the boiler unit. Heaters (6) and (9) and a deaerator (7) make a system of regenerative feed water heating, which uses steam from unregulated extractions of the steam turbine. (Scheglyaev, 1976)

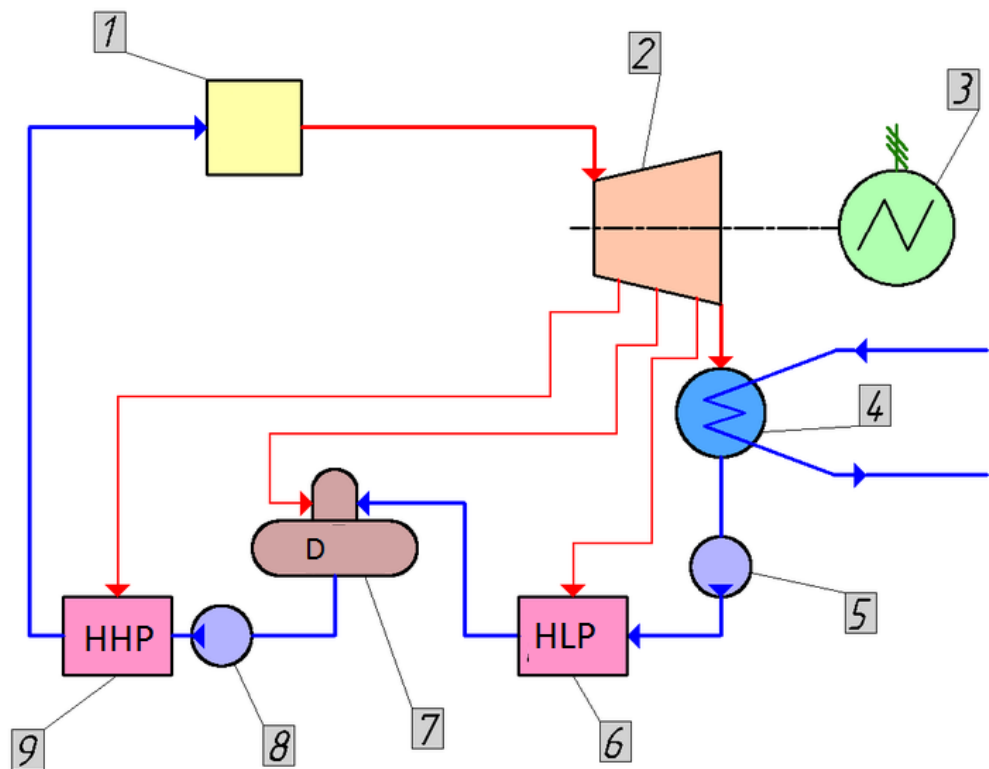


Figure 1. Schematic diagram of the steam turbine

### 2.3.2 Thermal power plants

A thermal power plant is a reliable and productive power plant that produces electricity exclusively. The basic principle is in the action of steam turbines. Fuels for condensing power plants can be such as natural gas, oil or coal, pulverized recycled to the

state. Burning gas, oil or coal in the boiler furnace produces large amounts of heat, this heats the purified and desalinated water in the pipes inside the boiler and turns it into steam. In the superheater the steam continues to heat and at a temperature above  $500^{\circ}\text{C}$  and pressure 13 - 24 MPa enters the condensing turbine. Under the influence of steam turbine rotor is set in motion, a generator transforms the rotational energy of the rotor into electrical energy. This steam expands and cools, its pressure drops to very low numbers. Cooled vapor is returned to a liquid state. Condensates are pumped back to the boiler. For this purposes, the condenser and feed water pumps are used. Thus, the steam-water circuit is almost closed. Water for cooling condensers may be pumped from natural waters reservoirs and at the end of the cycle. It could be output back or constantly circulated through the system, cooling by air or water in the reservoirs or cooling towers. The benefits of thermal power plant are: simple flow chart reliability, a small amount of backup equipment and the possibility of rational expansion or renovation, thanks to modular construction.

Thermal power plants are built close to the places of fuel extraction and convenient water supply. They are made of a series of modular units with a capacity of 20 to 1 200 MW of energy producing supply in the network 110 - 750 kV. Thermal power plants units are not sufficiently maneuverable: the preparation of starting, starting up, synchronization and load take set 3 - 6 hours. Therefore it is preferable for them for operation with a uniform load. The efficiency of thermal power does not exceed 32 - 40 %. They have a strong influence on the environment - polluting the atmosphere, changing the thermal regime of water sources.

Combined power plants are built near heat consumers, while they generally use imported fuel. Operating these power plants is most economical. The efficiency of heat is as high as 60 – 70 %. Units have a capacity of 30 - 250 MW. Energy goes into the 6 - 10 kV grid. (Bystritskyi 2005, 153)

### 2.3.3 Nuclear power plants

Nuclear power plants may be constructed in any geographic area, including inaccessible, areas it there is a water supply source. The amount of fuel consumed is low, therefore there is no need of transport links. Under the terms of the regulation and operation the mode with a uniform load is preferred. The efficiency is about 35 - 38 %. NPPs pollute the atmosphere very little. Emissions of radioactive gases and aerosols

are small, that allows constructing nuclear power plants near cities and loading centers. One difficult problem is the disposal or recovery of spent fuel elements. (Bystritskyi 2005, 159)

#### 2.3.4 Water power plants

A water power plant (WPP) is a power plant using water flow as a source of energy. Water power plants are usually built on the rivers by building dams and reservoirs. Two main factors require efficient production of electric power: a guaranteed supply of water all year round and possibly high slopes of the river and also water engineering favor canyon terrains.

The principle of the water power plant is quite simple. The circuit of hydraulic structures provides the necessary water pressure entering the turbine blades which drives a generator producing electricity. Required water pressure generated by the construction of the dam, and as a consequence of the concentration of the river in a certain place, or diversion - the natural flow of water. In some cases, to obtain the required water pressure and the dam and the diversion are used together. All needed hydroelectric power machines are situated in the building. Depending on the purpose, it has a definite division. Hydroelectric machines which is located in the engine room, directly converts the energy of the water flow into electrical energy. In addition, there are more kinds of auxiliary devices and control systems, transformer stations, distribution systems, and etc. A schematic diagram of a water power plant is shown in the fig. 2.2. (Martens, 1934)

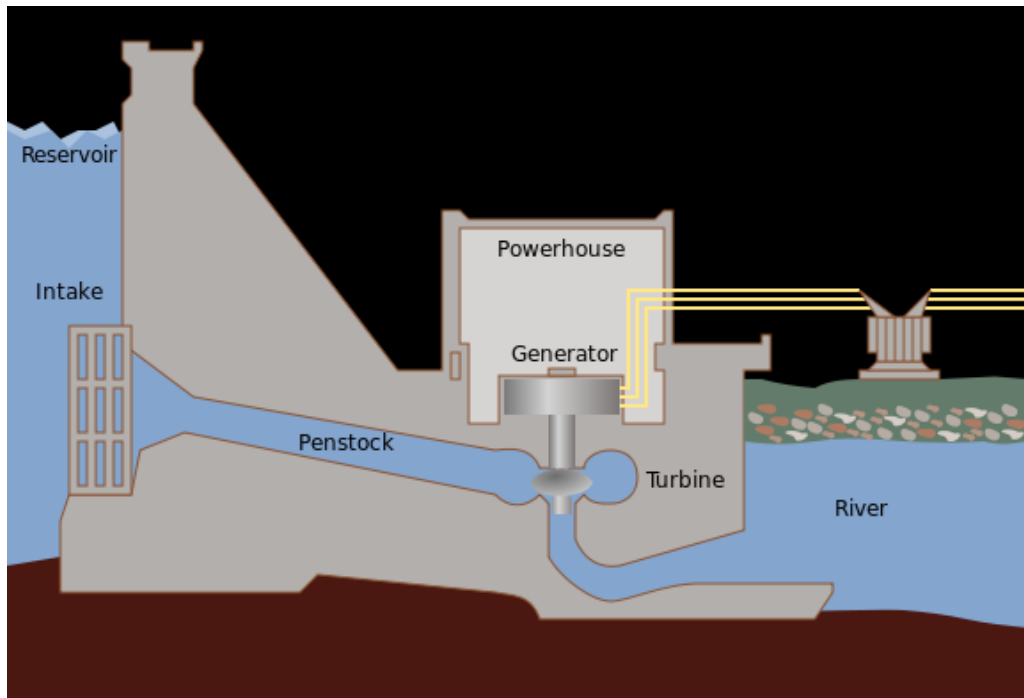


Figure 2. Schematic diagram of a water power plant

#### 2.4 Day and night time load

We can notice that the graph (Figure 3) of the power system load is not uniform. Also, summer and winter schedules are different. A very distinct peak appears in the period from 14:30 to 16:30. Secondly there are two further peaks: one in the morning and one in the evening. This is easily explained by the fact that electricity consumption occurs mostly during the day in homes and factories, but that does not diminish the difficulty of generating electricity. During the peak load additional power is needed while at night some power less is needed. To solve that problem a population needs more rational ways of energy usage. The energy consumption during the day is shown in the figures below. (Sustainable energy authority of Victoria, 2004)

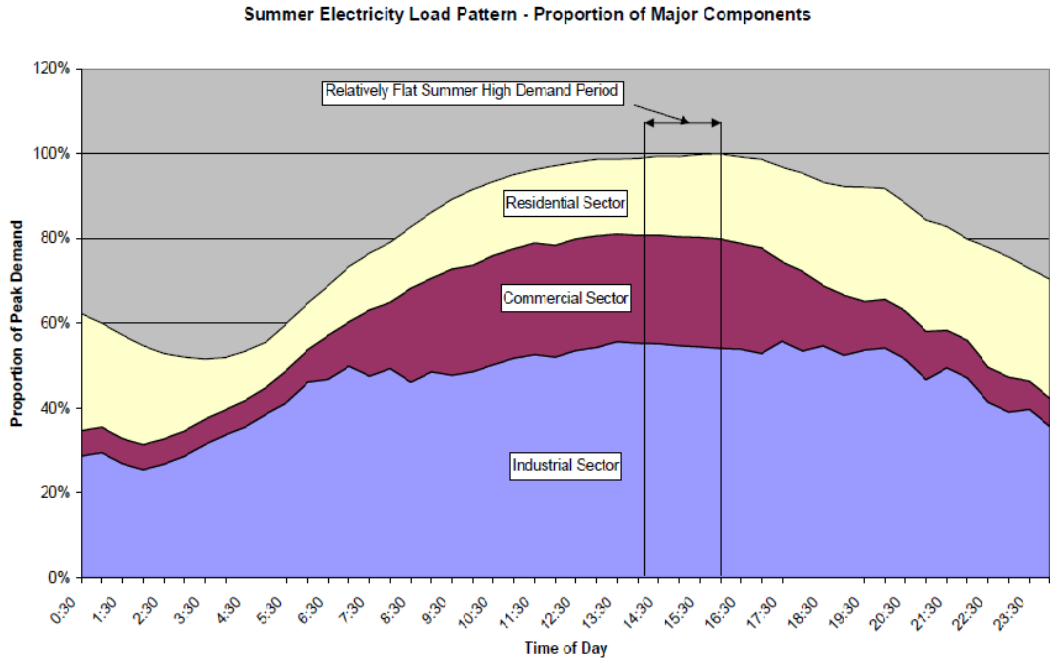


Fig.3. Energy consumption during summer day

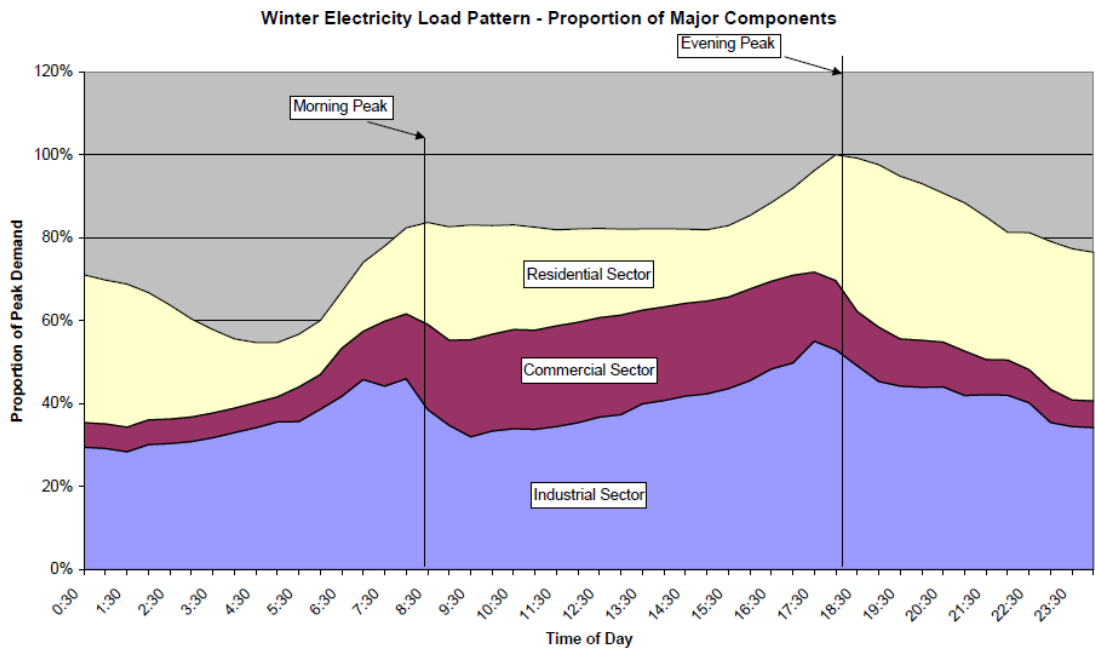


Figure 4. Energy consumption during winter day

### 2.5 Rational use of energy

While the world has no shortage of energy in the coming two to three decades in most countries, the potential for serious problems exists if there will be no alternative sources of energy, or no limitations of its consumption. Obvious, there is need for a

more rational use of energy. There are a number of proposals to improve the efficiency of storage and transportation of energy, as well as more efficient use of it in various branches of industry, transport and households.

The load power varies during the day. There are also its seasonal changes. The efficiency of the power plant can be improved if in times of graph's failure to expend excess energy load power for pumping water in large tanks. Then, during peak periods the water can be produced, causing generating of additional electricity for pumped storage. More widespread use could be found by using the basic mode of power plants in pumping compressed air into underground cavities. Turbines operating on compressed air would allow saving the primary energy during periods of high load.

Large energy losses associated with the transmission of electricity. To reduce losses, the use of transmission lines and distribution networks with high-voltage increases. An alternative direction is the using of superconducting power lines. The electrical resistance of some metals drops to zero when cooled to temperatures close to absolute zero. Superconducting cables could transmit power up to 10 000 MW, so to provide electricity for the whole New York only by using one cable with a 60 cm diameter. It was found that some ceramic materials become superconducting at very low temperatures which can be reached by conventional refrigeration art. This surprising discovery could lead to important innovations not only in the field of power transmission but also in the field of land transport, computing and engineering of nuclear reactors.

Hydrogen is a light gas, but it liquefies at  $-253^{\circ}\text{C}$ . The heating value of liquid hydrogen is 2.75 times greater than natural gas. Hydrogen has environmental advantages over natural gas: the combustion air makes it basically only water vapor. Hydrogen can be transported without difficulty by pipeline for natural gas. It is also possible to keep it in liquefied form in the cryogenic tanks. Hydrogen diffuses readily into some metals such as titanium. It can be accumulated in such metals, and then sampled by heating the metal. (Encyclopedia of Kol'er, 2000)

### 3 POWER SUPPLY IN NORTH-WEST RUSSIA

Electric power is one of the leading production areas in the Leningrad region. Its percentage of the total gross income is accounted for 7 %. Electricity is generated by one nuclear power plant, one thermal power plant, 14 combined power plants, 6 water power plants. More detailed list of power plants is shown in Table 1. (Newsruss, 2013)

#### 3.1 Total energy production in Leningrad region

Table 2. List of power plants in Leningrad region (Appendix 1)

Name and type of power plant	Energy production, MW
Leningrad NPP	4000
Kirishskaya TPP	2100
Avtovskaya CPP	291
Vasileostrovskaya CPP	85
Vyborgskaya CPP	255
Dubrovskaya CPP	192
Pervomaiskaya CPP	330
Pravobereznaya CPP	244
Severnaya CPP	500
CPP – 2	73.5
CPP - 3	5
Iuznaya CPP	800
CPP of glass factory	3.8
Luzskaya CPP	36
NGK CPP	190
Verhne-svirskaya WPP	160
Volhovskaya WPP	83
Lesogorskaya WPP	94
Narvskaya WPP	125
Nizne-svirskaya	99
Svetogorskaya WPP	70.3
Severo-zapadnaya CPP	900

Except for big power plants, the Leningrad region has plenty of small ones which are connected with some special factory. Overall energy production in the region is accounted for 11.1 GW. In spite of such a huge amount of energy produced, Leningrad region is lacking the energy needed for manufacturing and the general population.

### 3.2 Lack of energy

Against the backdrop of economic crisis, the Russian generating companies have to reduce capacity because of falling demand which, according to the System Operator UES, in January 2009 compared to the same period last year decreased by 7.7 %. However, the Leningrad region is the least likely for this process. Because of the high degree of deterioration of generating equipment and insufficient capacity of the power grid, consumption of electricity is limited in a number of industrial enterprises in the region. In particular, the deterioration of transfer lines of Lenenergo reaches 60 %, and the deterioration of substations – 80 %. Many substations use German devices and machines 80 year old.

There are problems with the commissioning of new capacity. For example, the case when the start of the second block of the Severo-Zapadnayay Power Station in St. Petersburg was postponed due to lack of gas. The most problematic area of the Leningrad Region is currently Vsevolozhskiy. The total energy deficit in the area is 1.5 GW. In addition the Vyborg District is included. In every deficient area from Zelenogorsk to Primorsk, problems with the supply of electricity exist.

The situation in the St. Petersburg is equally difficult where the shortage of energy today in different parts is 120 - 150 MW. Since many years the city has had no new power suppliers. According to the Committee for Economic Development, Industrial Policy and Trade of the City Government, by 2014 in St. Petersburg, 704 MW of generating equipment will run out. That is 24 % of the installed capacity of thermal power plant.

Wear and tear on the facilities of electric substations of different voltage classes (330-220-110 kV) at the moment is not less than 50 %. Other unsatisfying moments are at electric grid facilities 35 kV, located in the center of the city: its deterioration is esti-

mated at 100 %. Heating systems each year wait for relaying the pipeline of 300 km but actually an average of 170 km is made. (Aenenrgy, 2013)

### 3.3 Electricity transfer networks and Vyborg DC link

In the Leningrad region a number of different voltage levels are represented: 110 kV, 220 kV, and 330 kV. Also one line from the Leningrad nuclear power plant reaches a voltage of 750kV. Detailed location and voltage class lines are shown on the map in Appendix 1.

On the map (Appendix 1), it is possible also to see the extent of energy supply network in the Leningrad region goes. The situation is shown in February 2006. It is easy to see that about 1.2 GW come to the region from the Kaliningrad nuclear power plant. 200 MW goes to the Pskov region, 200 MW to Estonia, about 200 MW to Karelia, and approximately 700 MW to Finland. Energy exchange with Finland has become possible by inserting a DC link.

The DC link Vyborg is Russia's only link of direct current. It was built for the export of electricity from the Soviet Union to Finland. This operation began in 1981.

The DC power transmission was chosen for economic reasons. The commonly used line with the alternating current of electrical systems of the USSR and Finland should have been synchronized. The costs of synchronization would have exceeded the economic profits of exports. The power line connects Vyborg substation (400 kV) and substations Yllikkälä and Kymi (400 kW). From substation Kamennogorsk (city Kamennogorsk) is installed overhead 330 kV (W1D and W2D) to Vyborg substation (v. Perov) while the 330 kV AC is converted to DC 400 kV and is exported to Finland. In the 2010 - 2011, a two-sided transmission was implemented. Now, Finland can sell up to 350 MW of electricity from its grid (which will certainly be a good idea at the forced repair / crash) to Russia.

The station consists of four independent units of thyristor converters operating at a constant voltage 85 kV DC. The capacity of each unit is 355 MW. At the moment, the transmitted power is 1 400 MW which makes this link the most powerful in the world. (Balyberdin p. 63-67)

### 3.4 Technical concepts of connecting wind power to electrical network

There are some common patterns connecting consumers to wind power systems. At the same time, each case must be considered as an individual project following wind power concepts are this guidance for developers.

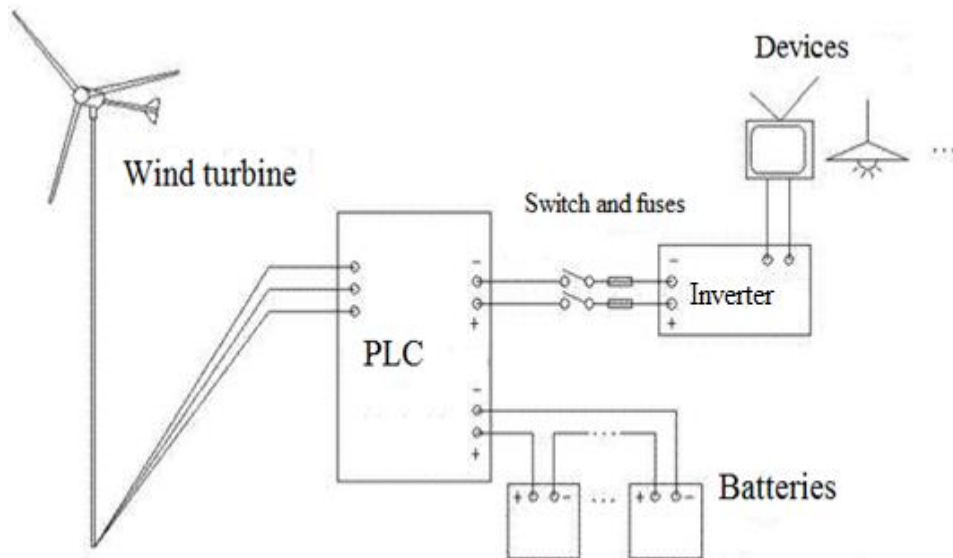


Figure 5. Wind generator with a battery pack

Consumer devices are powered exclusively by a wind turbine. (Alternativenenergy, 2010)

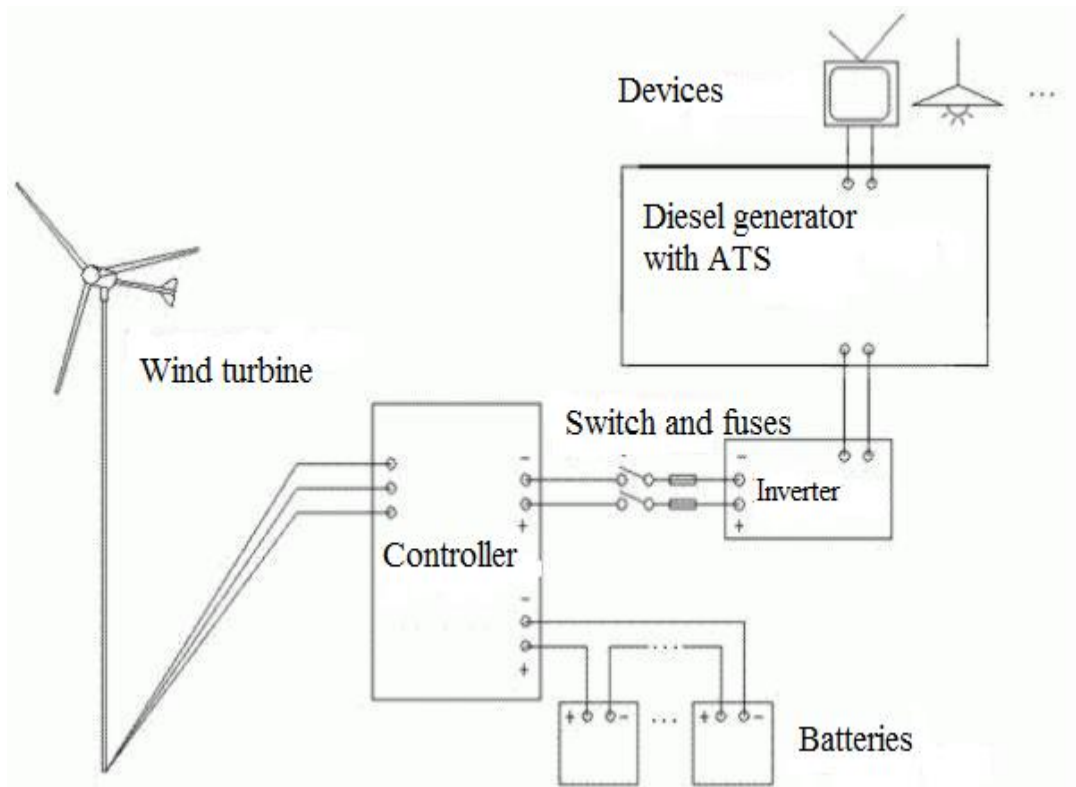


Figure 6. Wind generator with a battery pack and a backup diesel generator

ATS - automatic transfer switch

If there is no wind or the speed is insufficient, the wind turbine will not start. When the battery is discharged a backup generator automatically starts. (Alternativenenergy, 2010)

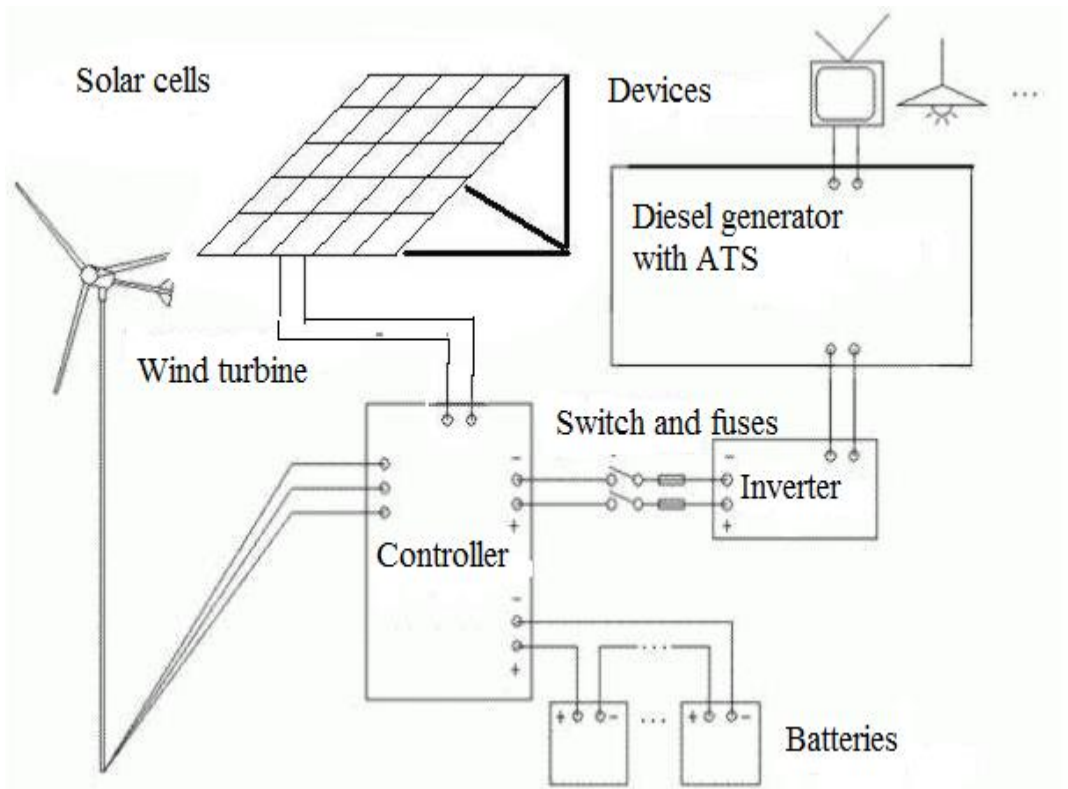


Figure 7. The hybrid autonomous system using sun and wind.

This option provides the connection of solar cells to the system of the wind turbine. Connection can take place through a hybrid controller or a separate controller, which is used for photovoltaic systems. (Alternativenergy, 2010)

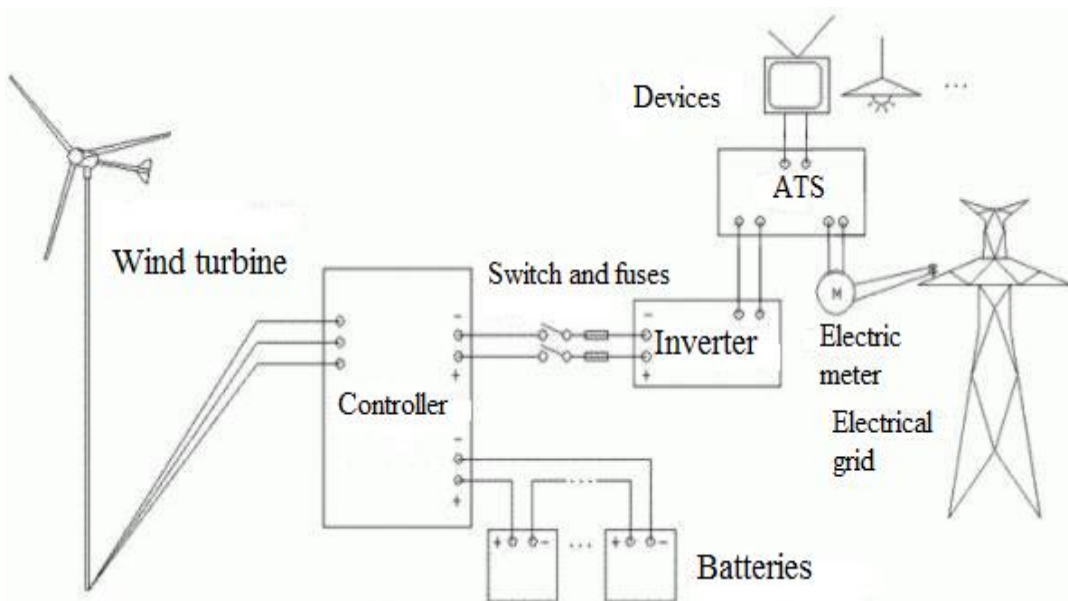


Figure 8. Wind generator with a battery pack and switching network

If there is no wind or the speed is insufficient, the wind turbine will not start. When battery is discharged, the ATS allows the user to switch to the main grid. This circuit can be used in a bidirectional mode, i.e. on the contrary in this case the wind generator is used as a backup power source. In this case, the ATS will switch you to the battery of wind turbine in case of loss of power supply from grid. (Alternativenergy, 2010)

In the wind industry there are problems with an alternative network and local network connection. How the household with 1 kW energy consumption but short-term of 3 kW consumption should be supplied. Then there are save the batteries, but they do not last forever, and the other for 1 kW wind turbine inverter needed of 3 kW. It is significantly more expensive than 1 kW. Civilized countries have found another way: if somebody have clean energy, more than needed, give it to the neighbors across a public network (recovery, such as counter spinning in the opposite direction). If somebody needs more electricity, then get out of the local network and even earn money or cover consumption. (V.Moseichuk, 2009)

### 3.5 Internal electrical network of a wind power park

According to the textbooks (Rozkova, 1986, pp. 3, 365-377, 415-420) for 110 kV circuit to take two workers (A1, A2) and bypass (A0) bus systems (Figure 5). According to the textbooks (Rozkova, 1986, pp.402-411) for 6 kV circuit one partitioned bus system is acceptable. Switching circuit is shown in Figure 9.

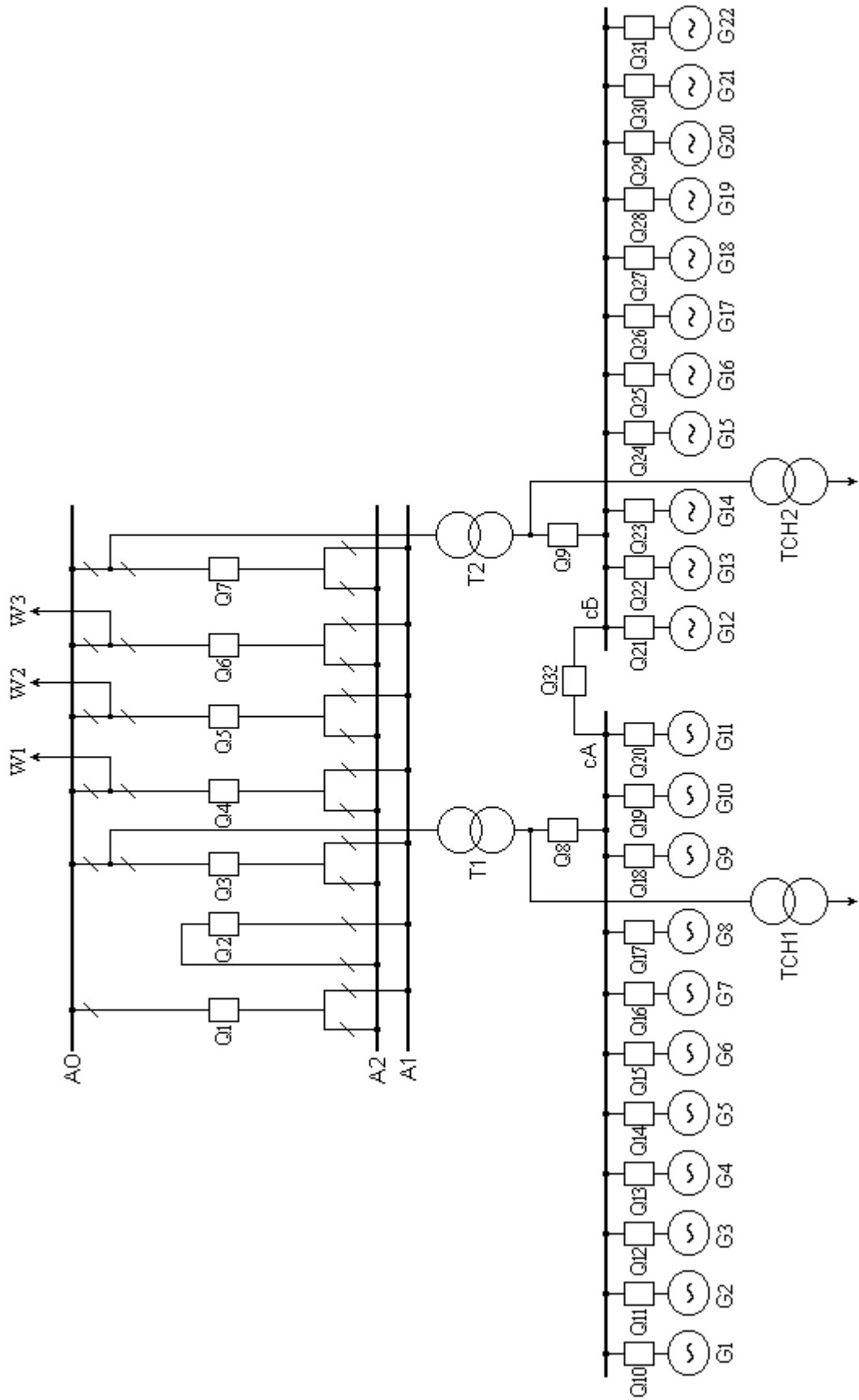


Figure 9. Scheme of internal connection of the wind turbines

## 4 ELECTRICITY TRADE MECHANISMS OF RUSSIA

Russia is actively involved in globalization, including the electricity sector. The development of the correct political doctrine is one of the questions of the global energy field. The role of legal regulations in this process is crucial. The cause of energy reforms are the issues connecting with the lack of full competition in these sectors, which, in its turn, leads to a lack of investments to main funds, shortages of energy resources, loss of reliability of energy supply, etc. Today the main goal of energy reforms is to open energy market to competition and to attract new investments.

### 4.1 Owners of the grid

Unified Energy System of Russia (UES of Russia) consists of 69 regional energy systems, which form 7 integrated energy systems: East, Siberia, the Urals, Middle Volga, South, Central and North-West. All systems are connected with power lines of 220 - 500 kV and above and work in a synchronous mode. The total installed capacity of power plants of UES is about 223 070 MW (223 GW).

As a result of major events related to the reform of the electricity industry in 2008, the structure of system has become quite complicated. This industry section consists of several groups of companies and organizations, each of which performs a particular function. They are divided into wholesale generation companies (OGK), electrical network companies, supply companies, companies that manage the power grid modes, the companies which responsible for the development and operation of a commercial market infrastructure, organizations implementing the control and regulation of the industry, electricity consumers and small producers of electricity.

Generating companies (OGK) own different types of power plants. There are twenty companies which own in total all the thermal power plants, there is one company which controls all electricity production in hydropower plant (RusHydro) and one company which manages all nuclear power plants - ROSENERGOATOM. Among twenty thermal companies, six of them manage large thermal power plants GRES (State District Power Plant), the total installed capacity of each is over 8 GW. Power plants are situated in different regions of Russia. Also there are 14 territorial generating companies (TGK) who own the medium-sized thermal power stations. All power stations belonging to one TGK are located in one part of the country. In addition, there

are several large generating companies that are not controlled by RAO UES. They are four so-called independent companies: Tatenergo, Bashkirenergo, Novosibirskenergo and IrkutskEnergo. In several parts of Russia there are still power plants, controlled by the state, because of the serious imbalance of power generation capacity and low demand for electricity. Such areas are called non-market areas and include the regions which are far away from the central part of the country: Far East, Kamchatka, Chukotka, Sakhalin, a large part of Yakutia, the Kaliningrad Region, the Komi Republic and Arkhangelsk region.

Electrical Network Company is represented by one big company called FSK (Federal Grid Company) and by interregional distribution grid companies (MRSK) which are combined into a single holding company - Holding MRSK. This holding was renamed JSC RosSeti in 2013, and FSK also become a part of this company. FSK owns transmission networks including the high voltage power lines of 220 kV, 330 kV and 500 kV. These power lines connect different energy systems (power plants) in a whole country, providing the possibility of significant amounts of electricity and power flow over long distances between remote large power systems. FSK is mostly controlled by the government, which owns nearly 80 % stock in the company. JSC RosSeti consists of several local companies:

- JSC MRSK of Center and Volga Region
- JSC MRSK of South
- JSC MRSK of North - West
- JSC MRSK of Northern Caucasus
- JSC MRSK of Volga
- JSC MRSK of Urals
- JSC MRSK of Siberia
- JSC TyumenEnergo
- JSC Moscow Electric Grid Company
- JSC Lenenergo
- JSC Yantarenergo.

The last four companies are small territorial grid organizations (TSO), they can belong as to the municipal authorities so to the private investors. There are also local grids which do not have any legal owners.

Supply companies are represented by so called guaranteeing supplier companies and independent suppliers. We as consumers buy electricity from these suppliers. The structure of the electricity market will be described in the next paragraphs.

Companies that regulate the power grid modes of Russia are the System Operator of the Unified Energy System of Russia (SO UES) and its subdivisions. The operation way of SO UES is obligatorily for generating and Electrical Network companies. Unfortunately, not all electrical energy systems of Russia are connected to one whole system. Due to this there are also some local companies which regulate the power grid modes in isolated power districts, for example, in the northern territories of Yakutia.

The company which is responsible for the development and operation of a commercial market infrastructure is Non-Commercial Partnership Market Council and its subsidiary companies: JSC ATS and CJSC CFR. Non-Commercial Partnership Market Council involves all participants of the wholesale market of electrical energy. The main function of this company is to develop and finalize an agreement of joining to the trading system of the wholesale market. This agreement defines all the rules and orders of functioning of wholesale market. Also Non-Commercial Partnership Market Council develops rules for the functioning of retail markets. JSC ATS is the commercial operator of the wholesale market. He organizes the work of the market and the interaction of market participants. CJSC CFR holds financial calculations on the market.

The control and regulation of the electricity industry is provided by various bodies of executive power in Russian Federation and its subdivisions. Direct influence on the processes in the industry has the Ministry of Energy. Significant roles are played by the Federal Tariff Service (FTS), Ministry of Economic Development, Government of the Russian Federation itself, Rostehnadzor company, State Corporation Rosatom and etc. The retail market is regulated by the bodies of executive power in the field of regulation of tariffs (regional energy commissions, committee's rates, etc.). (Non-Commercial Partnership Sovet Rinka, 2013)

## 4.2 Grid of North-West Russia

The main grid company in Northwest-Russia is JSC Lenenergo. It is an electrical network company whose main function is the transmission of electric energy through the networks 110; 35; 6; 0.4 kV, and the connection of consumers to electric networks in

St. Petersburg and the Leningrad region. JSC RosSeti owns 53.41 % of the stocks of JSC Lenenergo, 26.57 % stocks belong to the government of Saint-Petersburg and other stocks belong to the private investors. The total amount of power is about 21 952 MVA which includes 377 substations of 35 - 110 kV and 15 025 substations of 6 - 35 kV.

The area where we plan to install wind turbines belongs to the Leningrad region. The Leningrad region includes the Vyborg district where the small town Primorsk is situated. This Primorsk district is the place where we exactly consider to install wind turbines. The owner of Primorsk electrical grid is a branch of JSC Lenenergo - Vyborg electrical networks. It is responsible for uninterrupted power supply of Vyborg, Priozersky and some parts of Vsevolzhsk districts of the Leningrad region.

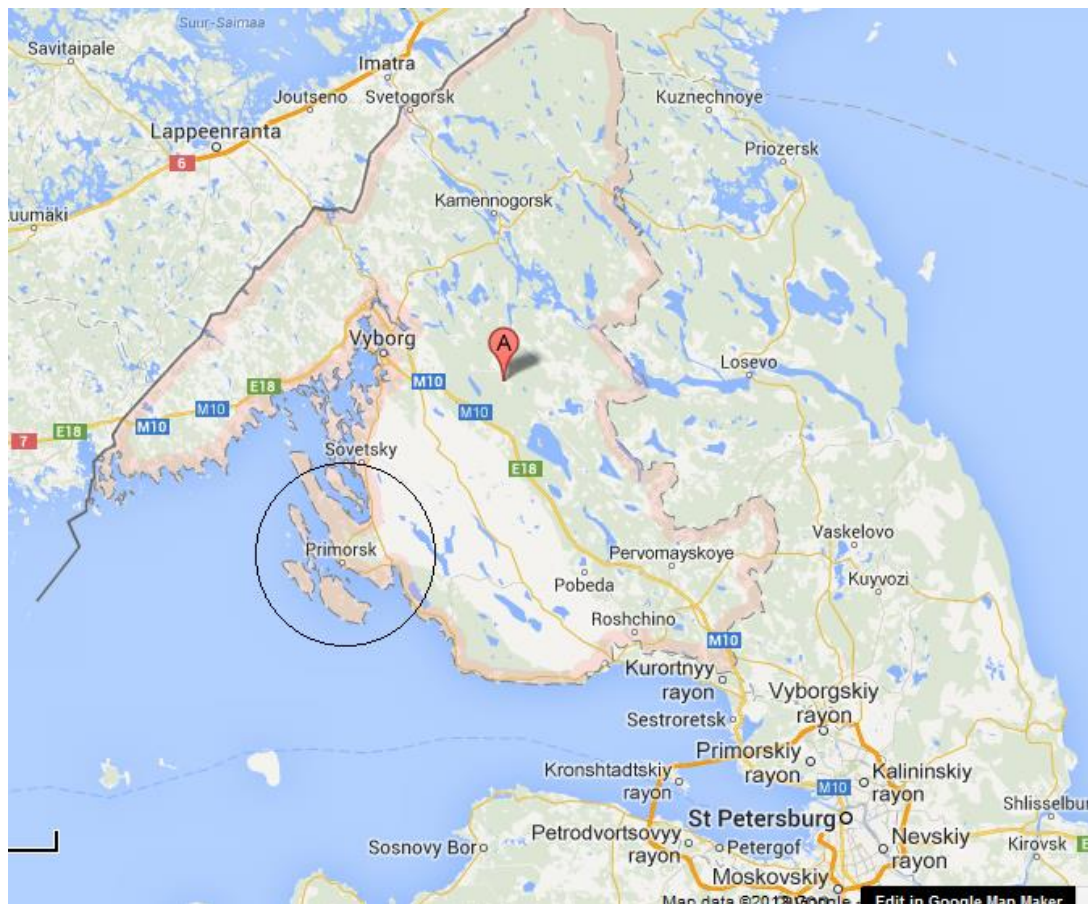


Figure 10. Part of the Leningrad region (Map. Google, 2013)

Vyborg's electrical networks include five districts (Figure 10): Vyborg district electric networks (RECs), Roshchinskiy RES, Priozersky RES, RES Sosnowski, High voltage district. RES is russian abbreviation for a district electrical grid. The biggest electricity consumers in this region are:

- JSC Poultry Roskar
- poultry company Primorje
- JSC Svetogorsky Pulp and Paper Mill
- JSC The Soviet PPM
- compressor station of JSC Gazprom Port and port Ltd. Vysotsky.

Large communities are:

- Vyborg
- Priosersk
- Svetogorsk
- Kamennogorsk
- Primorsk
- workers' settlements Roshino
- Sosnovo
- Lesogorskiy
- Kuznechnoye.

Overhead power lines with voltage range of 100 V – 0.4 kV are extending 6 316 kilometers away and cable lines for 279.91 kilometers. There are about 41 substations of 35 - 110 kV. The total power of Vyborg district is about 1271 MWA. (Lenenergo, 2013)

#### 4.3 The transfer prices and the electricity prices

The final unit price of electricity can vary widely not only in different regions, but also for a variety of customers of the same supplier. The price depends on the type of the tariff, used by the consumer to calculate the cost of consumed electricity.

### 4.3.1 Electricity market

Russian Federation has a two-tier market for electricity: wholesale and retail. In the wholesale market, electricity suppliers (generating companies, importers of electricity) sell to customers (to guaranteeing supplier companies, large consumers, exporters of electricity) two products - electricity and heat. The wholesale market operates on the most territory of the country, and it is divided into two connected price zones: the European part of Russia including the Urals, and Siberia. The regions of the Far East, Kaliningrad, Arkhangelsk region and Komi Republic belong to the so-called non-price areas. In these regions, due to technological reasons (isolation from the unified power grid), the organization of a competitive market is currently not possible.

Wholesale market prices can vary considerably in some regions, due to the different efficiency of power plants serving different regions of the country and the insufficient capacity of the transmission lines. In the retail market, guaranteeing suppliers and supply companies sell purchased in the wholesale market electricity to final consumers. The guaranteeing supplier Energy Company is obliged to sign a contract with each customer that appears in its area of operation. Conditions of contract are same for all consumers. The service area of a guaranteeing supplier usually coincides with the boundaries of the subject of the Russian Federation. Other retail companies which are not supplying the population can sign contracts with customers on any terms. In the retail market there are several possible tariffs: so called two tariffs which include payment for electricity and power (double-rate fare); and the single tariff for electricity which takes into account the price of power (single rate). The cost of electricity to final consumers is primarily determined by the amount of electricity, for which the guaranteeing supplier will pay fixed (controlled) price in the current year.

For electricity and heat over the volume recorded in the regulated contracts, the consumers pay the price according to the price in the wholesale electricity market plus all the necessary payments (transfer services, marketing allowance, etc.). The amount of electricity which can be sold for free prices by guaranteeing suppliers during each month is calculated by the commercial operator JSC ATS (its subsidiary company of Non-Commercial Partnership "Market Council"). These data are published on website of JSC ATS.

The whole price package is calculated for retail buyers: single rate tariff (for electricity by taking into account price for the power), double-rate tariff (separate payment of electricity and heat), zone tariff (price, differentiable on the time of day - night, semi-peak, peak), prices for consumers with hourly cost of electricity (with the establishment of prices for each hour of the day). Rates are calculated separately for payment deviations from the planned consumption. The limit (finite) levels of unregulated prices in retail markets are calculated on the relevant settlement period and reported to the customer organization delivering electrical energy.

In addition to the cost of electricity and heat on the regulated and unregulated prices, the end user pays for: 1) Services infrastructure organizations of the wholesale electricity market for the operation of its IT infrastructure (system operator) and commercial infrastructure (commercial operator), 2) for the services of a supplier, 3) the purchase of electricity from the generating companies of retail market (if necessary). (Non-Commercial Partnership Sovet Rinka, 2013)

#### 4.3.2 Electricity prices in North-West Russia

First of all we need to determine which consumers do we have and which tariffs should be used. For example, electricity prices for population are set in accordance with the type of settlements (urban or rural). The price for urban population depends on whether it has a gas stove or an electric one (electric heaters). Moreover, electricity prices are calculated in accordance with the time of the day. Most groups of population pay so-called single prices, when the cost of one kilowatt per hour does not depend on the time of the day. However, a number of people choosing a two-part (day-night) or even three-part tariff is increasing. In this case, the electricity is cheaper for the consumer at night and more expensive in the afternoon.

Table 3. Electricity tariffs for the population living in urban areas of the Leningrad Region in houses, equipped with gas stoves. (Energovopros, 2013)

Tariffs	Prices, euro/kWh
One-part tariff for electricity	0.071
Electricity tariff, consisting of the two zones of the day	
day area (from 7 am to 11 pm)	0.072
night area (from 11 pm to 7 am)	0.035
Electricity tariff, consisting of the three zones of the day	
peak area (7 am to 9 am and 5 pm to 8 pm)	0.121
semi peak area (from 9 am to 5 pm and from 8 pm to 11 pm)	0.72
night area (from 11 pm to 7 am)	0.35

Table 4. Electricity tariffs for the population living in urban areas of the Leningrad Region in houses equipped with electric stoves, and (or) electric heating appliances. (Energovopros, 2013)

Tariffs	Prices, euro/kWh
One-part tariff for electricity	0.05
Electricity tariff, consisting of the two zones of the day	
day area (from 7 am to 11 pm)	0.051
night area (from 11 pm to 7 am)	0.024
Electricity tariff, consisting of the three zones of the day	
peak area (7 am to 9 am and 5 pm to 8 pm)	0.084
semi peak area (from 9 am to 5 pm and from 8 pm to 11 pm)	0.05
night area (from 11 pm to 7 am)	0.024

Electricity tariffs for the population of the Leningrad region, living in rural areas are the same as in Table 5.

#### 4.4 Comparison of EU and Russian regulations

The creation of competitive market needs new mechanisms and the decrease of government regulation. The competitive market relies on self-regulation mechanisms that

liquidate the possibility of extremely high income. Competition forces companies to reduce costs, stimulates innovation and development.

The creation of competitive market with legal regulation goes unequally in different countries. In the European strategy for sustainable, competitive and secure energy (2006), Europe has not yet created a fully competitive internal energy market. In 2003, new instructions were adopted by the EU in the energy supply sector (2003/54/EC), which creates a common format for the liberalization of the relevant markets of 25 countries - members of the EU. In 2007 a new package of amendments and changes to the EU directives on electricity was published.

The current EU electricity directive, adopted in 2003, requires a separate transportation and production between the different organizations, but they can be part of an integrated company. In the case of the adoption of new directives major European energy companies such as, for example, the German E.ON and France's EDF will be broken up and for Gazprom it will be closed the path to expansion in Europe.

The legal regulation of energy market in Russia is affected by the international integration processes in the energy sector, for example the membership of World Trade Organization (WTO). The main feature of the legal system of WTO is that the obligations accepted by its members, do not require special fixation on the national legal systems. However the necessity to meet the obligations makes to create appropriate institutions and procedures in the national legal systems. (Skurko EV WTO, 2003, pp. 84 - 85). In the case of Russia's joining to this international organization, the legal system has to follow the norms of the WTO laws, including the energy sector.

In the electricity sector in the countries of EU since July 1, 2004 all regulations are carried out in accordance with the EC Directive on electricity 2003/54/EC. According to this Directive, the electricity market is based on the following principles of public service: safety and security of supply; standards of quality, moderate price, environmental protection, etc.

Another EC Directive 2005/89/ES focuses on the actions of security of electricity supply and infrastructure investment. Particularly, this directive obliges the countries to take some measures to improve the level of security and reliability of electricity supply.

One basic principle in EU is the protection of consumer rights as the main condition for the effective functioning of market economy. It is reasonable because the ongoing reforms without social and legal mechanisms will lead to lower quality of life. In accordance with these directives, since July 1, 2007 all EU consumers got an opportunity to purchase electricity from any supplier. This indicates quite high level of competition in the European energy markets.

Nowadays reforms in the electricity sector are carried out by more than a hundred countries around the world. Russia began reforms in the energy sector later than many industrialized countries. Some of them did not introduce full competition in all sectors of the market and the establishment of limited competition in the wholesale markets. Large manufacturers have started to sell electricity energy directly and freely to largest (energy-consuming) buyers. However, most countries have established full competition regardless of the size of producers and consumers. After several years of reform two thirds of countries - members of the IEA have received as a result of steady growth markets.

Russia began to carry out reforms in the power sector in 2003, with the adoption of legislation aimed at market reforms in this sector of the economy. It is assumed that these reforms will bring the industry out of the crisis, and the economy will eliminate the infrastructure constraints to growth. The reforms are a fundamental change of the subject composition of the industry. First of all, it is about the emergence of new market players: Commercial Operator, System Operator, the Federal Grid Company, the wholesale generating companies and territorial generating companies, distribution companies, etc. The law set in April 1, 2006 bans on combining natural monopoly activities (transmission and operational control) to potentially competitive production and marketing.

The area of supply cannot be controlled only in the plane of private law, as it objectively laid the public (common) interests that require special legal regulation mechanisms (defense). It is obvious that Russia has not yet had the understanding of social and public role of energy sector as infrastructure and life-supporting industry for the economy of the country. It was not a principal in the previous model of regulation, as it was based on the direct management of the sector by the government, as owner of the major energy assets. Therefore, the public interest is taken into account through

the mechanism of state property management and direct price regulation. In the course of market reforms, usually accompanied by the privatization of production and marketing, as well as in terms of free prices, these problems tend to be purely theoretical. It should be understood that a significant increase in the price of electricity can make it unaffordable product for the population, and the freedom of contract in its pure form can lead to discrimination on the part of consumers of electric power industry, with market power.

During the development of a new model of regulation in the infrastructure sectors of the Russian economy it should be taken into account the experience of regulation of energy markets in Europe. In EU directives, the protection of consumers in energy markets requires significant regulatory effort on the part of the state. The total regulatory policy in Europe means that the state does not rely only on market forces but creates a clear format of regulation.

Trends in International Energy Regulation show the unavoidable complications of the regulatory system as we move toward the creation of competitive markets. There are new trading technologies, new trading facilities, new services and new markets. The role of legal regulation in the transition to a market increases significantly which should be taken into account when making the decision to hold the state of a given reform. So, now in the power sector reform, the organization of the wholesale and retail markets require quantitative and qualitative complexity of rules and regulatory institutions. (Ad Hoc Group, 2005, p.243)

## 4.5 Economic benefits of wind farms

Until recently the development of the energy sector had a clear consistent pattern: the development was in such energy production areas which provide a fast direct economic effect. Social and environmental impacts were considered only as an attendant and their role was negligible.

With this approach, we considered renewable energy just as an energy source of future, when the traditional sources of energy will be exhausted or their production will be extremely expensive and time-consuming. Since this future seemed to be really far away, the use of renewable energy was an interesting and exotic modern discussion rather than a practical problem.

The situation dramatically changed when humanity understood that there are ecological limits to growth. Rapid exponential growth of negative human impacts on the environment leads to significant deterioration of the human environment. Maintaining this in normal conditions and the possibility of self-preservation is becoming one of the priority objectives of the society. Today it is not enough to evaluate and consider just economical sides of some energy production. We also have to take into account social and environment aspects.

### 4.5.1 Economic benefits of existing wind farms

The impulses for intensive development of renewable energy for the first time became not promising economic calculations but it was public pressure, based on environmental requirements. The belief that the use of renewable energy sources will significantly improve the environmental situation in the world - that's the basis of this pressure.

Renewable or regenerative energy means energy from sources that are on a human scale are inexhaustible. The basic principle of the use of renewable energy is that it is permanently removed from occurring in the environment of processes and the provision of technical applications. Unfortunately nowadays there is not a lot of wind energy production in Russia, at the moment wind farms are just experiments.

#### 4.5.2 Methods of rising economy of wind farms

The main advantage of wind sources of energy is that it is inexhaustible and environmentally clean. It can help resolve the problems of energy security and reduction of environmental load. Using wind sources do not alter the energy balance of the planet. This caused the rapid development of renewable energy abroad and very optimistic projections of their development in the next decade.

Wind energy has also significant social advantages over conventional energy sources. For example, in Russia the increased use of renewable energy technologies could help to reduce unemployment, improve the conditions of life, to stop the outflow of population from rural areas and the northern and eastern areas. Replacement of traditional energy sources in the green renewable energy technology could also lead to a decrease in the level of degradation of the environment and improve health and well-being of the population.

Most of the territory of Russia is not economically developed and populated. About 80 % of its 145 million of the population lives in the European part of the country. The population density varies from 26.6 h/km<sup>2</sup> in European and 2.4 h/km<sup>2</sup> on the Asian side. About three quarters of the population lives in cities, the most populated Central Urals, North Caucasus and the Volga economic region. Currently, more than half of the territory of Russia, especially Far North, the Far East and Eastern Siberia does not have a centralized electricity and heat. In addition, there a significant proportion of farms, horticultural areas, logging companies and a number of local industries remain without electrification in the European part of Russia. The problem of electricity supply is relevant not only for the facilities of the national economy but also for the posts of law enforcement agencies, solving important national problem.

Solving the electrification of low-power distributed objects by conventional methods (as was done in Alaska and northern Canada), according to expert estimates on the sparsely populated territory of Russia will require more than \$ 350 000 000 000 and nearly half a century for its implementation.

About 10 million people in Russia who do not have access to the electrical grid are currently served by autonomous systems which traditionally run on diesel or gasoline. According to available information, about half of diesel and gasoline units do not

work, due to disruptions in the supply of fuel and high prices for imported fuel. In remote areas of the Far North and the Far East, fuel is delivered by rail or by road, and sometimes by helicopters. These supplies are unreliable and expensive. Installations of wind turbines will be good economical solutions in such cases even with sufficiently large capital investments but with low operating costs, the absence of a fuel component and environment impact. (Energovopros, 2013)

## 5 WIND ENERGY BASICS

A wind generator (a wind power installation or a wind turbine) is a device for converting wind flow kinetic energy into mechanical energy of rotation of the rotor with its subsequent transformation into electrical energy. Wind turbines can be divided into two categories: industrial and domestic (for private use). Industrial ones are built by the state or large energy corporations. As a rule, they are combined in the network, resulting in a wind power plant. Its main difference from the conventional power plants (thermal, nuclear) is an absence of both raw materials and waste. The only important requirement for a wind farm is a high average annual wind. The power of modern wind turbines reaches to 7.5 MW. (Valeryi Chumakov, 2008)

### 5.1 Power from wind

Modern wind turbines are operated when wind speeds extend from 3 - 4 m/s to 25 m/s. The dependence of power output from the wind conditions is illustrated in the figure 10. The power wind turbine depends on the area, which the blades of the generator are sweep off. For example, a 3 MW turbines (V90) provided by the Danish company Vestas have a total height of 115 meters, the tower height of 70 meters and a blade diameter of 90 meters. In August 2002, a prototype of the Enercon E- 112 wind turbine capacity of 4.5 MW was built. Prior to December 2004 remained the largest turbine in the world. In December 2004, the German company REpower Systems has built its wind turbine power capacity of 5.0 MW. The diameter of the rotor of the turbine 126 meters, the nacelle weight - 200 tons, the height of the tower was 120 meters to the end of 2005, Enercon has increased its capacity to 6.0 MW wind turbine. The diameter of the rotor was 114 meters, the tower is 124 meters. The company develops Clipper Windpower 7.5 MW wind turbine for offshore use. The historical development of wind turbines is shown in the figure 11. (Altagroup, 2010)

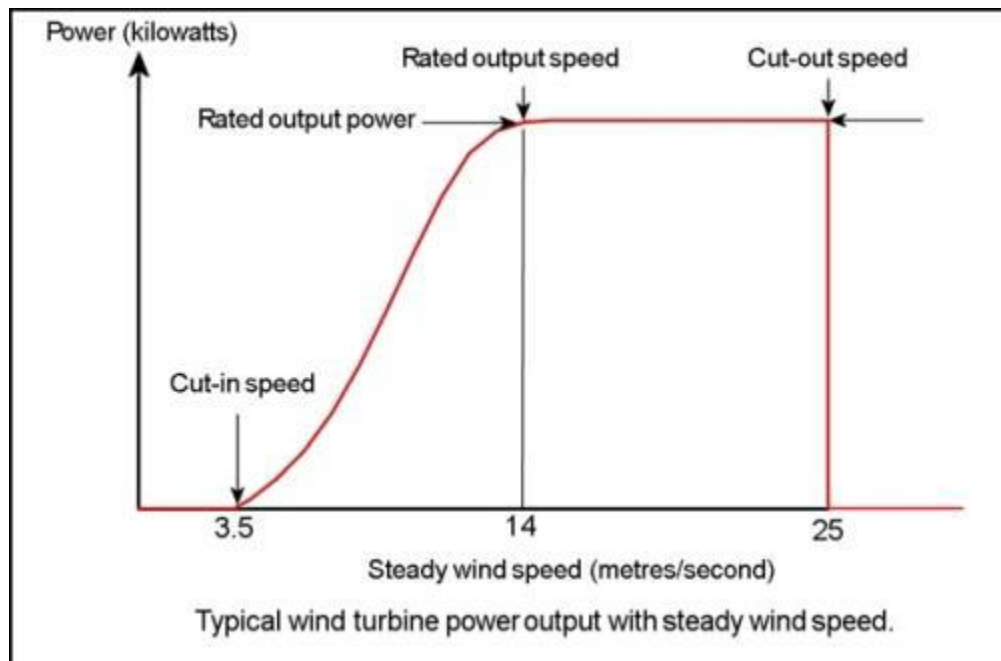


Figure 10. The turbine power curve (Evea, 2013)

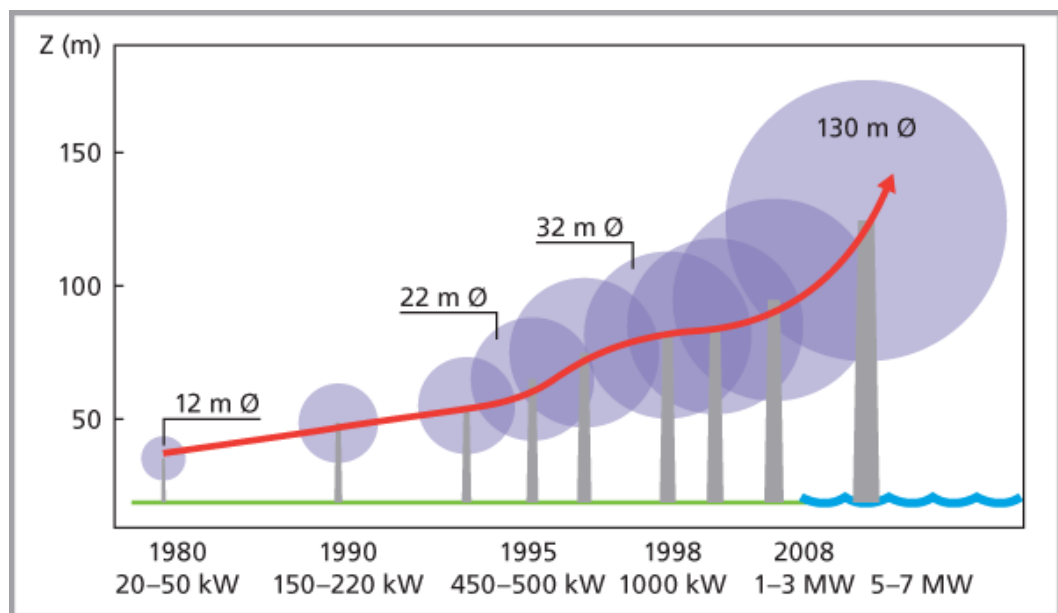


Figure 11. The capacity of wind turbines (Tuulivoimayhdistys, 2013)

Pros and cons of wind turbines:

Advantages of wind turbines conclude:

- The wind is an inexhaustible resource.
- Wind turbines do not consume fossil fuels.

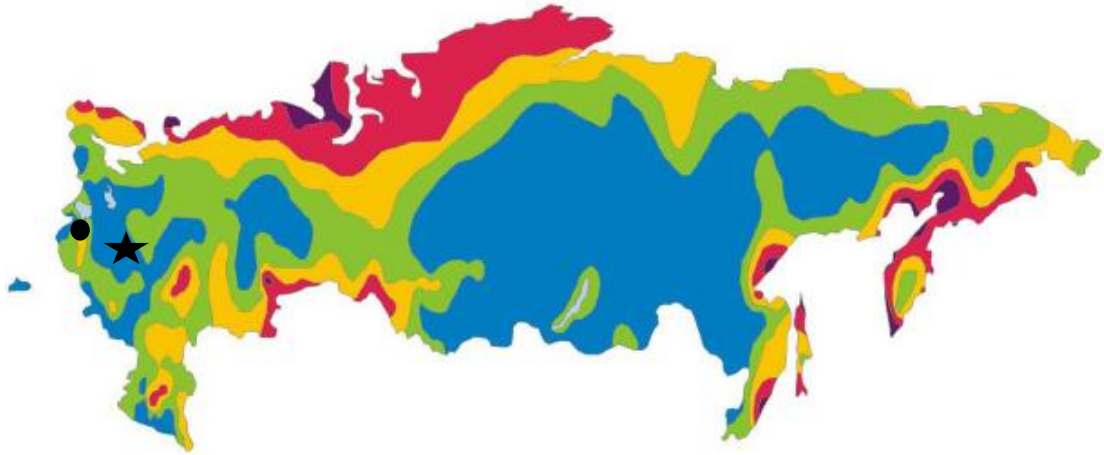
- A 1 MW wind turbine reduces annual emissions of 1 800 tons of CO<sub>2</sub>, 9 tons of SO<sub>2</sub>, 4 tons of nitrogen oxides.
- Unlike conventional thermal power plants, wind farms do not use water which can significantly reduce the pressure on water resources.

The disadvantages of wind turbines:

- Wind power is an unregulated source of energy.
- Large wind turbines are experiencing significant problems with a repair. The replacement of large parts (blades, rotor, etc.) at a height of 100 m is difficult and costly.
- Wind turbines produce a lot of noise.
- When operating wind farms in the winter when humidity is high, the formation of ice build-up on the blades. The expansion of ice is possible in a big distance. As a rule, the territory in which the cases are possible icing of blades are installed warning signs at a distance of 150 m from the wind turbine.
- Metal parts of wind turbines, especially the elements in the blades can cause significant interference to the radio signals. (Altalgroup, 2010)

## 5.2 Wind power potential

The potential of wind energy is distributed unevenly through the territory of Russia. Wind Atlas Russia indicates that there are many areas where the average wind speed exceeds 6.0 m/s. Figure 12 shows wind energy resources at a height of 50 meters above ground level for five different topographic conditions of the area. Colors mean highest wind speeds are found along the coast of the Barents, Kara, Bering and Okhotsk seas. Other areas with relatively high wind speeds (5 - 6 m/s) include the coast of the East Siberian and Chukchi seas and the Laptev Sea in the north and the east of the Sea of Japan. Slightly lower wind speeds (3.5 - 5 m/s) are found on the shores of the Black, Azov and Caspian seas in the south and the White Sea in the north- west. Significant resources are also in the Middle and Lower Volga region, the Urals, in the steppe regions of Western Siberia, Lake Baikal. The lowest values of the mean wind speed observed over the Eastern Siberia near the Lena -Kolyma core Asian anticyclone.



	Enclosed ground		Open ground		Sea coast		Open sea		Hills and mountains	
	m/s	W/m <sup>2</sup>	m/s	W/m <sup>2</sup>	m/s	W/m <sup>2</sup>	m/s	W/m <sup>2</sup>	m/s	W/m <sup>2</sup>
■	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
■	5.0 6.0	150 - 250	6.5 7.5	300- 500	7.0 8.5	400- 700	8.0 9.0	600- 800	10 11.5	1200- 1800
■	4.5 5.0	100 - 150	5.5 6.5	200- 300	6.0 7.0	250- 400	7.0 8.0	400- 600	8.5 10.0	700- 1200
■	3.5 4.5	50- 100	4.5 5.5	100- 200	5.0 6.0	150- 250	5.5 7.0	200- 400	7.0 8.5	400- 700
■	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400

Figure 12. Distribution of the wind speeds in Russia (Altalgroup, 2013)

Over most of the territory of the Russian wind speeds during the day is higher than at night, and these differences are much less pronounced in winter. The annual course of the mean wind speed (i.e. the difference between maximum and minimum average

daily rates) in most parts of Russia is insignificant and varies from 1 to 4 m/s, with an average of 2 - 3 m/s. Higher amplitudes are observed in the central part of European Russia, Eastern Siberia, Western Siberia (except for the northern regions) and especially in the Far East, where they reach 4 m/s. Annual amplitude which is less than 2 m/s are observed over the South-East and South-West of the European part of Russia and over central Siberia. In winter and autumn times winds speeds are bigger over most part of Russia, except of the southern part of central Siberia where the wind speed reaches its maximum in the warmer months. The highest wind speed over Yakutia and Transbaikal observed in April and May. (Altalgroup, 2013)

### 5.3 Vertical wind generators

Among the vertical wind turbines are the following set of rotors: orthogonal, Savonius, Darrieus, Gelikoydny, multi blade generator with guide vanes. The main advantage of the vertical wind turbine is no need to direct them to the wind. One disadvantage of limiting the range of their use and the unit capacity is their lower efficiency, as compared with horizontal-axis wind turbines, with the same swept area and higher material consumption, for the same capacity. (Alternativenergy, 2013)

#### 5.3.1 Orthogonal wind turbines

Orthogonal vertical wind turbines have a vertical rotation axis and in parallel to it there are several blades remote from it by a certain distance. The advantages of orthogonal wind turbines are: no need to use in their construction the guidance mechanisms, as the work of these plants does not depend on the wind direction. Due to a vertical main shaft, the driven equipment can be located on the ground level, which greatly simplifies its operation. The disadvantages of these systems are lower terms of service support units, due to higher dynamic loads on them by the wind turbine rotor, because when the rotor rotates, the lift of each blade changes its direction by  $360^\circ$ , which creates additional dynamic load. Blade systems of orthogonal generators are more massive than equivalent capacity for axial horizontal installations. The efficiency of the system of orthogonal paddle installations is lower compared to horizontal - axis as during one rotation of the rotor, the attack angle of wind flow on the blade vary within wide ranges, while in horizontal wind generators wind angle can be put close to the optimal. (Alternativenergy, 2010)



Figure 13. Orthogonal axis wind turbines (Alternativenergy, 2010)

### 5.3.2 Wind turbines with Savonius rotor

As Savonius rotor blades two or more parts of cylinders are used. Savonius turbines have a high starting torque. They work at relatively low speeds and relatively high manufacturability of its production. Disadvantages of Savonius rotors are lower efficiency of a blade system, compared with horizontal-axis wind turbines and relatively high material consumption. Currently Savonius wind turbines are available in the power range up to 5 kW. Savonius rotor is often combined with the Darrieus rotors, to ensure a high starting torque for Darrieus rotors. (Alternativenergy, 2010)



Figure 14. Wind turbines with a Savonius rotor

### 5.3.3 Wind turbines with a Darrieus rotor

Darrieus turbines have a rotor with a vertical axis of rotation, and two or three blades. It has a flat strip having no typical airfoils. The advantages of Darrieus rotors are the lack of orientation to the wind, technological ease of the blades fabrication, the ability to accommodate the driven, equipment at ground level, which greatly simplifies maintenance. Darrieus rotors disadvantages are the relatively low efficiency of the blade system, compared with a horizontal -axis- wind turbines, a lower lifetime of support assemblies, due to higher dynamic loads on the rotor side. The lift of each blade changes direction by  $360^\circ$  which creates additional dynamic load. Two-bladed wind turbines with a Darrieus rotor, with a uniform free stream cannot run by their own. (Alternativenergy, 2010)



Figure 15. Wind turbines with a Darrieus rotor

#### 5.3.4 Wind turbines with a Helicoid rotor

A helicoid rotor or Gorlov's rotor (his second name) is a modification of the orthogonal rotor. Due to the twist of the blades, the rotation of the rotor is more uniform that significantly reduces the dynamic load on the bearings and, thereby, increases their life, compared with the bearings of the orthogonal rotor. However, the technology of production is considerably complicated because of the twisted blades, which affects increasing their cost. (Alternativenenergy, 2013)



Figure 16. Wind turbines with helicoid rotors

### 5.3.5 Multibladed wind turbines

Multibladed wind turbines with guide vanes are a modification of the orthogonal rotor. They have two rows of blades, the first row is fixed. It is a guiding device, the purpose of which is to capture the wind flow, to compress it to increase the speed and pitch the wind flow at an optimal angle on the second row of blades which are rotating the rotor. The advantage of this type of rotor is its higher efficiency compared to other vertical wind turbines; operation at low wind speeds. The disadvantage of this rotor is it's a higher cost due to the use of a large number of profiled blades. (Alternativenergy, 2013)

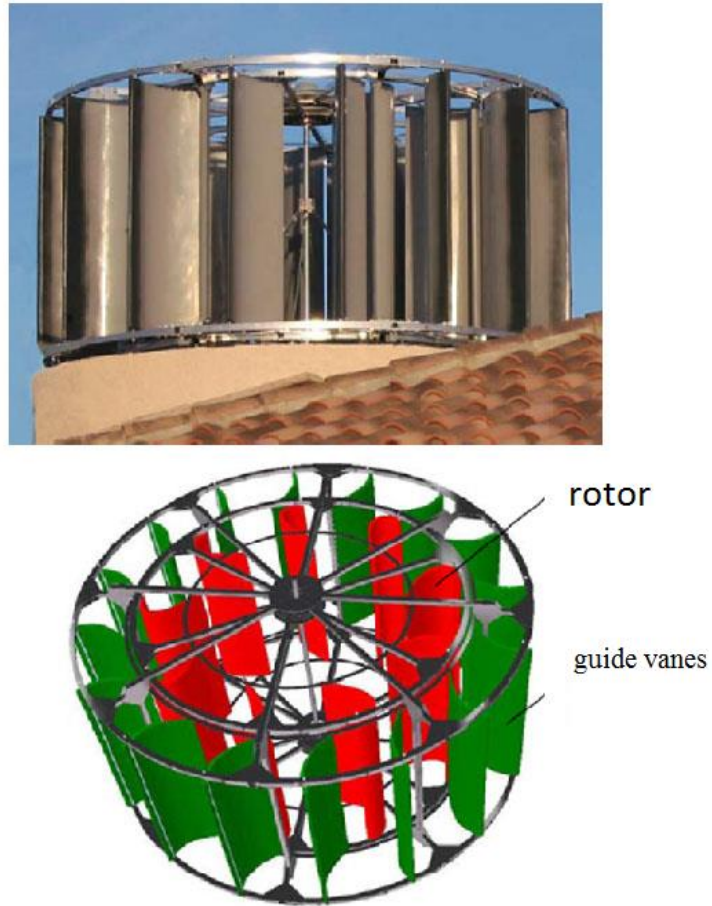


Figure 17. Wind turbines with multi bladed with guide vanes

#### 5.4 Horizontal-axis wind generators

The horizontal-axis wind turbines (HAWT) got their widespread use due to their high efficiency. Even not the best horizontal wind turbine easily reaches the utilization of wind energy flux in 30 %. The most thoroughly well-functioning vertical one gets its best at 20 %. (Chumakov, 2008)



Figure 18. Wind turbines with horizontal axis of rotation (Energybalance, 2013)



Figure 19. Structure of a wind generator (Altagroup, 2013)

1. Turbine blades
2. The rotor
3. The direction of rotation of the blades
4. Damper
5. Leading axis
6. The mechanism of rotation of the blades
7. Electric generator
8. Controller rotation
9. Anemoscope and wind sensor
10. Shank anemoscope
11. Nacelle
12. The axis of generator

13. The mechanism of rotation of the turbine

14. Engine rotation

15. Tower

### 5.5 Present wind farms in Russia



Figure 20. Anadyrskaya windfarm

There are a few wind power plants in Russia. Installed power of the Anadyrskaya windfarm on 1 January 2011 was 2.5 MW, which is less than 1% of the total installed capacity of the Chukotka Autonomous District. Electric power generation in 2011 will not exceed 0,2 million kW · h. At the same time diesel power plants are installed. (Stilman,1987)



Figure 21. Wind farm Tyupkildy

Wind farm Tyupkildy is located near the village of Tyupkildy Tuimazinsky district of Bashkortostan Russia. It is one of the most powerful Russian wind farms - 2.2 MW (the third largest installed capacity). It consists of four wind turbines made in Germany.

In 2010, the WPP has produced 0.30 million kWh of electricity in 2009 - 100 000 kWh in 2008 - 0.40 million kWh. The capacity factor in 2008 - 2010 did not exceed 2.2 %. (annual report "Bashkirenergo", 2010)



Figure 22. Zelenogradskaya wind farm

Zelenogradskaya wind farm's establishing electrical capacity is 5.1 MW.

There are several turbines in Zelenograd Wind farm:

- 1 type of wind turbine Wind World 4200/600 0,6 MW
- 20 wind turbines type Vestas V27/225 capacity of 0,225 MW each.

Equipment Zelenograd WPP purchased a used (1992 - 1993 model year wind turbine), and it ran between 1998 and 2002. By the end of 2012 five wind turbines had to be repaired. The generated power was:

- 4 690 000 kWh in 2008
- 3 538 000 kWh in 2009
- 3 596 000 kWh in 2010
- 3 878 000 kWh in 2011
- 3 057 000 kWh in 2012. (Kaliningrad Generating Company 2010)

## 6 GRID CONNECTION

Wind turbines cannot be directly connected to the grid due to variable power outputs. Wind turbines are like winds – always changing their output parameters and unpredictably. Different devices such as transformers, inverters, switches and etc. should be used between the grid and wind turbine. Nowadays, the grid connection of a wind turbine is one biggest and main challenging issue in this field of electricity production.

### 6.1 Operation of wind turbines

Mr.J.F.Manwell and Mr. J.G.MeGowan point out nine main operating states. Following stationary and transitional operation states are used:

- period of checking of the system
- readiness for operation
- starting
- connection to the grid
- electricity production,
- disconnection from the grid
- freewheeling
- general and
- emergency shut- down of the system (see Figure 6.1).

Some of these states can be absent or can consist of different several combinations. When the turbine operates in some states for long time then these states are called stationary states. Other type of operating states is transition state. It appears during switching from one state to another.

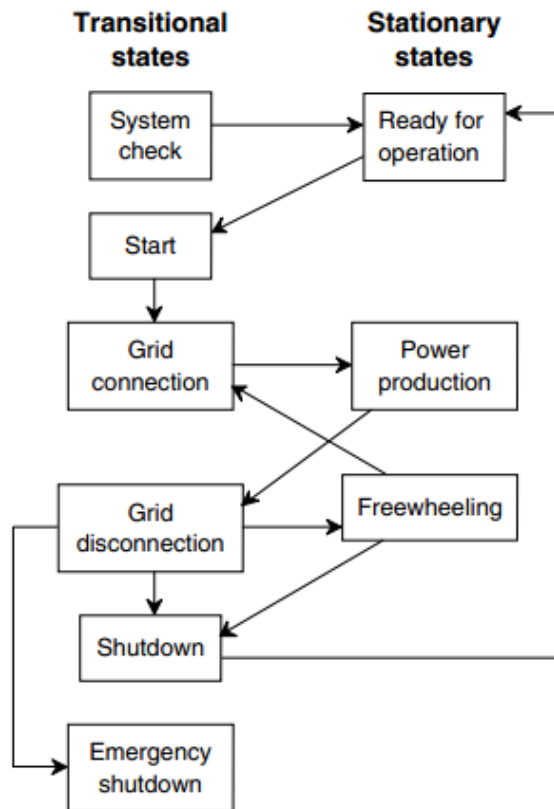


Figure 28. Typical turbine operating states (Manwell and McGowan, 2009, p. 217)

As can be seen in the figure, the first states is checking of the system (Transitional). The system check is performed when the control system starts working. This is transitional state. It checks the system readiness for use.

- Readiness for Operation (Stationary)

Ready for operation state is characterized by a stationary rotor and the parking brake. When the operating conditions are identified and the system checks find no fault, this state is started. There have to be enough wind to start the turbine. This is a stationary state in which the turbine may remain for a long period of time.

- Starting point (Transitional)

The start begins when all conditions are reached and brake is released. Many turbines start to accelerate to nominal speed without intervention, but pitch mechanism should be regulated to accelerate the rotor. For variable speed turbine this state can require the dynamic controllers operation.

- Connection to the grid (Transitional)

Some turbines may be needed run up to the operating speed by connecting the generator to the network for disengagement of the brake. After connection and achieving the correct speed electricity generation begins.

- Electricity Production (Stationary)

During the production of electricity there are can be faults caused by electric current. The supervisory controller monitors the faults in the system, the yaw orientation of the turbine, output power and the speed of rotation of the rotor.

- Disconnection from the grid (Transitional)

The main idea of this state is to disconnect the generator from the grid, which includes disengaging different control systems and providing new set-points. This state is transitional.

- Freewheeling (Stationary)

It is the state when generator is disconnected from the grid and rotor works freely until good conditions will not be reached for connecting to the grid or otherwise turbine will be shut down. Mainly this state happens when rotor waiting for needed range of wind flow.

- Shutdown (Transitional)

This state happens when wind or power is above some nominal level or vice versa wind is too low to produce power, and also it can happen when monitoring system indicates some faults and then give command to shut-down.

- Emergency Shutdown (Transitional)

The difference between emergency shutdown and general shut-down is that emergency shut-down is faster. And sometimes general shut down system can be broken and not possible to do his functions.

### 6.1.1 Faults

Different kinds of faults can happen in the wind turbine. These faults have different degrees of seriousness. Some are very serious and the wind turbine has to be rapidly shut-down while others are less severe.

A number of sensor faults are possible. For example, in the pitch position sensors can have electrical or mechanical faults and due to this measured values can be incorrect. Sensor faults can lead to unpredictably chains of controller operations even to shut-down of the wind turbine.

The converter and pitch systems can fail. The reason of these faults can be fails in hydraulic pitch systems. These hydraulic faults can result in changed dynamics due to dropped pressure or high air content in the oil.

System faults like changed dynamics of the drive train due to increased friction is not serious in the beginning, but during a period of time it leads to total wear and breakdown of drive train and then this will be a really serious fault.

System all the time have to be monitored to detect faults including component failures, sensor failures, grid failure and other unwanted operating conditions. Failures can be detected directly or indirectly. For example, if we see that the generator and rotor speeds do not correspond to each other than it means that there is the failure of a coupling between the generator and the gearbox. Such a failure could also be detected when the rotor speed is accelerating, or it is too high. The system is monitored mostly by using different sensors and transmitters. Due to these most robust and accurate sensors have to be chosen for a wind turbine, nevertheless sensor failures can also occur. To make more reliable systems, we should use two different sensors for the same measurements. Sensors have to be selected to withstand different weather conditions.

### 6.1.2 Determining the state of system components

To determine the system components wind turbines need in good control systems. For example, a control system can measure wind speed, check the health of system components, implement blade pitch settings, and etc. Without good control system, a wind turbine cannot successfully produce power. There are two levels of control system: supervisory and dynamic control. Supervisory control manages and monitors turbine operations and sequences control actions like brake release and contactor closing. Dynamic control manages machine operation aspects like changing blade pitch in response to turbulent winds.

## 6.2 Devices used for grid connections

The wind turbines can be connected to the grid at different voltage levels: low, medium, high and extra high voltages.

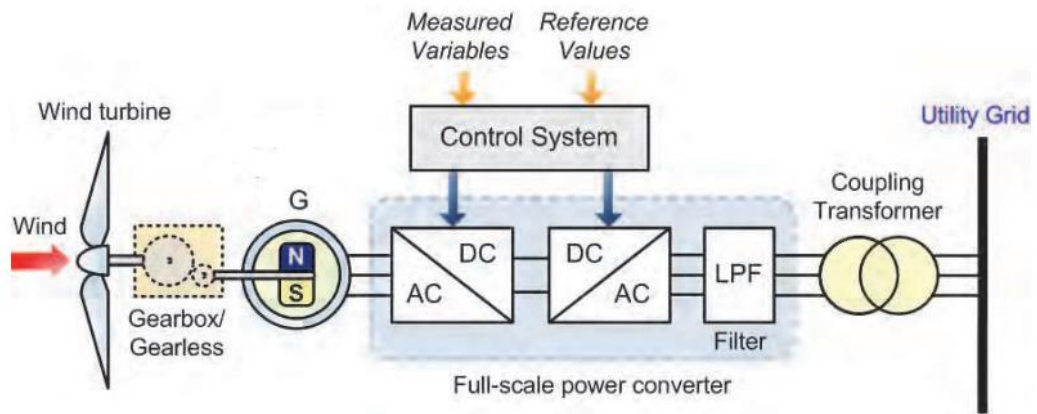


Figure 23. Connection of wind-turbine to the grid (Intechopen, 2013)

The turbine rotor, generator and gear box are the main components for electricity production. The rotor converts the wind energy into mechanical energy. The generator converts the mechanical power of the rotor into electrical energy, which is then fed into the grid. The gear box is used to adjust the rotor speed to the generator speed. DC link is used to get required frequency of the output power.

The main grid connection components of the wind turbines are the transformer, safety equipment (circuit breaker) and the electricity meter. To reduce losses in low voltage lines, each of the turbines in the wind power plant are featured with its own transformer which converts the voltage level of the turbine to the voltage line of the grid. The transformers are located directly near the turbine in order to use less cabling. In case of small wind turbines it can be used only one transformer to connect to the grid. Large wind farms with high powers are needed of a separate substation for transformation from the medium voltage level to the high voltage level. Between a wind turbine and the grid, at the point of common coupling (PCC), a circuit breaker has to be installed to provide disconnection in case of fault. The circuit breaker is usually installed at the medium voltage system, in the feeder, together with the electricity meter. The meter has its own voltage and current transformers.

### 6.2.1 Transformers

Power transformers are important components in power system. They are used for converting the generated power to the voltage level of the local electrical grid. In addition, different measuring transformer can be used for monitoring, control system and etc.

Power transformers are usually in the 5–50 kVA range. Transformers which are situated in substations has power range between 1000 kVA and 60 000 kVA. Transformers consist of two or more copper coils and metal core. Copper coils are called the primary and secondary windings. (Manwell and McGowan, 2013, p. 21)

### 6.2.2 Switches and axial devices

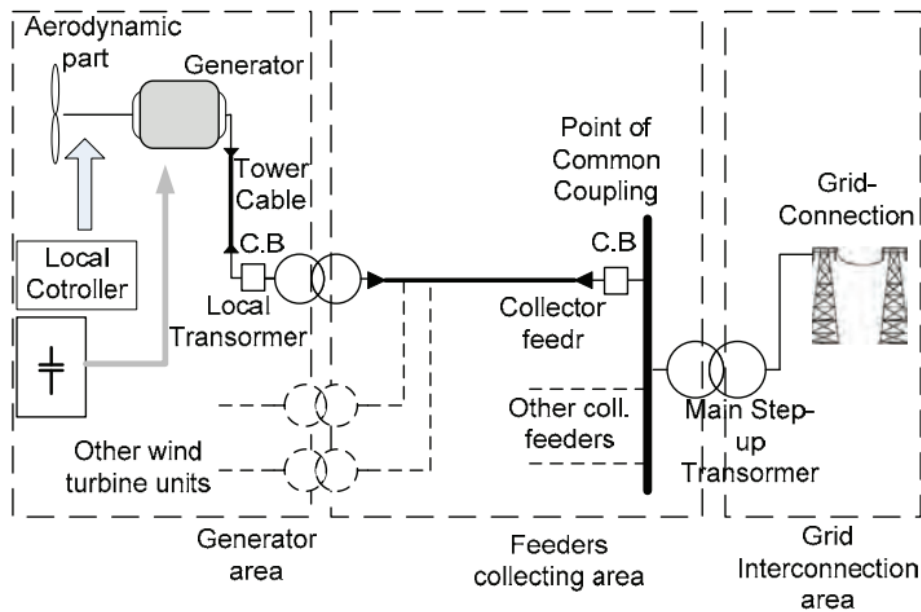


Figure 24. Typical circuit of wind turbine connection to the grid (Kawady, Naema Mansour and Abdel-Maksoud I. Taalab, 2007, p.269)

Power from generator have to be transferred through the tower to electrical cubicle at the base. This is done by using power cables. Three-phase generators have four copper conductors, which include ground or neutral. In order not to damage cables due to yaw system there is a slack is left in them. With sufficient slack the cables never wrap up tight in most sites.



Figure 25. Wind Turbine high-voltage equipment (Manwell and McGowan, 2009, p. 252)

There are circuit breakers and fuses between the generator and the electrical grid. Circuit breakers are used for connection/disconnection and protection purposes. The fuses are used only for protection aims. Circuit breakers can be reset after fixing the fault. Fuses have to be replaced.

### 6.3 Grid protection

Protection system is one of the most important parts related to the interconnection of wind generators (WG). Radial systems are general form of distribution network configuration. They are usually protected by using overcurrent protection schemes. Connection of WG to grid influences the existing protection schemes. If not carefully everything is set, then this can lead to failure of protection equipment.

#### 6.3.1 Short-circuit current

Short circuit level is one main parameter in the selection of circuit breakers, fuses, current transformers (CTs) and reclosers, and the coordination of overcurrent relays. Short circuit current is level of fault current. It is characterized by the equivalent system resistance at the failure point. When wind turbine is connected to the grid then

equivalent network resistance can decrease and this cause in fault level growth. There can be high fault currents which can exceed the interrupting capacity of existing circuit breakers. High fault currents can lead to CT saturation. Moreover, the changed fault levels can influence the coordination between overcurrent relays which may lead to their unsatisfactory operation.

The fault current level significantly exceeds load current level by this relays understand when to operate. When the contribution of fault current from a WG is limited, it becomes difficult for protection relays to effectively detect faults. Induction generators make a limited contribution of fault current to asymmetrical faults. Small synchronous generators are even not able to supply fault currents because they are greater than the rated current. Power semiconductor equipment cannot withstand significant overcurrent for long time and therefore power electronic converters are designed to internally limit the output current.

### 6.3.2 Islanding and auto recloser

Islanding is the situation when a part of the network is disconnected from the main grid and operates like independent system with one or more generators. Islanding results in variations of frequency and voltage in the island. If an auto recloser will open during a fault, it may lead to the formation of two independent systems with different frequencies. Reclosing of the auto recloser while the two systems are out of phase could bring to disastrous results. Islanding is recognized as an unsafe situation, because of which immediate disconnection of the WG from the grid is needed.

### 6.4 Voltage control

Interconnection of wind turbines with grid makes changes in power flows and the voltage profile in the feeder, and also results in overvoltage. Power quality depends on voltage and also voltage can influence in operation of under/over voltage relays.

Selection of tap settings for transformers becomes difficult with the increased amount of connected wind turbines. When the wind turbines are not equally distributed in the feeders it is become more difficult to set appropriate tap for transformer. Such a case is shown in Figure 25. There are two feeders supplied by same transformer, but wind turbines are connected on only one of them. When the wind turbine is connected, the

current through the transformer is decreased because the wind turbine supplies with the power the nearby loads. So because of that, the transformer tap should be changed to the light load setting. The resulting voltage can cause a voltage disturbance at the end of the feeder without wind turbine as in Figure 6.6. If to leave the transformer tap at heavy load it can cause overvoltage in the feeder with wind turbines.

To control the feeder voltage it can be used switched capacitors and static compensators but these solutions are often too expensive.

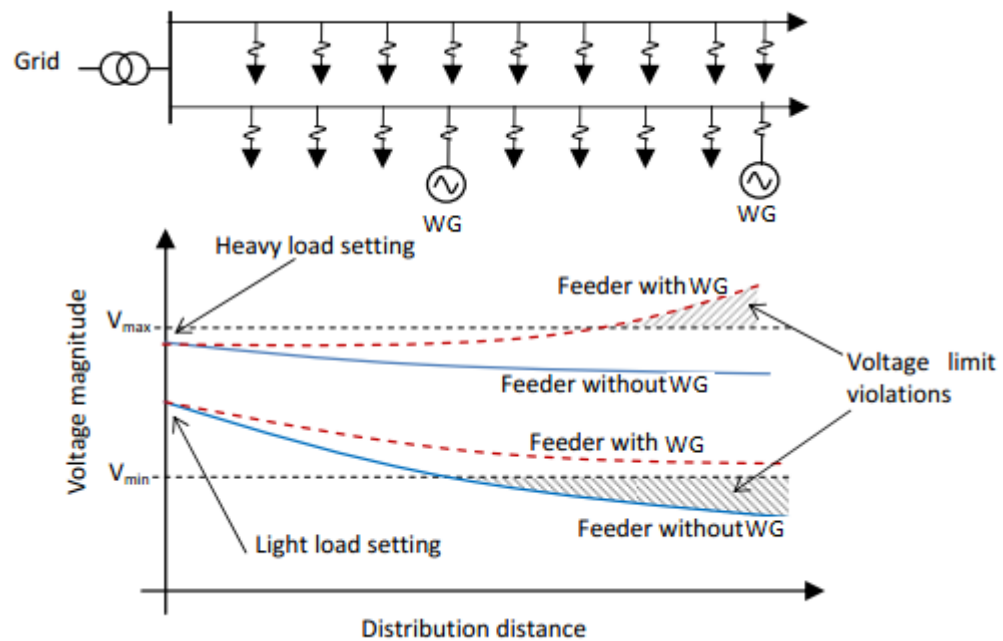


Figure 26. Possible WG interconnection configurations (Rajapakse, Muthumuni and Perera, 2006, p. 112)

Another effect of connection of wind turbines at distribution level is unbalanced voltage profile. As illustrated in Figure 30, the loads and wind turbine can be three-phase or single-phase. Single phase connection increases the system unbalance. Unbalanced distribution systems can make problems for the three-phase connected wind turbines: the unbalance currents in the wind turbine can cause overheating and frequent shut-downs.

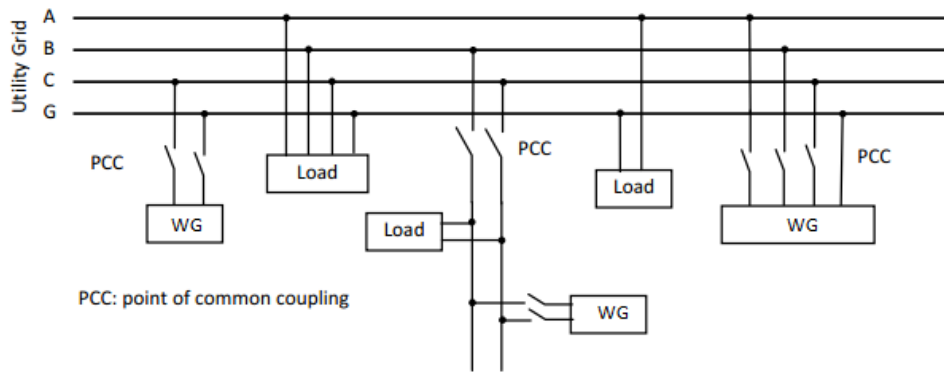


Figure 27. Possible WG interconnection configurations (Rajapakse, Muthumuni and Perera, 2006, p. 113)

## 6.5 Grid effects

Interconnection of wind turbine with grid causes different undesirable effects such as harmonics, voltage and frequency fluctuation, active and reactive power flow. To avoid disturbances and damages in the system it should be investigated and controlled grid effects.

### 6.5.1 Wind turbines power quality

Power quality can be expressed in terms of the physical characteristics and properties of the electricity and described in terms of voltage, frequency and their fluctuation. A perfect power quality is sinusoidal voltage waveform with constant amplitude and frequency. Figure 6.9 shows the classification of different phenomena affecting power quality.

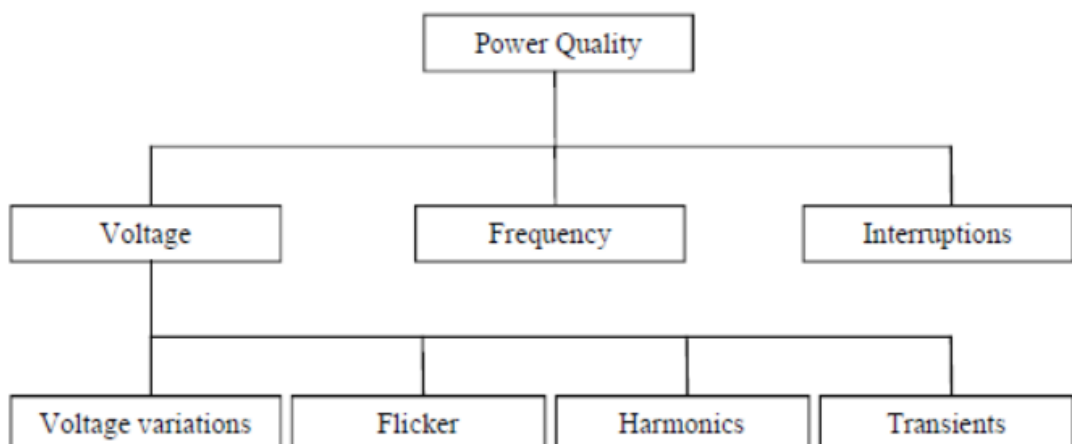


Figure 28. Classification of different power quality phenomena

The international standards say that the quality of the voltage should be fulfilled to allow a power source to connect to the grid. The voltage disturbances are divided into several categories: flickers, voltage variations, harmonic and transients distortions. Wind turbines affect power quality and are affected by disturbances which come from the grid. Large power system has usually stable frequency and the wind turbine normally does not cause interruptions in high voltage grid. When it is autonomous grids with diesel engines or wind turbines, the frequency variation should be taken into account.

### 6.5.2 Output behavior of wind power plants

Wind turbines influence in fluctuating real and reactive power values and may result in voltage and current transients or voltage and current harmonics. Constant-speed turbines usually use induction generators. Induction generators produce real power ( $P$ ) for the system and consume reactive power ( $Q$ ) from the system. Real and reactive power are constantly changing during wind turbine operation. Low-frequency real power fluctuations occur when the average wind speed changes. Higher frequency fluctuations of real and reactive power occur because of wind turbulence, dynamic effects from drive train, and blade vibrations.

Wind turbines with synchronous generators operate in a different manner than with induction generators. When connected to a large electrical network with a constant voltage, the field excitation of the synchronous generators can be used to change the line power factor and to control reactive power.

Variable speed turbines usually have a power electronic converter between the generator and the grid. It can control the power factor and voltage of the power. Power electronic converters should supply reactive power to support the magnetic field in the generator. The converter components can provide current to the grid at any power factor. This can be used to improve grid operation. When generators are connected or disconnected from a power source, voltage fluctuations and transient currents can occur.

When an induction generator is connecting then significant over current is occurred. These high currents can be limited using of a 'soft-start' circuit. When induction generators are disconnected from the grid, voltage spikes can occur. Synchronous generators have not high starting current requirements. Nevertheless, voltage transients can still occur.

### 6.5.3 Voltage and frequency response

Wind plants have to be able to operate continuously even when the voltage and frequency variation in normal operation range of the system but differ from nominal values. This ability depends on the voltage level at the point of common coupling (PCC) of the wind generator and the grid. Transmission level voltages are 110 kV and above. Lower voltages such as 35 kV and 10kV are usually sub-transmission voltages. Voltages less than 35 kV are used for distribution. Voltages above 220 kV are extra high voltages and special devices should be used.

The lowest voltage level in most countries has not to be lower than 90 % from nominal value. In some countries voltage can drop even until 70 % from nominal value but only for 10 seconds.

The frequency is one of the most important parameters. It varies by country. Most electric power is generated at 50 or 60 Hz. All the generating equipment operates at strict frequency. Usually frequency variation rang is 49.5 and 50.5 Hz. Even deviations from the nominal frequency during short time may lead to the loss of generation capacity. Further frequency deviation may lead to blackout.

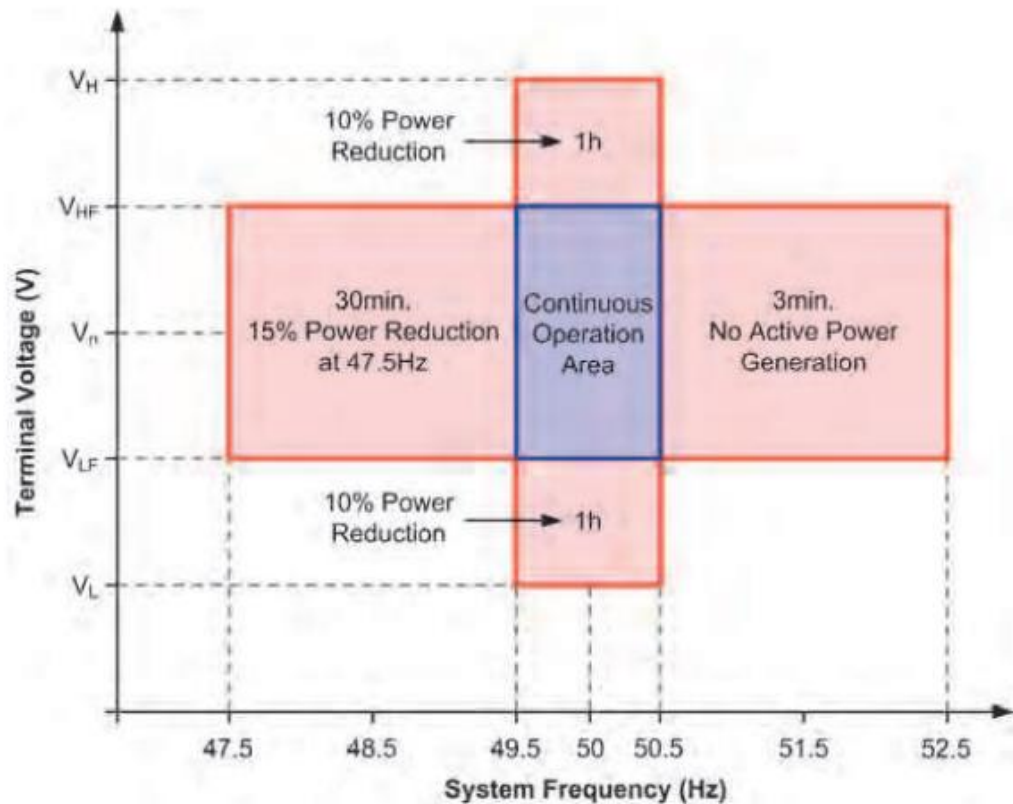


Figure 29. Typical voltage and frequency dimensioning for wind generators (Eltra & Ekraft System, 2004)

In this diagram:

- VL is the lower voltage limit
- VLF is the lower voltage limit for full-load range
- VN is nominal voltage
- VH is the upper voltage limit
- VHF is the upper voltage limit for full-load range.

In the full-load range wind farm can supply its nominal power without any disturbances (continuous operation area).

#### 6.5.4 Harmonics and methods to reduce them

The harmonics are voltage components with frequencies being multiples of the nominal frequency, i.e., 100Hz, 150Hz, 200Hz, etc. The interharmonics are components having frequencies located between the harmonics of the nominal frequency. Voltage and current harmonics and interharmonics are always present on the utility

grid. They are produced mainly by the rectifiers and inverters in motor drives, non-linear loads, power electronic loads, etc.. There are many negative effects of harmonics presence:

Problems of instantaneous occurrence include:

- distortion of the supply voltage
- voltages drop in the distribution network
- the effect of harmonics that are multiples of three (in three-phase systems)
- resonance effects on the frequencies of the higher harmonics
- interferences in the telecommunications and control networks
- increased acoustic noise in the electromagnetic equipment
- vibration in the electric machine systems.

Problems of a long-term occurrence include:

- heating and additional losses in transformers and electrical machines;
- heating capacitors;
- heating cable distribution network.

Heating capacitors Filters are LC systems, parallely connected to the power supply. The role of the filter LC is to retard higher harmonics. Figure 6.11 shows a typical circuit for filtering harmonics. There are three filter branches Related to 5, 7,11th harmonics. Number of branches arranged filter depends on the required the reactive power required for compensation as well as the measurement and accurate specific analysis of the content of harmonics in the network.

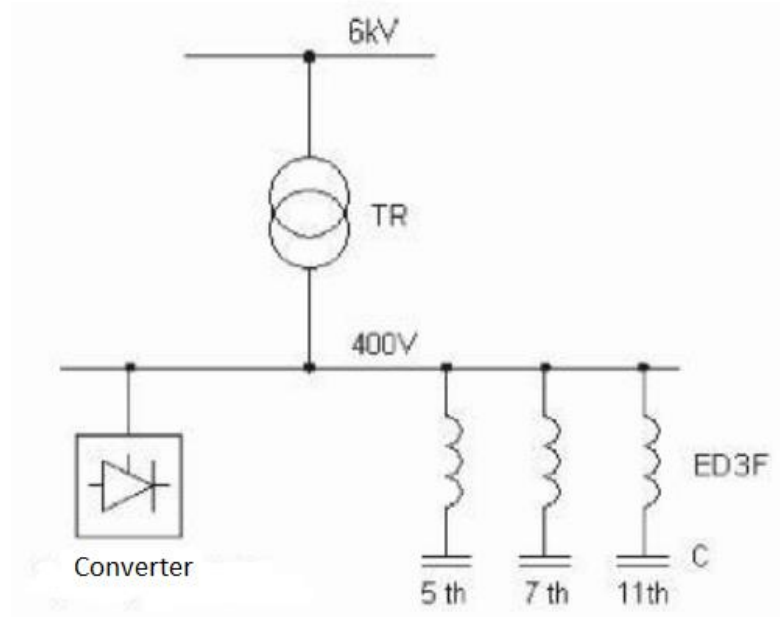


Figure 30. Typical circuit for power factor correction

## 6.6 Grid connection rules

The first “Grid Code” in the world, regulating the procedure for connecting wind farm to the network, was performed in Germany in 2003. The main points of this document are:

- Operation of wind farm in the network during a fault (short-circuit current).
- The creation of an intelligent system for the possibility of separation different groups of wind turbines in wind farm to separate loads (" Island formation ").
- The reverse connection of wind turbine to the wind farm with a minimum voltage or frequency deviation.
- Minimize power losses of wind power plant.

At the moment, in every European power system, there are some technical requirements for connecting wind farm to the grid. Uniform requirements for assessing the possibility of parallel operation of wind farm and power system is not developed, but in each document there are certain general requirements. These documents are generally classified by voltage of networks which connect the wind farm. The first group includes documents regulating wind farm connection to the network voltage below of 100 kV, the second group - a voltage above of 100 kV. There are basic requirements:

- maintaining required frequency
- maintaining required voltage
- indicators of quality of electric energy
- protection and automation of wind farm.

The basic requirement for the development of wind farm capacity is the organization of a more or less uniform power. In general, the output power of wind farm is the uniform and have only seasonal fluctuations when the wind changes. Seasonal fluctuations of output power of wind farm are almost unavoidable. If the output power of wind farm reaches 15-20 % of the installed capacity of the whole unified power system, then the wind farm power fluctuations can affect the dynamic stability of the power system. In some European countries, the share of wind farm exceeds 30 % of the capacity of unified energy system (Denmark), so to maintain required frequency, near nominal value is really important. Basic requirements for wind farm in frequency is to maintain the frequency range  $f = 50 \pm 0.5$  Hz for 97 % of the time.

Power system with high share of wind farm needs reserved power production source in the conventional power plants with the total capacity which equal to wind farms total output power. Traditional power plants must be able quickly generate power in case of wind farm disconnection, for these purposes it is better to use HPS (Hydroelectric power plants). Thus, the guaranteed capacity of wind farm is considered to be zero.

Voltage in unified energy system is characterized by fluctuations caused by uneven production and consumption of reactive power. The voltage at the nodes of the network depends on the balance of reactive power. It should be noted that the asynchronous generator (ACG) and a synchronous generator (SG) which are used in wind turbines produce reactive power; thereby they influence the voltage at the connection point to the network. Asynchronous generators consume reactive power; therefore, they require the installation of static capacitor banks at the output of wind turbines.

Technical papers about parallel operation of wind farm with the network say that the voltage at the output of wind turbines has to be in the range  $\pm 10$  % of nominal value. Voltage level can be regulated by transformers equipped with OLTC (On-load tap-changer).

Power quality of electric energy includes the definition of the limits of flicker, harmonics, and the availability of voltage variation. According to the technical documents of European power systems, presence of flicker, the harmonics and voltage variation is regulated by the European standard EN 50160. Limit of voltage drop is also determined on the basis of standard EN50160. On the basis study of Russian and European technical documents it can be concluded that there are no uniform requirements for connecting the wind farm to the grid. This is explained by the uneven development of wind power in the countries: the share of wind farm in UES, types of wind turbines, etc. However, in all technical documents have the same requirements:

- Provision of wind turbines under specified conditions;
- regulation of the power and speed of the rotor;
- control of active and reactive power in certain ranges.

## 7 CONCLUSIONS

Nowadays production electricity from wind power is one the interesting and developing fields in the world. Because people understand that conventional energy sources are limited and also health of environment is limited.

In Russia there are a lot of places with good conditions where wind turbines can be installed. Several wind farms exist in different parts of Russia, but they are unfortunately only experimental. The main reasons of poor development of wind farms in Russia are:

- low economic benefits
- politics, no low regulations
- grid connection challenges
- a lot of capacity of conventional energy source

In this thesis we tried to consider these problems and solve some solution for their reduction. Mostly thesis contains a review to wind energy utilization in North-West Russia. According to our thesis we can say that wind energy can be utilized in North-West, but it will be a long process. With our review we tried to move this process somewhat forward.

Also it can be concluded that it is needed to develop technical document for regulations the connection and parallel operation of WPP with grid. Considering that about 70% of the Russian area refers to areas of decentralized power supply with high cost of electricity, we can talk about the possibility of building a joint wind- diesel plants in these areas. Important part of the construction will be the organization of parallel operation of wind power plants and diesel generators.

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