LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
FACULTY OF TECHNOLOGY
BIOENERGY TECHNOLOGY

**MASTER'S THESIS**

# TECHNICAL WIND ENERGY POTENTIAL IN RUSSIA

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# ABSTRACT

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**Technical Wind Energy Potential in Russia**

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Keywords: Wind, wind energy, wind energy potential, wind energy resources, Russian Federation, windmill, wind power plant

The goal of the master's thesis is a detailed research of the technical wind energy potential in Russian Federation: the distribution of the potential all over the territory of the country and the possibility of the application of the potential for power supply of various objects. The main attention of the thesis is devoted to the assessment of wind energy resources (potential) of Russian Federation, both for the territory of country in whole and for every region. Theoretical basic wind energy concepts and the scheme of transformation of kinetic energy of a wind into electric energy by modern wind turbines are given in the work. Also the costs of energy, stimuli of development of wind-engineering and obstacles which impact the industry development are analyzed. The review of existent and projected wind power plants in Russia is carried out.

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## Abbreviations

DVAWT – Darrieus Vertical-Axis Wind Turbine

HAWT – Horizontal-axis wind turbine

SVAWT – Savonius Vertical Axis Wind Turbine

TsAGI – is a transliteration of the Russian abbreviation for Центра́льный аэрогидродинами́ческий институ́т (*ЦАГИ*) or "Tsentralniy Aerogidrodinamicheskiy Institut", the Central Aerohydrodynamic Institute.

UPS – Unified Power System

VAWT – Vertical-Axis Wind Turbine

WPP – Wind Power Plant

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $A$ | swept area | [m$^2$] |
| $a$, $b$ | length | [m] |
| $c_p$ | power coefficient | |
| $c_T$ | torque coefficient | |
| $D$ | diameter | [m] |
| $E$ | energy | [Wh] |
| $E_G$ | gross energy potential | [Wh/year] |
| $E_T$ | technical energy potential | [Wh/year] |
| $h$ | hub height | [m] |
| $H$ | layer | [m] |
| $n$ | number | [unit] |
| $P$ | power | [W] |
| $q$ | part of total area | |
| $S$ | area | [m$^2$] |
| $T$ | work time | [h/year] |
| $t$ | time | [h] |
| $t_i$ | part of use time | |
| $v$ | velocity | [m/s] |
| $\lambda$ | tip-speed ratio | |
| $\eta$ | efficiency | |
| $\rho$ | density | [kg/m$^3$] |
| $\Omega$ | angular speed | [s$^{-1}$] |

Subscripts

| | |
|---|---|
| $aa$ | average annual |
| $avg$ | average |
| $c$ | covered |
| $el$ | electric |
| $G$ | gross |
| $i$ | mode $i$ |
| $max$ | maximum |
| $mech$ | mechanic |
| $O$ | outer |
| $T$ | technical |
| $w$ | wind |
| $wm$ | windmill |

# 1. INTRODUCTION

The goal of the master's thesis is a detailed research of the technical wind energy potential in Russian Federation:  the distribution of the potential all over the territory of the country and the possibility of the application of the potential for power supply of various objects. The major component of the development of any power industry is the determination of its resource potential, detection of the zones of greatest values of the potential and determination of possible volumes of using the energy source. The statement is especially topical for wind-power engineering because this industry has a considerable stochastic component of energy supply.

The main attention of the thesis is devoted to the assessment of wind energy resources (potential) of Russian Federation, both for the territory of country in whole and for every region, with the aim of determination of the most suitable place for windmills and wind power plants. The work gives the estimation of wind energy resources of Russia with definite results for each region.

The description of the basic characteristics of wind is given in the beginning of the work for the complex review of the issue. The characteristics allow presenting a full picture of a wind conditions for the certain region.

The stated design procedure of technical wind energy potential is based on the concept that the technical wind energy potential is a part of natural wind energy resources which possible to realize by modern engineering tools in the territory. Therefore the review of modern windmills used on territory of Russia, a domestic production and import, is given in the work. Also the scheme of conversion of kinetic energy of a wind into electric energy is described and the cost of the electric power is analyzed.

Wind-power engineering is the developing industry. And it requires considerable economic investments, scientific and technical progress and the governmental support. Therefore the major stimuli of the development of wind-power engineering in Russia and obstacles which impact the industry development are analyzed in the work.

# 2. KEY CONCEPTS

## 2.1 Wind

Wind is movement of air masses concerning an earth surface. This movement or circulation arises and is formed in atmosphere under the influence of a difference of pressure in its various areas (or a pressure gradient), generated by heterogeneity of their heating and cooling under the influence of radiating, phase, turbulent and a convective inflow and heat transformations. (Nicolaev, et al., 2008)

Wind energy can be considered as one of forms of a solar energy because the Sun is that primary source which influences the weather phenomena on the Earth. The wind arises because of non-uniform heating of a surface of the Earth by the Sun. The water and territory surface, closed by clouds, heat up much more slowly; accordingly, the surface of the earth accessible to sunlight, heats up faster. Air which is over warm with a surface heats up and rises upwards, creating areas of the lowered pressure. Air from high pressure areas moves in the direction of low pressure areas, thereby creating a wind. (Kargiev, et al., 2001)

Moving air masses are affected by Coriolis forces caused by rotation of the earth, force of inertia, force of gravitation or weight in a ground layer of atmosphere – forces of a friction of air flow about an earth surface.

For practice, as a rule, the greatest interest is represented by the horizontal component of a wind defined at its ground measurements (wind gauge, weather vanes and other) or with the help pilot-balloon supervision and which usually considerably surpasses a vertical component of a wind. (Nicolaev, et al., 2008)

## 2.2 Wind parameters

The wind is characterized by two measured parameters: in the speed expressed in m/s, km/h, knots (miles/h) or standard units (points) and a direction, whence it blows. The direction is defined or in points or in corners which the vector of speed forms with a meridian and counted from a direction on the north clockwise.

Wind speed and wind direction changes eventually owing to turbulence of an air flow (casual internal fluctuations) and under the influence of the external factors caused by non-uniformity in space and in time of temperature and pressure of various parts of atmosphere, being its integral properties. Variability of parameters of a wind is characterized by spatial and temporary variations of different scales(Nicolaev, et al., 2008)

Wind characteristics are measured on meteorological stations. Specialized winds maps are made on the basis of the given long-term supervision of speeds of a wind in various areas of Russia. (Kargiev, et al., 2001)

### 2.2.1 Speed of wind

The major characteristic defining power value of a wind is its speed. (Elistratov, 2008)

The wind varies with the course of time. In the majority of regions considerable seasonal changes of wind streams are observed. In winter months wind speed usually above, than in the summer. Changes of speed of a wind are observed during the day, as a rule, near to the seas and the big lakes. In the morning the sun heats up the earth faster, than water, therefore a wind blows in a coast direction. In the evening the earth cools down faster, than water, therefore a wind blows from coast. (Kargiev, et al., 2001)

Owing to some meteorological factors and also owing to influence of relief conditions continuous duration of a wind in the given district, its speed and direction essentially change in the course of time.

Fluctuations:

- Micrometeorological with duration from shares of second about several minutes;

- Mesometeorological with duration from several minutes till several o'clock;

- Synoptic with the period of fluctuations about 4 days, caused by cyclones and anticyclones;

- Global – from a week about one month;

- Interannual variability, connected with fluctuations of radiating balance of the Earth and activity of the Sun.

The first of this list make considerable impact on quality of the electric power produced by windmill. Influence of these fluctuations is especially strong affects at electro supply of the consumer from independently working windmills.

Mesometeorological, synoptic and global fluctuations are defining from the point of view of support of consumers with necessary power of the electric power, and also influence volume of its output for any period. Thus it is possible to consider size of speed and a wind direction changing on the casual law. Therefore power which windmill is capable to give out during any certain moment of time, it is difficult to predict with high probability.

At the same time total output of the windmill, especially for a long time interval (year or some years), pays off with high level of reliability as average speed of a wind and frequency of distribution of speeds within a year change a little.

As the basic lacks actively interfering use of wind energy, it is possible to name the following:

- Low specific density air energy flow, especially in comparison with traditional energy sources;

- Essential dependence of size of energy of a wind stream on an environment. Moreover, the periods of various duration calms which cause discontinuation of electric energy production take place;

- An insufficient readiness of methods of a substantiation of economic efficiency of wind installations and a choice of their key parameters in new market conditions taking into account ecological and social orientation. (Elistratov, 2008)

Wind speed depends on height over earth level. Close to the earth the wind is slowed down at the expense of a friction about a terrestrial surface. Thus, a wind is stronger at the big heights in relation to the earth. For agricultural fields and deserted territories when height increase over an earth surface twice the increase in speed of a wind approximately on 12 % is observed. (Kargiev, et al., 2001)

Geographical conditions and character of a terrestrial surface, including various natural and artificial obstacles, such, as hills and so forth, and also trees and buildings, have considerably influence on wind speed. For this reason windmills dispose, whenever possible, on ennobled and removed from high trees, apartment houses and other constructions places since such obstacles reduce speed of a wind and lead to the turbulences of a stream complicating transformation of a wind power. (Kargiev, et al., 2001)

In connection with variability of parameters of a wind, windmills are recommended to be used in the productions permitting discontinuation of electricity supply. If the guaranteed support of electric power is required, then it is necessary to apply energy systems, including, along with windmills, accumulators or duplicating power plant. (Elistratov, 2008)

# 3. METHODOLOGY FOR DETERMINING THE WIND RESOURCE

The condition of possibility of gross potential of wind energy use enters into its definition, as the wind occupies huge volumes in atmosphere of the Earth over region so even theoretically probably to use only a small part of the general resource of wind energy. Taking into account it, gross (theoretical) resource (potential) of wind energy of region (the country, continent) is a part of average of long-term total wind energy which is accessible to use on the area of region within one year. (Bezrukih ed., 2007)

## 3.1. A design procedure of total resources

On figure 3.1 the arrangement of 332 stations used for an estimation of gross potential of wind energy of Russia, and conditional splitting of its territory into Managements of hydrometeorological services are shown. For an estimation of potential wind resources of region following assumptions are used.

The first assumption consists that energy is selected at a wind flow by windmill with certain height H above a surface of the Earth. In this case, the gross potential calculate as total energy of the air mass, which use probably modern windmill with as much as possible big height of enveloped ground layer H and height windmill’s hub h. On modern windmills with capacity of 750 kW makes the hub height 60 – 80 m, and windwheels diameter 50 – 80 m. Windmills with capacity 1000 – 1500 kW with even big heights of towers and windwheels diameter became serial installations. Therefore in the given work value h = 75 m is accepted; thus the thickness of a used layer of air streams H makes approximately twice the big size, i.e. 150 m.

The second assumption consists that at a flow air streams of an obstacle ("an air dam”) in height H, the indignant flow completely is restored on distance 20 H after an obstacle. In this case as much as possible full use of a wind power is carried out by wind-energetic system "air dams" in height H, focused perpendicularly to a direction of a wind and distant from each other on 20 H. (Bezrukih ed., 2007)

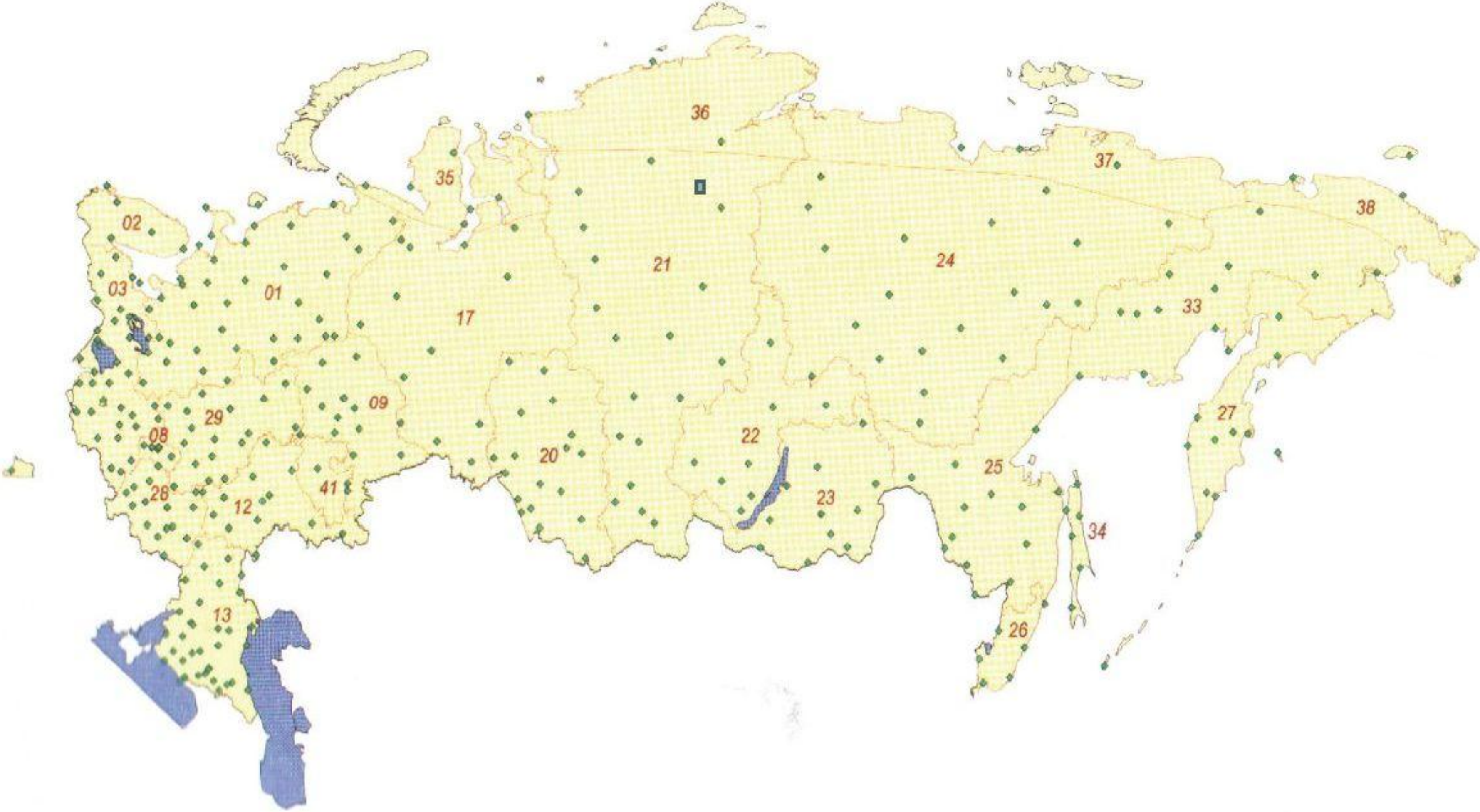


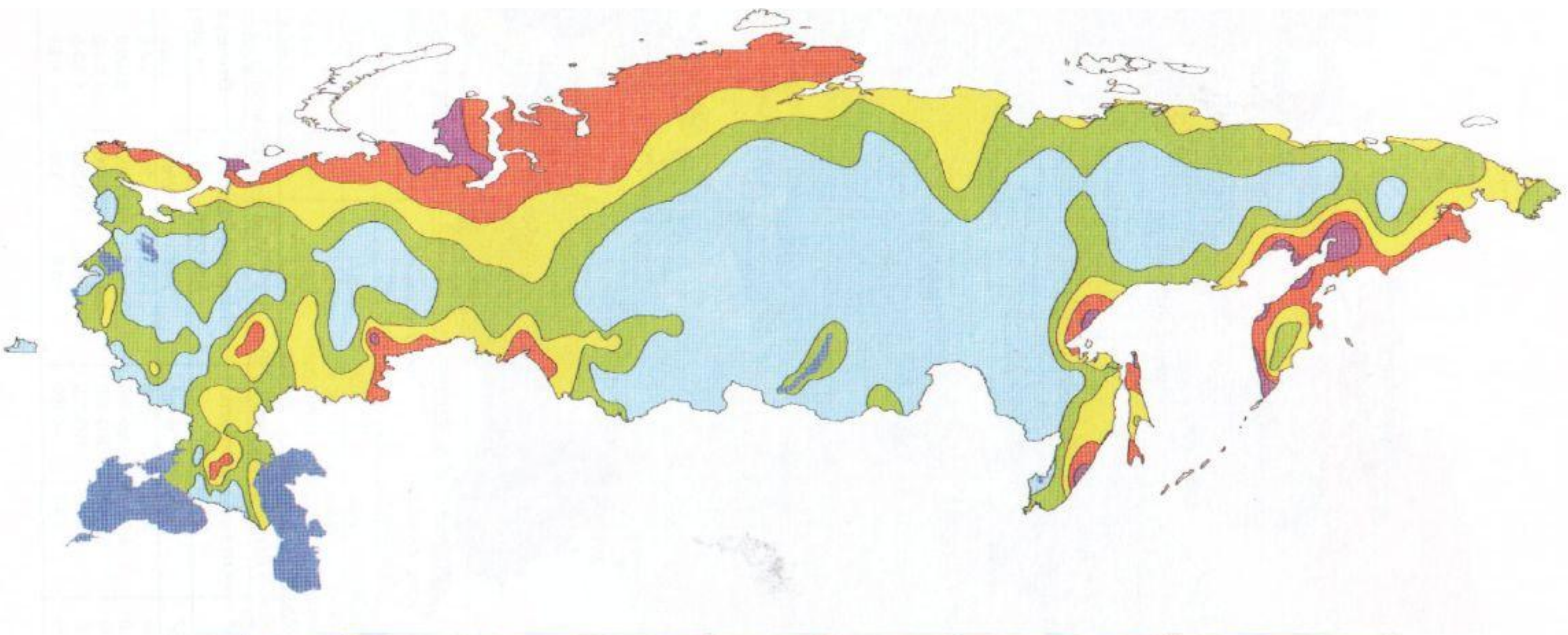

Figure 3.1. Arrangement of meteorological stations of the Atlas of winds and conditional splitting on of its territory into Managements of hydrometeorological services.

(Bezrukih ed., 2007)

Thus, the gross potential does not depend on height of a ground layer. It is necessary to find out, what speed is necessary to take for calculation of total potential? It is necessary to consider a profile of speed of a wind on height from 0 to H. As a first approximation it is necessary to count speed of a wind on height, to define average value and on this value to define necessary for calculation $v_i$ and $t_i$.

For estimated calculations of total potential it is possible to accept speed of the wind, equal speed of a wind at height h, a component about half H.

Wind resources of Russia are presented on a color card (see figure 3.2.), executed according to all used meteorological stations on which different colors correspond to different gradation of speed. Such representation reveals regions with perspective wind energy potential values and shows laws of its geographical distribution to territories of Russia. (Bezrukih ed., 2007)



| | Sheltered terrain | | Open plain | | Sea coast | | Open sea | | Hills and ridges | |
|---|---|---|---|---|---|---|---|---|---|---|
| | m/s | W/m$^2$ | m/s | W/m$^2$ | m/s | W/m$^2$ | m/s | W/m$^2$ | m/s | W/m$^2$ |
| | > 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 | 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 3.2. Wind resources at height of 50 m over level of the earth for five various (Bezrukih ed., 2007)

## 3.2. Design procedure of technical resources

Proceeding from the general definition of technical potential of renewed energy sources, and also noted above specificity of use of wind energy, it is possible to formulate following definition.

The technical resource (potential) of wind energy of region is a part of total potential of wind energy which can be used at a modern level of development of means and observance of ecological norms.

The technical potential of region represents the sum of technical potentials of zones making it.

To one of key parameters of technical potential of a zone represents the area of territory $S_T$, which for economic and ecological reasons is represented expedient for use of wind energy; it is equal to a part q to total area S remaining after subtraction of the areas of parks, agricultural grounds, industrial and water economic territories, inhabited, medical and cultural structures, taking into account possibility of arrangement windmill in large forests, at separate coasts, in water areas of the seas and oceans, etc

$$S_T = q \cdot S \tag{3.1}$$

Values *q* are specific to each zone, and in the present work following positions are accepted:

- Recycling of wind energy is expedient in areas where mid-annual speed of a wind at weather vane level not below 5 m/s, or, according to more exact approach, operating ratio of the established windmill capacity by capacity more than 100 kW appear an order 18 – 20 %;

- In the specified areas for development wind energy can be used no more than 10 % of territory;

- The most effective is recycling of wind energy with the help wind-electric installations of the big capacity (from 100 to 1500 kW).

In Russia the total area of regions with mid-annual speed of a wind over 5 km/s makes about 20 % of its territory. Thus, for Russia it is received an average estimation q ≈ 0.20 which for different subjects of the Russian Federation differs considerably.

Proceeding from the influence analysis wind-energetic installations on environment and on the person, some ecological requirements to their placing and corresponding alienation of the area are considered also.

Other important parameters of technical potential are an achievable technological level modern wind-electric installations, expressed as much as possible achievable capacity depending on speed of a wind, and also placing order wind-electric installations for maximum use of a wind stream.

Average windmill's power P is defined on expression:

$$P_{avg} = \frac{\pi}{8} \cdot D^2 \cdot \rho \cdot \sum_{i=1}^{n} v_i^3 \cdot \eta_{wm}(v) \cdot t_i \qquad (3.2)$$

$$\eta_{wm} = c_p \cdot \eta_{mech} \cdot \eta_{el} \qquad (3.3)$$

where

$\eta_{wm}$ – total windmill efficiency;

$c_p$ – power coefficient;

$\eta_{mech}$ – the mechanic windmill efficiency;

$\eta_{el}$ – the electric windmill efficiency;

As well as at definition of total potential, for estimated calculations, with sufficient accuracy it is possible to accept speed of a wind of a constant on all windmill area and equal speed of a wind at hub height *h*.

The placing order windmills for maximum use of a wind stream, generally, depends on a wind rose on district. The question consists in how it is often possible to have windmills.

In some works it is recommended on the basis of experiments in a wind tunnel to place units on the distance equal 10 – to 15 windmills diameters.

The recommended distance between wind turbines is equal in other sources 6 – to 18 diameters. In practice of designing foreign windmills when the wind changes in directions in regular intervals or close to uniform, the distance between wind turbines is accepted equal 10 ×*D*.

On the basis of the aforesaid for definition of technical potential the distance equal 10×*D* is accepted. Then on conditional rectangular platform S = a × b, it is possible to place n units:

$$n = \left(\frac{a}{10D}\right)\cdot\left(\frac{b}{10D}\right) = \frac{a\cdot b}{100D^2} = \frac{S_T}{100D^2} \tag{3.4}$$

So the energy produced within year ($T$ = 8760 h/year) all installations on area $S_T$, (i.e. technical potential of wind energy $E_T$), appears equal:

$$E_T = \frac{P_{avg}\cdot T\cdot S_T}{100D^2} \tag{3.5}$$

At substitution in (3.5) values of power by (3.3) it will appear, that the technical potential in an explicit form depends only on average speed of a wind and its distribution.

However, considering that the speed of the wind accepted in specified formulas depends on height and the tower height gets out depending on capacity (windwheel diameter) it is necessary to recognize dependence of technical potential on capacity of windmill.

To define ratio between technical and gross potential as a first approximation is of interest. Accepting in (3.3) constant efficiency of wind turbine, we receive the formula of technical potential $E_T$:

$$E_T = \frac{1}{100}\cdot\frac{\pi}{8}\cdot\rho\cdot T\cdot S_T\cdot\eta_{wm}\cdot\sum_{i=1}^{n} v_i^3\cdot t_i \tag{3.6}$$

Gross potential ($E_G$) is similar calculated by total area *S*. Having divided (3.6) on (3.1), we receive

$$\frac{E_T}{E_G} = \frac{\pi \cdot \eta \cdot S_T \cdot 40}{8 \cdot 100 \cdot S} = \pi \cdot \eta \cdot \frac{S_T}{20S}\,. \tag{3.7}$$

Accepting $\eta \approx 0.3$ taking into account $S_T = 0.2S$, it is received:

$$\frac{E_T}{E_G} = 0.01 \tag{3.8}$$

I.e. technical potential in 100 times less than gross potential at least. But it only average value at the accepted assumptions. (Bezrukih ed., 2007)

## 3.3. Definitions of economic resources

The economic potential of wind energy is a size of annual receipt of electric energy in region from use windmills which production is economically sound for region at an existing price level on production, transportation and consumption energy and fuel and observance of ecological norms.

The ecological potential of region represents the sum of economic potentials of zones making the region. It is necessary to mean, that amount of zones in region and their sizes at definition of technical potential do not coincide with amount of zones and their sizes at definition of economic potential. Really, at calculation of technical potential the amount of zones and their sizes were defined on the basis of similarity mean annual speeds of a wind and geographical conditions. Whereas the amount of zones at calculation of economic potential along with signs of allocation of zones of technical potential should be defined by the account of real requirements for energy of the given zone and a constancy of cost indexes accepted for calculations in it. Especially it concerns specific cost of construction windmill. It should be taken into consideration, that at removal windmill from a connection point to a network expenses for a construction of an electric main which should be considered in specific cost of building increase. Besides, the economic potential unlike technical is not meaningful in the territories removed from settlements on many hundreds of kilometers.

Thus, the economic potential is much less than technical. In other words, the area defining economic potential is much less than the area defining technical potential. (Bezrukih ed., 2007)

# 4. WIND TURBINES

The history of windmills amounts more than 2000. They have been used basically for grinding grain or pumping water. Modern windmills are used for wind power conversion. Such windmills have been developed in 1920. But only in 1980 they have found professional interest as a source of renewed energy. (Stiebler, 2008)

## 4.1. Types of wind turbines

Existing systems of wind turbines are divided into three classes under the windwheel structure scheme and wind wheel position in a wind stream (Ageev, 2004):

- Horizontal-axis rotors;
- Vertical-axis rotors;
- Crosswind horizontal-axis rotor - the wind turbines working by a principle of a water mill wheel, so-called the drum-type. The axis of such wind wheel rotation is horizontal and perpendicular to a wind direction. (Ageev, 2004)

### 4.1.1. Horizontal-axis rotors

Direction of the windstream is parallel to the axis of windwheel rotation. (De Renzo ed., 1979) The windwheel is in a vertical plane; the rotation plane is perpendicular to a wind direction (see figure 4.1) (Ageev, 2004)

Figure 4.1. Horizontal Axis Wind Turbine. (HAWT) (Energy, 2009)

Horizontal-axis wind turbines, depending on windwheel type and tip-speed ratio, are divided into three groups (Ageev, 2004):

- Multiblade wind turbines, with tip-speed ratio $\lambda \leq 2$;
- Wind turbines with 3, 2 or one blades, slow-running, including conventional windmills, tip-speed ratio $\lambda > 2$;
- Wind turbines with 3, 2 or one blades, fast-running with tip-speed ratio $\lambda \geq 3$.

An early style of HAWT was the big Dutch-style windmill used for grinding grain (see figure 4.2).

Figure 4.2. Dutch-style windmill (Source: Wikipedia, 2005)

### 4.1.2. Vertical-axis rotors

The axis of windwheel rotation is vertical. (Ageev, 2004) Windstream is perpendicular to axis of windwheel rotation; axis of windwheel rotation is perpendicular to surface of the earth (see figure 4.3). (De Renzo ed., 1979)

Depending on the constructive scheme VAWT are divided into groups:

- turbines at which non-working blades either are covered with a screen, or with a fin against a wind;
- Savonius system rotor-type windmills. (Ageev, 2004)

VAWT works irrespective of the wind direction. Savonius Rotor is an early style in several centuries age. The Savonius Rotor is the simplest design of VAWT. The very complicated VAWT is the Darrieus Rotor. It looks like an egg-beater with usually either two or three bent vane (see figure 4.4). (Johnson, 2009)

Figure 4.3. Darrieus Vertical-Axis Wind Turbine. (DVAWT) (Energy, 2009)

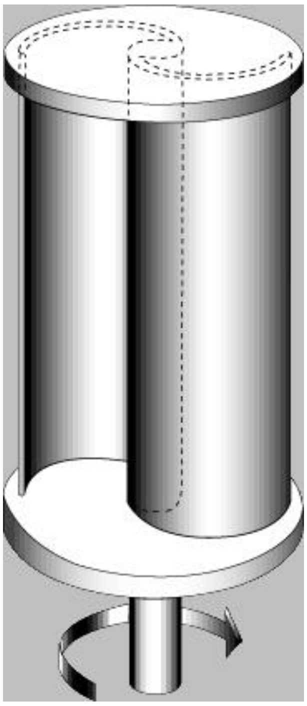


Figure 4.4. Savonius Vertical Axis Wind Turbine. (SVAWT) (Krugosvet, 2009)

### 4.1.3. Crosswind horizontal-axis rotor

The wind turbines work by a principle of a water mill wheel, so-called the drum-type. The axis of such windwheel rotation is horizontal and perpendicular to a wind direction. (Ageev, 2004) This type of wind rotor is not very effective. (De Renzo ed., 1979)

### 4.1.4. Advantages and disadvantages of different wind turbine types

The basic disadvantages of VAWT and drum-type wind turbines follow from the principle of a placement of working windwheel faces in a wind stream (Ageev, 2004):

1. As working blades of a wheel move in a direction of an aerial stream, wind loads not simultaneously on all blades, but serially. As a result each blade suffers a discontinuous loading. The wind power operating ratio is rather low and does not exceed 10 %. That is established by experimental researches.
2. Movement of windwheel surfaces in a wind direction does not allow developing the big speed. As surfaces cannot move faster that a wind.

3. The sizes of a used part of an air stream (swept area) are small in comparison with the sizes of the wheel. That considerably increases its weight relative to unit of an installed capacity of a wind turbine

At system Savonius rotor-type windmills the greatest operating ratio of a wind power of 18 %.

HAWT are free from listed above disadvantages of VAWT and drum-type wind turbines. Good aerodynamic qualities of HAWT, constructive possibility to produce bigger power, rather light weight relative to unit of power - the basic advantages of wind turbines of this type. (Ageev, 2004)

But VAWT have advantage over HAWT. They do not have to turn when direction of a wind changed. This allows reducing the design complicacy. (De Renzo ed., 1979)

## 4.2. Wind Energy Conversion

### 4.2.1. Scheme of conversion of kinetic energy of a wind into electric energy

Wind power use in practice is carried out by wind turbines or windmills. The kinetic energy of a wind stream is transformed into mechanical energy of rotation of wind wheel, and then into electric energy of the generator. In general, traditional horizontal axis wind turbines are used. Now unit power of large industrial wind turbine amounts of 2-4 MW. Hub height of such wind turbine is 60-100 m and windwheel diameter is 60-80 m. Wind turbines with low power are used for individual consumers and small economic objects. Power of such wind turbines is 0.1-100 kW. Wind turbines with unit power from 100 to 2000 kW are most extended for the power purposes. (Elistratov & Kuznetsov, 2004)

Figure 4.5 shows the major wind turbine components. This design is a horizontal-axis, three-bladed upwind rotor. Rotor is kept into the wind direction by an active yaw system. The drive train components: the rotor – a low-speed shaft – gearbox - high-speed shaft – generator. Generators are usually asynchronous. Additional small generator is used to improve production in low wind speeds in some turbines. All turbines are equipped with a transformer to step up the voltage to the system voltage. (NYSERDA, 2005)

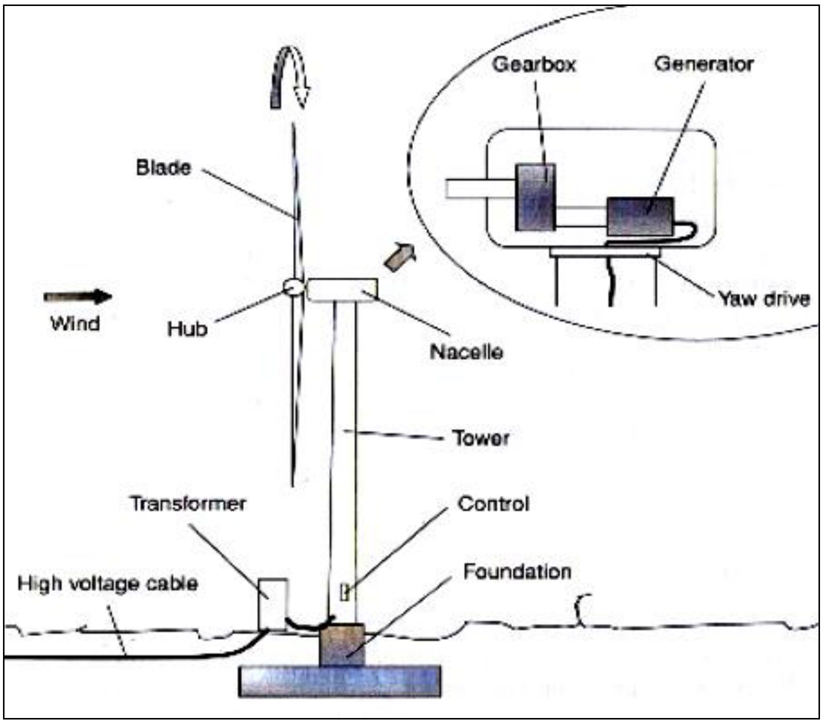



Figure 4.5. Major Turbine Components (NYSERDA, 2005)

Figure 4.6 shows that wind power production depends on wind speed. Power curve is relationship between power and wind speed. Power curve is specific for each turbine model. (NYSERDA, 2005)

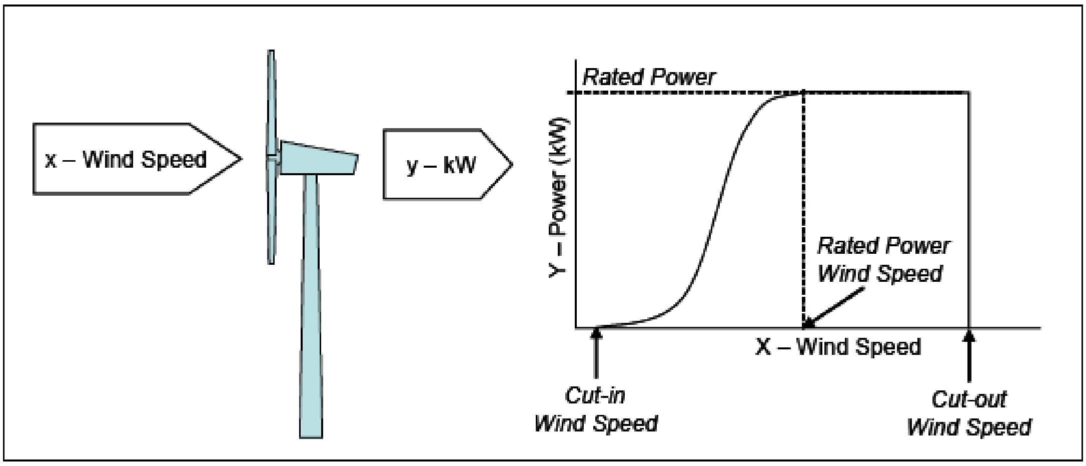



Figure 4.6. Relationship of Wind Speed to Power Production (NYSERDA, 2005)

Cut-in Wind Speed – is the minimum wind speed when wind turbine begins to produce power. In general, cut-in.
Wind Speed – is wind speed when wind turbine achieves the rated power. Rated power wind speed value approximately is 13-15 m/s
Cut-out Wind Speed – maximum wind speed when wind turbine stops to produce power. Cut-out wind speed value is about 25 m/s. (NYSERDA, 2005)

When wind speed is above the cut-out wind speed the wind turbine automatically stops. Owing to that wind turbine is not suffered from overloads at storm wind speeds. Storm wind speeds is one characteristic value. Construction of wind turbine reliably stands the storm wind speed. (Elistratov & Kuznetsov, 2004)

**4.2.2. Advantages and disadvantages of wind turbines**

Disadvantages:

- The wind usually is not constant also the power produced by wind turbine, all time varies, there is an additional problem for an electric power system on frequency/power control;
- There is no wind, there is no also an energy, the reserve source therefore is always necessary; (for small powers - the accumulator);
- Without communication with an electric power system the wind-driven electric power station cannot work, and in wind-diesel stations the special control systems providing parallel work of the wind turbine and diesel-generators are necessary;
- The utilization factor of maximum capacity is rather small;
- High enough incremental cost of an installed capacity.

Advantages:

- It is not required fuel is main advantage;
- Issue of C02 and other firm and harmful gaseous emissions that takes place on all power stations using organic fuel is prevented;
- For wind-driven electric power station work water and air which are in large quantities consumed on thermal power stations are not required;
- The territory on which settle down a wind-driven electric power station or is unsuitable for economic use, or can be used for animal industries and plant growing, i.e. alienation of the fertile earths is much less, than on hydroelectric power station and thermal power station;

- Possibility of full automation of work, absence of the personnel on duty;
- Short term of a construction from signing of the contract before the installation termination. It is possible to construct for 18 months a wind-driven electric power station power 50 MW and the further expansion of station is carried out without problems;
- Simple technology of work of station. After start-up of the first installation the station starts to produce energy, except electric - no dependences on fuel and a mode between wind turbines are present. (Bezrukih & Bezrukih Jr. 2002)

### 4.2.3 Power conversion and power coefficient

The kinetic energy of air mass is equal to half the air mass times the square of air velocity. (Boyle ed., 2004)

From the expression for kinetic energy in moving air the wind power expression is following (Stiebler, 2008):

$$P_w = \frac{\rho}{2} A v_1^3 \tag{4.1}$$

The useful mechanical power obtained is expressed by means of the power coefficient $c_p$:

$$P = c_p \frac{\rho}{2} A v_1^3 \tag{4.2}$$

The wind velocity suffers retardation due to the power conversion to a speed *v*3 behind the wind turbine, see figure 4.7.

The velocity in the plane of the moving blades is of average value $v_2 = (v_1 + v_3)/2$. (Stiebler, 2008)

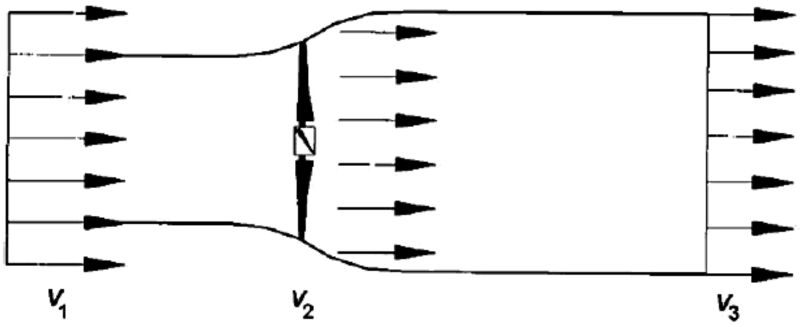



Figure 4.7. Idealized fluid Betz model for a wind rotor (Stiebler, 2008)

According the Betz (1966) calculation useful power is maximum when $v_3/v_1 = 1/3$ and power coefficient $c_p \approx 0.59$. Really wind turbines power coefficient maximum values $c_{p,max} = 0.4 - 0.5$. That because of profile loss, tip loss and wake rotation loss.

Tip-speed ratio is an important parameter of wind turbines. Tip-speed ratio is the ratio of the peripheral velocity of the turbine blade tips and the wind speed (Stiebler, 2008):

$$\lambda = u / v_1 = \frac{D_O}{2} \cdot \frac{\Omega}{v_1} \tag{4.3}$$

where

D - outer turbine diameter

Ω - the angular rotor speed

According the power concept the power of rotation mechanical system is torque multiplied by angular speed.

$$P = T \cdot \Omega \tag{4.4}$$

Hence the torque coefficient $c_T$ can be calculated:

$$c_T(\lambda) = \frac{c_p(\lambda)}{\lambda} \tag{4.5}$$

Than torque equation is following:

$$T = c_T \frac{D}{2} \frac{\rho}{2} A v_1^2 \qquad (4.6)$$

Power coefficients $c_p(\lambda)$ for different types of rotor is presents on figure 4.8. The figure shows both constant Betz maximum value and revised curve $c_p$ calculated by Schmitz and, before, Glauert. (Stiebler, 2008)

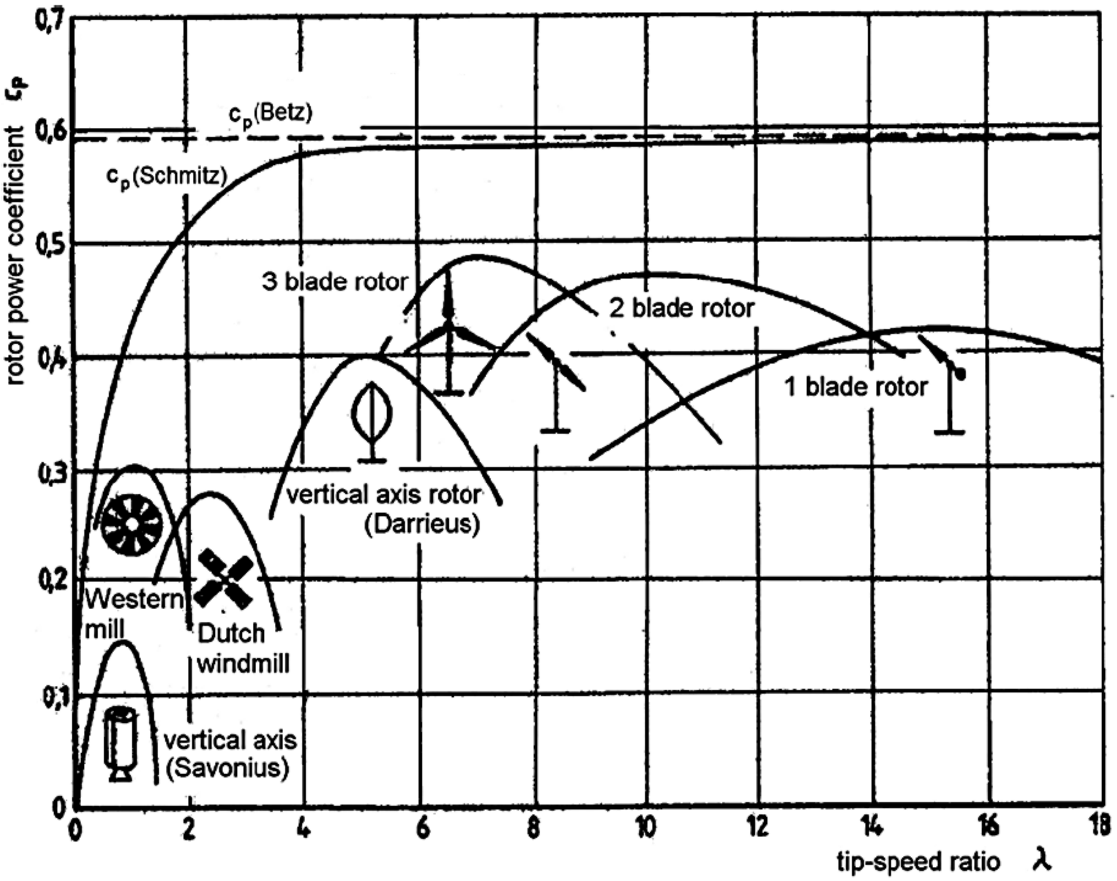



Figure 4.8. Typical power coefficients of different wind turbine types over tip-speed ratio (Stiebler, 2008)

The preference to three-blade HAWT is understood from Figures. 4.8 and Figures 4.9. The so-called fast-running turbines show the larger values of *c*p and the poor starting torque capability. The turbines are usually designed to tip-speed ratio values $\lambda$ = 5-8. (Stiebler, 2008)

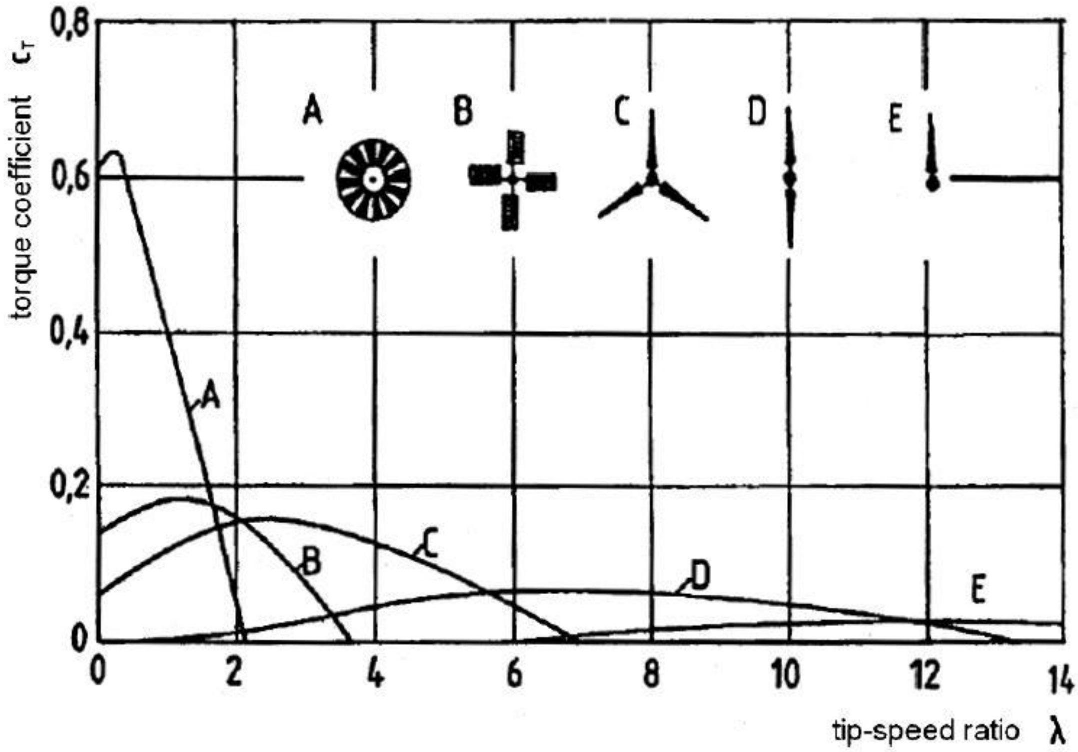



Figure 4.9. Typical torque coefficients of different horizontal- axis rotor (Stiebler, 2008)

## 4.3. The approximate calculation of annual generation of electricity by windmill

Output of electricity by wind unit in a place of its installation depends on power characteristics of a wind and a wind unit design.

Power of a wind stream is calculated under the following equation:

$$P = \frac{1}{2}\rho A v^3 \quad (4.7)$$

where $P$ – power of a wind flow;

$\rho$ – air density [1,225 kg/m$^3$, under usual conditions];

$A$ – the cross-section area of a wind flow;

$v$ – speed of a wind.

If average speed of a wind is known, for example, for a year and distribution of speeds of a wind has typical character then average power of a wind stream is defined from equation:

$$P_C = 1{,}17 A v_{avg}^3 \quad (4.8)$$

Modern windmills are capable to transform only about 25 % of full power of an air stream to useful power.

Thus:

$$P_{WM} = 0{,}25 \cdot 1{,}17 A_C v_{avg}^3 = 0{,}292 A_C v_{avg}^3 \quad (4.9)$$

where

$P_{WM}$ – output power of windmill;
$A_C$ – The surface area covered by windwheel;
$v_{avg}$ – Average wind speed at windwheel hub level.

The amount of energy which produces a windmill for the rated period of time can be defined as follows:

$$E = \frac{P_{WM} T}{1000} \quad (4.10)$$

where

$E$ – Amount of generated energy ;
$T$ – estimated windmill work time.

The average amount of energy which windmill will generate for a year is calculated by the equation:

$$E_{aa} = \frac{24 \cdot 365 \cdot P}{1000} = 2{,}56 A_C v_{aa}^3, \quad (4.11)$$

where

$E_{aa}$ – average annual windmill power generation [kWh/a];

$v_{aa}$ – average annual wind speed.

Thus, for windmill the average annual electricity generation depends on windwheel diameter and average annual wind speed.

## 4.4. Commercial use of wind turbines

Commercial use of wind turbines has begun since 1980. For the last 14 years power of wind turbines has increased in 100 times: from 20-60 kW at diameter of a wind wheel about 20 m in the beginning of 1980 to 5000 kW at diameter of a rotor over 100 m by 2003 (see figure 4.10). Some prototypes of wind turbines have still big power and diameter of a rotor. (Ageev, 2004)

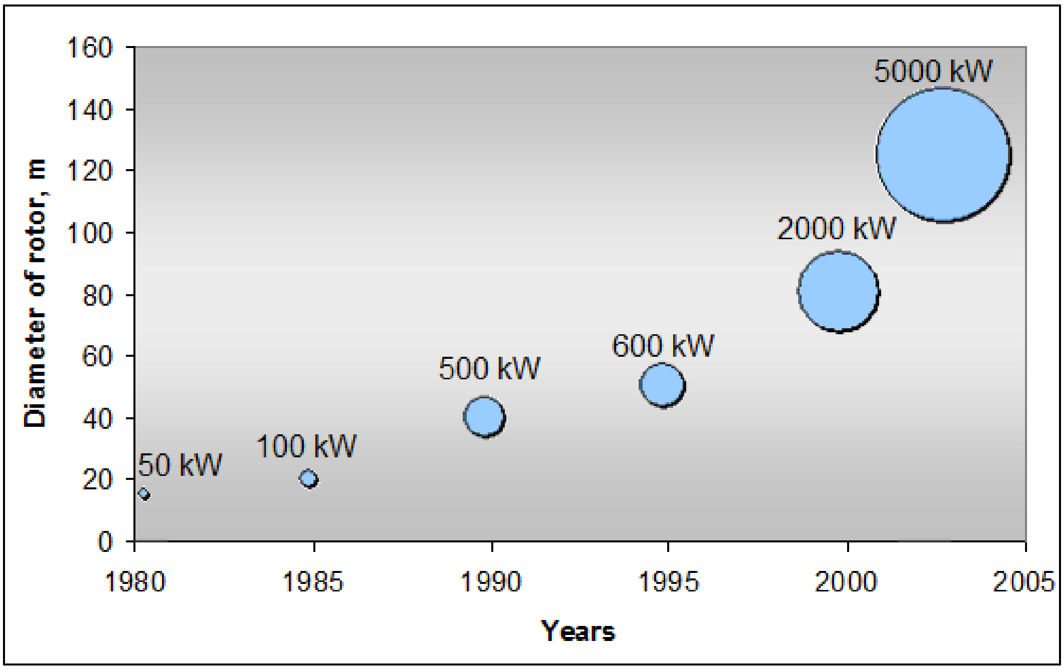



Figure 4.10. Development of power and diameter of rotor of commercial wind turbines (Ageev, 2004)

For the same period cost of energy generated by wind-driven generators has decreased on 80 %. (Expert RA, 1999) Dependence of the electric power cost on power of wind turbines both at coast and far from the sea is presented on figure 4.11 (in the prices of 2001).

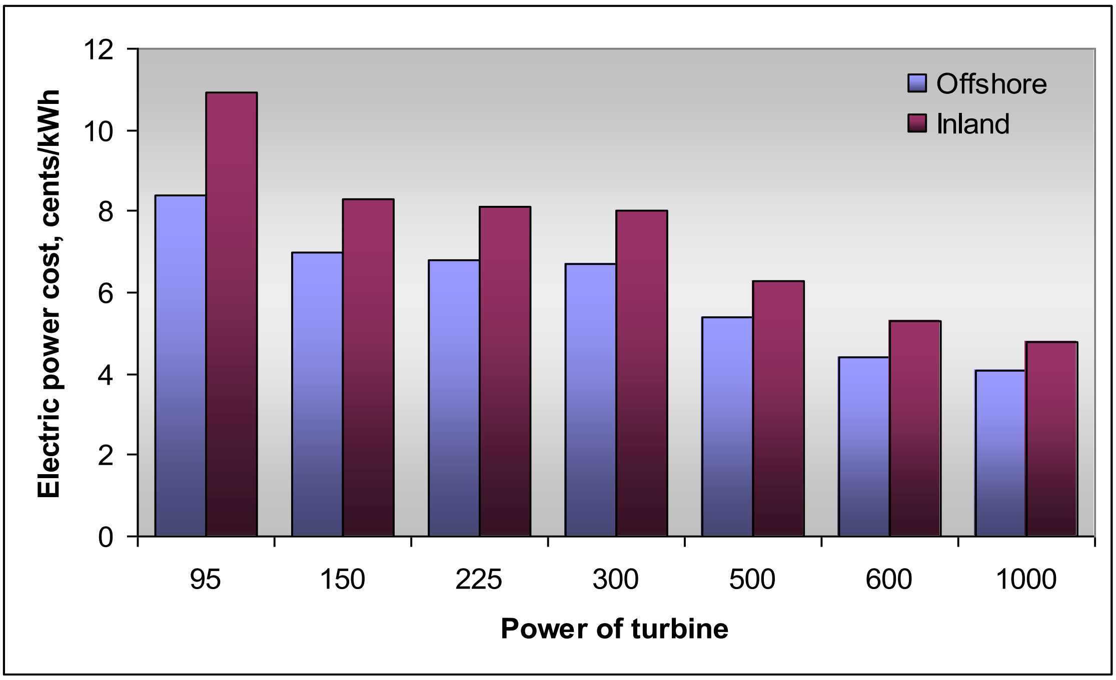



Figure 4.11. Dependence of the electric power cost on power of wind turbines (Ageev, 2004)

## 4.5. Costs of energy

For last 15 years cost of the electric power from the wind power plants connected to an electric power system, has fallen more than in 6 times. In the early eighties, when the first stations have been entered into work, the electric energy made by average power station cost 30 cents for kWh. Now working wind power plants make the electric power under the price less than 5 cents for kWh. This price is comparable with the price of any technologies for not renewed fuel (see table 4.1). On figure 4.12 change of the price for the electric power from a wind power plant within last 15 years is resulted. (Bezrukih & Bezrukih Jr., 2002)

Electric power cost produced by wind power plants decreases year by year. It is connected with the technical progress, new materials and technologies of their manufacture. New methods of use allow increasing operating ratio of the installed power of windmills. New laws supporting wind-power engineering and giving the big discount for taxes for wind power plants and energy which produce are passed.  Its and many other different reasons influence on price of electric power.

Table 4.1. Electric power cost produced by wind power plants and installed capacity incremental cost of its.

| Year | Electric power cost, cents/kWh | Installed capacity incremental cost, dollars/kW |
|---|---|---|
| 1981 | 30 | 4000 |
| 1982 | 28 | 3520 |
| 1983 | 23 | 3360 |
| 1984 | 19 | 3040 |
| 1985 | 18 | 2640 |
| 1986 | 15 | 2180 |
| 1987 | 13 | 1840 |
| 1988 | 11 | 1600 |
| 1989 | 8 | 1520 |
| 1990 | 6 | 1200 |
| 1994 | 5 | 1100 |
| 1995 | 4 | 1000 |
| 1996 | 4 | 980 |

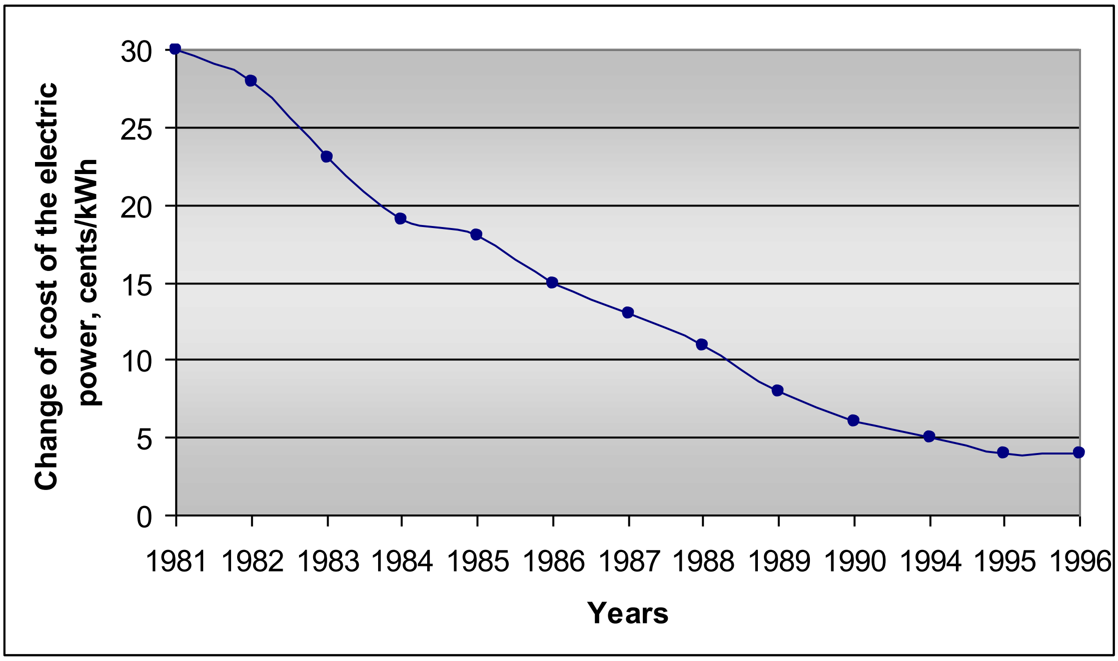



Figure 4.12. Change of cost of the electric power produced by wind power plants.

For same time the incremental cost of the windmills connected to an electric power system, has decreased with 4000 dollars/kW to 1000 dollars/kW, i.e. in 4 times and continues to decrease (see figure 4.13). Thus, in the prices of the beginning of 1998 windmill by power 250 kW should not cost more than 250 thousand dollars (factory price).

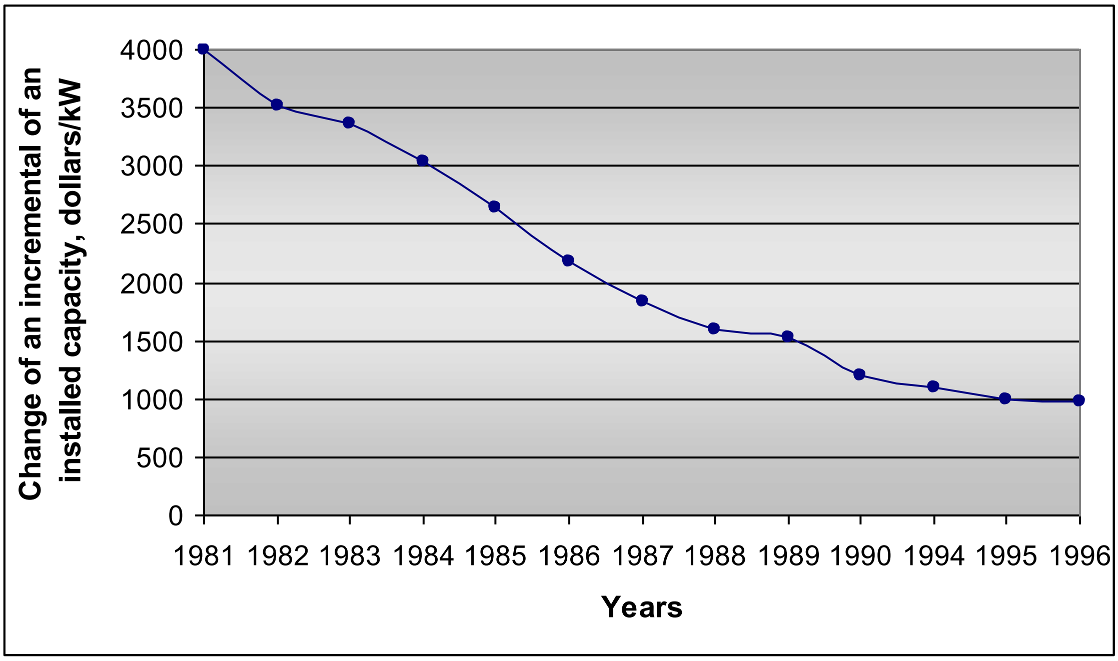



Figure 4.13. Change of an incremental of an installed capacity of wind power plants.

On figure 4.14 parities of the price of the electric power produced on wind power plants, and on the electric power produced on power stations of other type are visually shown. From them follows, that a wind - one of the cheapest renewed energy sources and a wind power plant can successfully compete to any power stations on not renewed energy sources, under condition of their construction in those places where mid-annual speed of a wind makes 8 km/s and above.

Many research centers, the organizations and firms, such as DEWI (Germany), RISO (Denmark), NREL (USA), etc., closely co-operating with the industry at support of the governments, work over following generation of windmills. Result of these works occurrence of the windmills producing the electric power under the price, the comparable electric power with the price produced by the steam-turbine power stations on gas is expected.

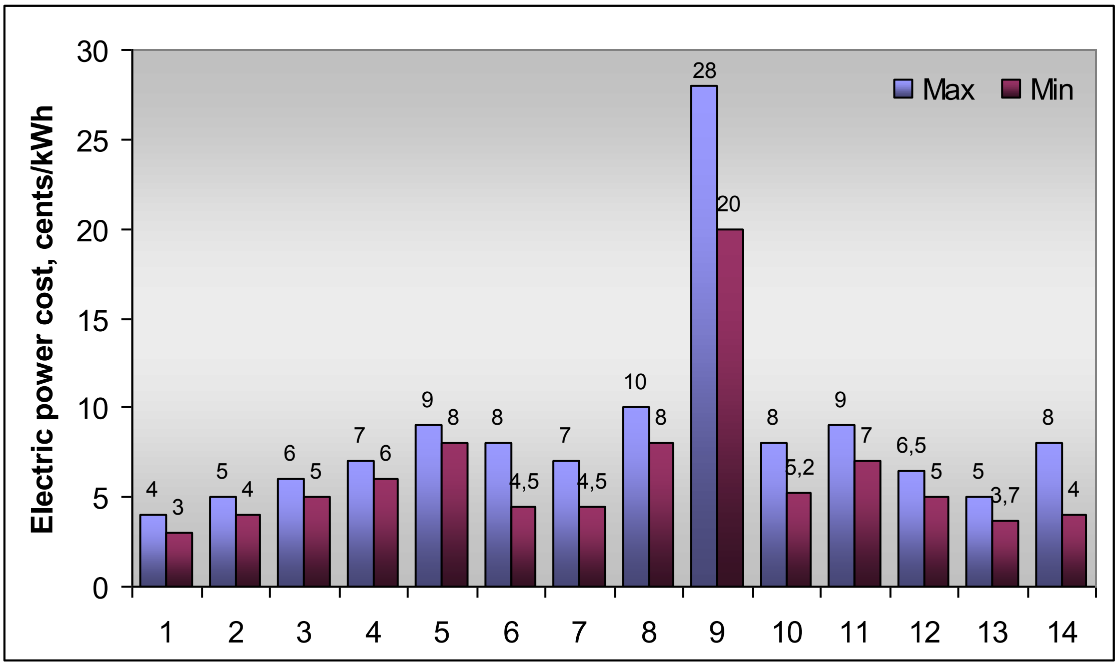



Figure 4.14. Average maximum and floor prices for the electric power from different sources:

In Figure: 1 - micro and small hydroelectric power stations; 2 - wind power plants; 3 - geothermal stations; 4 - a thermal power plant on a woodworking waste; 5 - biomass gasification; - gas; 7 - a firm household waste; 8 - solar thermodynamic stations; 9 - photo-electric stations; 10 - a thermal power plant on coal; 11 - ecologically pure a thermal power plant; 12 - a thermal power plant on gas; 13 - gas-turbine with the combined cycle; 14 - nuclear stations.

# 5. THE CURRENT USAGE OF WIND ENERGY IN RUSSIA

## 5.1. The Russian Energy System

Russian Federation is the largest country of the world, its territory of 17 075 400 square kilometers. (Wikipedia, 2009a)

The population of Russia amounts 141.9 million persons. (ENIN, 2002) Also it takes fourth place in the world on energy manufacture, after the USA, China and Japan. (ENIN 2002)

After disintegration of the USSR in 1991, Russia saw serious economic recession, a default, and also economic boom. The economy has essentially changed in connection with occurrence of a free competition, privatization and foreign investments. All it has affected also power sector, in which it was possible to observe many problems, as in camps of east Europe: uneconomical tariffs, non-payments and the out-of-date equipment. It is considered, that full manufacture of energy has not reached level of 1990 year. (ENIN 2002)

In 1992 by the presidential decree for power re-structuring had been created uniform joint-stock company (Russian Open Society "United Power Systems"). Also has been created Rosenergoatom, for management of all nuclear power. After that, in 1994, the Russian Open Society "United Power Systems» has started to switch-off consumers for non-payment. It has led to increase of norm of payment to 90 %. Gradually the situation in power has improved, but the uniform structure of management did not allow to make a scale of charges enough flexible. (ENIN 2002)

Therefore, in 2008 (Wikipedia, 2009b) the Russian Open Society "United Power Systems" have been transformed to some independent legal entities. It has allowed to generate own home market in many areas of the country and to increase accessibility of energy to many firms.

Things described above, huge deposits of minerals and many other things have generated the main line of power in Russia – an emphasis on thermal power and heterogeneity. For example, in Northwest region of 41 % of all energy it is made by nuclear power stations, and in Siberia and the Far East the nuclear power is not present at all. Also in Russia there are many hydroelectric power stations. (ENIN, 2002) Generation energy capacity mix in 2000 is presented on figure 5.1.

| **Generation capacity mix (2000)** | Capacity (MWe) | Percent of Total |
|---|---|---|
| Nuclear | 21,242 | 10.42% |
| Thermal | 138,700 | 68.04% |
| Hydro | 43,900 | 21.54% |
| Other renewables | 11 | < 0.01% |
| *Total* | 203,853 | 100% |

Figure 5.1. Generation energy capacity mix in Russia in 2000. (ENIN, 2002)

## 5.2. Economic development of Russia and renewable energy

Energy strategy of Russian Federation for the period to 2020 year based on two basic scenarios of social and economic development: “optimistic” and “moderated”. “Optimistic” scenario include next conditions: in the country economic, tax and price reforms will be spent reasonably and effectively, and in the external power market there will be no essential changes.

In the moderate scenario Power strategy assumes gross national product growth on 5-6 % a year till 2020. Under this scenario that the power sector did not become a brake of economic growth, essential growth of power efficiency will be necessary. Growth of volume of consumption of primary power resources within 0.5-1.13 % a year that is essential more low, than gross national product growth is supposed. It means power consumption reduction on the average on 2.8-4 % a year.

Under forecasts the International Power Agency, the Russian total demand for primary energy till 2030 will grow on 1,4 % a year, at growth of gross national product of 3 % a year and power consumption reduction on the average on 1,6 % a year. For gross national product doubling by 2013 the economy should grow higher rates. It increases expediency of development of renewable energy sources. The general and some power characteristics of regions of Russia are showed in Appendix I. In many respects levels of power consumption of regions depend on a population. Losses of fuel and energy resources in certain degree are connected with the area of regions. Representation about new renewable power resources of regions bases on two characteristics: specific gross potential of wind energy (see Appendix II). (Bezrukih ed., 2007)

Development of renewable power engineering will promote the decision of economic, ecological, power and social problems. It especially concerns regions with deficiency of traditional energy sources. The renewable power engineering is important for the decision of problems in energy supply of the isolated and remote consumers. The increase part of renewable power engineering will promote development of the domestic industry. In long-term prospect export of technologies of renewable power engineering and renewable "green" energy could become one of locomotives of driver of economy.

On the beginning of 2001 the full established power in the Russian Federation made nearby 205 GW. To the beginning of 2000 in Russia there were more than 500 thermal power stations, more than 90 hydroelectric power stations and 10 atomic power stations. The general deterioration of the equipment in electric power sector makes about 60-65 %. Many individual and industrial consumers already face frequent restrictions and electricity and heat switching-off. In some cases projects renewable power engineering can replace the nuclear and put out of action nuclear or thermal powers. Projects of renewable power engineering often represent the most economic choice because of the scales. Their modular nature and the small sizes mean that they can be designed, constructed and integrated into existing power supply systems in short terms, in process of demand growth. Besides, the big centralized systems of power supply usually are projected for satisfaction of the future demand which can and not appear.

Energy from renewable sources can promote increase of power safety of Russia. Many Russian regions deliver fossil fuel from other regions. Such fuel dependence is the important stimulus for development of local renewable power resources. (Bezrukih ed., 2007)

## 5.3. Development history of wind-power engineering in Russia

In the beginning of 19th century the wind power in Russia was used mainly for a grain grinding. The number of windmills reached 200 thousand units. It there were wooden windmills with four blades average capacity of 3.5 kW. The greatest mills had windwheel diameter 20-24 m and capacity of 10-15 kW. Windmills milled about 34 million ton grains in a year. All windmills were local country manufacture and their construction was based on long-term practical experience. (Kargiev V., 2001)

Theoretical and experimental works on windmills have started in 1920th years therefore have been developed for needs of agriculture multiblade windmills of an all-metal design in diameter of 5-8 m (TV-5 and TV-8). Mass production of these installations refers to 1936 when 1300 installations completed with piston-type pumps have been built. Productivity of TV-5 was 1 $m^3$ per hour at speed of a wind of 3 km/s and 5 $m^3$ per hour at speed of a wind of 5 km/s. TV-8 provided in 3-3.5 times the big productivity.

Development of windmill with windwheels in diameter of 8 and 12 m refers to the pre-war period. Last installation has been completed by the oscillator of 15 kW. It was used at 16 stations of Northern sea way and has shown high safety in operation in the conditions of the Far North.

The world's first wind energy power plant by power of 100 kW with the asynchronous oscillator has been developed in TsAGI and the Station is built in Crimea near to Sevastopol in 1931. The power plant worked on local power system, it had windwheel diameter of 30 m. Station successfully worked, but has been destroyed in 1942 during war.

In the fifties in the USSR windmills have been delivered by 44 factories. The manufacture maximum level has been attained in 1955, when have been delivered 9142 units. The TV-8 windmill which began to be applied not only to rising of water, but also for rehash of forages had the greatest demand. 2352 installations worked for water supply of farms in 7 areas of Russia in 1958. Windmills paid for themselves for 1-2 years of work. Windmill D-12 also was used for mechanization of labor-intensive processes in animal industries and for rising of water. More than 3 thousand broadcasting centers in the country in 1956 were all-mains from accumulator battery, charged by means of wind-electric sets of type WE-2 power of 100 kW. The wind-diesel power station by power of 25 kW and multimodular power station by power of 400 kW has been created on baseline of windmill D-18.

With development of electrification in farming windmills began to lose the former meaning for village. A wind-power engineering target at a new stage – energy supply of objects of agriculture not connected to networks. It distant pastures of the Volga region, Siberia, Kazakhstan, Turkmenia.

During the period since 1968 to 1975 in a number of the organizations new wind-electric sets by power from 1 to 30 kW have been developed. The design double-blade windmill with windwheel diameter of 6 m and power of 4 kW was the most successful. The volume of annual manufacture in 80th years made 400-500 units. Double-blade windmill was applied as a part of installations of different function: for rising of water and heating of premises, for a charge of accumulators on lighthouses, for desalination sea and saltish water, for cathode protection of the main water pipelines. In particular, 10 windmills provided a heat supply of household premises in Antarctica at station Novolazarevsky.

Only small wind-electric sets by power from 0.1 to 10 kW are serially made now days, but already high powers wind-electric sets are developed and checked. (Kargiev V., 2001)

There is begun wind-driven electric power station creation by power 22 MW near Elista (Kalmykia). (NIIES, 2006)

The "Polar" wind power plant by power 2.0 MW equipped with network domestic windmills works in Vorkuta.

In the conditions of Russia with its huge and poorly populated northern territories independent windmills have the greatest prospects, and also hybrid systems of an electric-power supply of agricultural users. (Kargiev V., 2001)

## 5.4. The current usage of wind energy in Russia

The potential wind energy is allocated on territory of Russia non-uniformly. There is a set of areas where average annual speed of a wind exceeds 6 km/s. On fig. 3.2 are shown wind energy resources at height of 50 meters over level of the earth for five various topographical conditions of district. Colors in the first column of the table correspond to colors in drawing. (Bezrukih ed., 2007)

Average annual speed of a wind should be 4-6 km/s and more in perspective regions for application of windmills. Russia has considerable resources of wind energy. They are concentrated mainly in those regions where there is no centralized power supply. Such situation is characteristic for all Arctic coasts from Kola Peninsula to Chukchi Peninsula, and also for coast and island territories Bering and the Okhotsk Seas. The distribution geography wind energy resources allow using rationally them both independent windmills and large wind energy plant as a part of local power systems. (Kargiev, et al., 2001)

The highest average speeds of a wind are found out along coast Barents, Kara, Bering and the Okhotsk Seas. Other areas with rather high speed of a wind (5-6 km/s) include coasts of the East-Siberian, Chukchi seas and Laptev Sea in the north and Sea of Japan in the east. A little smaller speeds of a wind (3.5-5 km/s) are found out on coast of the Black, Azov both Caspian seas in the south and the White Sea in the northwest. Considerable resources are also in areas of the Average and Bottom Volga region, in Urals Mountains, in steppe areas of Western Siberia, on Baikal.

The lowest values of average speed of a wind are observed over the Eastern Siberia around the Lena-Kolyma kernel of the Asian anticyclone.

Over mostly territory of Russia speed of a wind in the afternoon above, than at night, and these distinctions are essentially less expressed in the winter. The annual course of average speed of a wind (i.e. a difference between a maximum and a minimum of daily average speeds) in the majority of areas of Russia is insignificant and varies in limits from 1 to 4 km/s, averaging 2-3 km/s. Higher amplitudes are observed in the centre of the European part of Russia, in the Eastern Siberia, in Western Siberia (except for northern areas) and especially in the Far East where they reach 4 km/s. Annual amplitudes less than 2 km/s are observed over the southeast and the southwest of the European part of Russia and over the Central Siberia. In the winter and in the autumn speed of a wind above over mostly Russia, except, for a southern part of the Central Siberia, where the maximum of speed of a wind is necessary for warm months. The highest speeds of a wind over Yakutia and Transbaikalia are observed in April-May.

Wind energy can be used in many areas of Russia, including the Arkhangelsk, Astrakhan, Volgograd, Kaliningrad, Magadan, Novosibirsk, Perm, Rostov, Tyumen areas, Krasnodar, Krasnoyarsk, Seaside stole, Dagestan, Kalmykia and Karelia. The potential most part is necessary in territory, where population density below one person on square kilometer. (Bezrukih ed., 2007)

Thus, in many places of Russia wind energy can be used as an energy source for the small isolated consumers. In territory of subjects of the Russian Federation is probably building of wind parks of considerable power. Results of calculations of categories of potential of wind energy are brought in table 5.1.

Table 5.1. Estimations of wind energy resources in Russia and in its federal districts (Bezrukih ed., 2007)

| | Potential categories | | | | | |
|---|---|---|---|---|---|---|
| | Gross | | Technical | | Economic | |
| | TWh | m ton of coal equivalent | TWh | m ton of coal equivalent | TWh | m ton of coal equivalent |
| Russia, total | 2606635 | 886256 | 65190 | 22150 | 325.7 | 110.8 |
| Including districts: | | | | | | |
| The Central | 28717 | 9764 | 720 | 240 | 3.6 | 1.2 |
| The Northwest | 173034 | 58832 | 4330 | 1470 | 21.6 | 7.4 |
| The Southern | 70633 | 24015 | 1770 | 600 | 8.8 | 3 |
| The Privolzhsky | 94502 | 32131 | 2370 | 800 | 11.8 | 4 |
| The Ural | 646795 | 219910 | 16170 | 5500 | 80.8 | 27.5 |
| The Siberian | 605192 | 205765 | 15130 | 5140 | 75.6 | 25.7 |
| Far East | 987762 | 335839 | 24700 | 8400 | 123.5 | 42 |

In 2002 the electricity share produced by wind-driven electric power stations was only 5 MW.

In Russia it is created "Unified Power System (UPS)" completely to cover the areas, the demanding electric power. This system unites 70 power systems of the country, the largest hydroelectric power stations (> 300 MW) and thermal power stations (> 1 ' 000 MW). In 1992 25 power systems of regions had surplus of the energy, all the others had deficiency. For association and balancing of systems, for the purpose of avoidance of crash of all system, the joint-stock company has been created. The generated system can be used for transfer of the electric power from areas having high potential of a wind in areas plentifully occupied and demanding a lot of electricity. Also it is possible to use areas near mountains and reservoirs to make the general system steadier and stable. Therefore presence UPS both the western experience and researches are essential stimulus of development of wind-power engineering.

In 1989 after the decision of Ministerial council of the USSR all researches in the field of renewed energy sources have been united in the project "Ecologically Clean Energy". The given project included all projects of wind-power engineering – development of turbines by power 0.25 – 1.250 kW. But further projects of turbines with power 30 kW and 1.250 kW have been closed because of insufficient financing. In total it was planned to install wind-driven electric power stations total power approximately 175.000 MW. In due time the advanced organizations in the given branch were Raduga (Design Office), Energobalance-SoVENA, Vetroen and Yuzhnoe (both Science Production Associations), Hydroproject (Scientific Research Institute) and "Kirovskii zavod" in St. Petersburg. "Kirovskii zavod" projected the turbine power 250 kW, Hydroproject – since 1986, the turbine power 1000 kW, for the distant east. Now active remain only Vetroen (but now it is the Ukrainian company) and" JSC TMZ "(Tushino Engineering Works) which searched for buyers on turbine Raduga-1 with power 1.000 kW. Under statements JSC TMZ 11of all pre-production models of this turbine (one of them in Elstia (Kalmykia)) have been installed. Feature of the given project is possibility of turbines to work in a temperature span from-50 °C to +40°C. It is precisely known, that the turbine in Elstia is the worker till now, the destiny of other samples is unknown. All it means that these organizations cannot master even a part of huge potential of a wind power of Russia. The basic direction of works now should be applications of the western technologies to modern to the Russian realities. The main obstacle to realization of the given project is the unwillingness of the large companies to invest a means in "new" branch.

The obvious fact, that Russia possesses enormous Wind Energy Resource Potential because has the greatest territory from all countries on the Earth. However the greatest potential areas at coast of oceans and the seas, extensive steppes and mountains possess.

## 5.5. Existent and projected wind power plants in Russia

Now the percent of renewable energy in Russia of the total primary energy supply makes approximately 3.5 percent. If to exclude water-power engineering there it’s only 1.2 percent. (Russia in Global Affairs, 2008) If to speak about wind-power engineering now in territory of the Russian federation following objects are constructed and are maintained (see Figure 5.2 and table 5.2):

1. Kulikovskaya a wind power plant (the Kaliningrad area)

Power is 5.1 MW (20 windmills x 225 kW and 1 windmill x 600 kW).

The designer - Open Society "Yantarenergo".

The manufacturer - the Danish company «SEAS Energi Service A.S». (RUFO, 2007)

On July, 26th, 2002 in settlement Kulikovo of the Kaliningrad area opening of the largest in Russia wind power plants has taken place. A wind power plant in settlement Kulikovo - the first joint international project in the field of the wind-power engineering, carried out at support of the Russian Open Society "United Power Systems", administration of the Kaliningrad area, Ministry for the Power Generating Industry of the Russian Federation and the Ministry of ecology and power of Kingdom of Denmark. The wind power plant consists of 21 windmills of the Danish manufacture by total power 5.1 MW. Windmill operation is carried out without presence of attendants at the expense of full automation of productions. Start and a stop of windmills occur in automode, and the information on possible failures of the mechanism is transferred through system of cellular communication and onboard computers.

The beginning of the Russian-Danish cooperation in the field of wind-power engineering was in May, 1998 when according to the intergovernmental agreement between Ministry for the Power Generating Industry of the Russian Federation and the Ministry of ecology and power of Denmark in settlement Kulikovo of the Kaliningrad area the first windmill by power 0,6 MW has been established. Considering successful cooperation on realizations of the project of the first windmill, the party have shown desire to continue and expand teamwork.

On October, 10th, 1998 Open Societies "Yantarenergo" and the Danish company «SEAS Energi Service A.S» at support of the Danish Power Agency, have signed «the Agreement on intentions of mutually advantageous cooperation in erection in the Kaliningrad area of the Russian Federation of the first wind power plant power to 5 MW». As a result of long negotiations with the Danish party of Open Society "Yantarenergo" has received the equipment of windmills absolutely free of charge - under the grant of the government of Denmark.

In 2000 4 windmills everyone by power 225 kW have been established. In May - June, 2002 Kaliningrad power have established 16 more windmills on 225 kW. From the moment of start-up of the first windmill a wind power plant in settlement Kulikovo has produced and has released in a network of an electric power system of 5.5 million kWh. (RUFO, 2007)

2. Anadyrskaya wind power plant (Chukotka)

Power is 2.5 MW (Vyacheslav Sinyugin, 2005) (10 windmills x 250 kW). (Cleandex, 2008)

3. A wind power plant "Tyupkildy" (Bashkortostan)

Power is 2.2 MW. (Cleandex, 2008) (4 windmills x 550 kW) (Sokolsky A.,2007)

Manufacturers of windmills – Hanseatische AG. (Sokolsky A.,2007)

The produced electric power – 2 millions kWh/a. (RUFO, 2004)

The third-large wind-driven electric power station of Russia has been opened near to village Tyupkildy in 2001. The wind-driven electric power station is constructed Bashkir energy supplying by Open Society "Bashkirenergo" enterprise.

According to the chief of service of perspective development of Open Society "Bashkirenergo" object building has managed to the enterprise in 80 million rubles. Accumulation of experience in wind-power engineering area, and also search of possibilities of the further development of this segment of power generation became the project main task. Now the enterprise carries out research of mid-annual speeds of a wind on all territory of Bashkiria for what special installation recently has been bought. A research objective is definition of the most favorable places for placing of the subsequent wind-driven electric power stations. (RUFO, 2004)

4. Zapolyarnaya wind-diesel power plant (republic Komi)

Power is 1.5 MW (5 windmills x 250 kW and 1 windmill x 200 kW). (Expert RA, 1999)

The designer - «HydroOGK». (Dmitriy Prokofev, 2008)

Manufacturers of windmills - research-and-production association "Vetroen" and a production association "Uzhmash" (Ukraine). (Bezrukih & Bezrukih Jr., 2002)

The designed capacity - 4 MW. (Anna Kireeva, 2008)

5. Bering Island’s wind power plant (the Kamchatka territory)

Power is 1.2 MW. (NIIES, 2006)

The occurrence history on islands of this station is very unusual. Danish firm NEG Micon in memory of the fellow countryman, Vitus Bering buried on an island of Bering has given inhabitants of Aleutian area an unusual gift - a wind-driven electric power station. In 1996 it has started in operation. (Andrey Trofimov, 2008)

6. Kalmyk wind power plant (Kalmykia)

Power is 1 MW (1 windmill «Raduga-1» x 1 MW). (Michael Classon, 2007)

Produced electric power - 2.65 millions kWh/a. (Kavkazki uzel, 2007)

The designer - Samarahydroproject. (GmbH (dena), 2008)

Manufacturers of windmills - joint-stock company «Tushensky machine-building factory», joint-stock company "Electric power" and joint-stock company "Atommash". (Expert RA, 1999)

The investor - the Czech company «Falkon Capital». (Cleandex, 2008)

The designed capacity - 22 MW. (NIIES, 2006)

The Designed producing of electric power – 52.94 millions kWh/a. (General Energy System of South, 1999)

Open Society "HydroOGK" on December, 5th has entered into trial operation the windmill power 1 MW to Kalmykia. The windmill has been constructed for the civil-engineering design of the Kalmyk wind-driven electric power station. Its predicted annual development will be 2.65 millions kWh. The settlement utilization factor of maximum capacity of installation makes 30.2 % that is a high indicator for the European windmills. Mid-annual speed of a wind around a wind-driven electric power station is about 7,5 km/s. Preparation for trial operation of the windmill was spent by project modernization «Raduga-1», developed in Russia in the early nineties the last century.

For today annual power consumption in Kalmykia exceeds 550 million kWh, the load capacity during winter time reaches 90 MW and 80 MW in the summer. Thus in republic before wind-driven electric power station occurrence there were no generating objects, and requirements for the electric power completely became covered at the expense of overflows from the next regions.

HydroOGK plans to continue building of windmills in Kalmykia. By 2010 it is supposed to place in operation a wind-driven electric power station the general power 9

MW. Prospective investments into the project will make about 400 million rubles. (Andrey Trofimov, 2008)

7. Markinskaya wind power plant (the Rostov area)

Power is 0.3 MW. (NIIES, 2006)

The designer and the manufacturer - German firm Huzumer Shiftsvert with production association participation "Lenpodemtransmash" and associations "Sovena". (Bezrukih & Bezrukih Jr., 2002)

In 1996 under the joint Russian-German project in Tsimlyansky area of area the wind station Markinsky - an experimental wind-driven electric power station by power of 300 kW has been mounted.

Germany has free of charge given then 10 windmills, and Russia - all other equipment, buildings and wind-driven electric power station constructions. Company "Rosteploelectroproject" has executed the station equipment design. Cost of the electric power from a wind power plant after its start-up made nearby 1 ruble/kWh. For that time it was more expensive than energy of traditional power stations, but now when traditional energy has sharply risen in price, the electric power from a wind-driven electric power station became cheaper than other electricity rates for consumers.

The station occupies the space in 3 hectares and consists of 10 trellised 27-metre towers located in chessboard order with 12-metre blades which start to rotate already at speed of a wind in 4 km/s. The received energy is transferred in the general electrical network through the transformer plant and serves requirements of small settlement. This object became the working in Russia working and trial station on which long-term unique field experience of windmills is saved up and research works are spent. (Maria Bondarenko, 2009)

8. Murmanskaya wind power plant (Murmanskaya area)

Power is 0.2 MW [16] (1 windmill x 200 kW). (Sokolsky A.,2007)

The produced electric power is 553 kWh/a. (Anna Kireeva, Rashid Alimov, 2008)

Manufacturers of windmill – Wincon. (Sokolsky A.,2007)

Also it is necessary to consider about many small wind power plants established in territory of the country. They are very useful in the conditions of the big territorial extent. For an example we will consider, independent wind-diesel installation in village Krasnoe the Arkhangelsk area.

Village Krasnoe - the small settlement located on island Nikolsky in delta of the river Northern Dvina in 15 kilometers on the northwest from a city of Arkhangelsk. In village constantly lives nearby 30 persons, during the summer period the number of inhabitants considerably increases. Until recently electrosupply of this object was carried out at the expense of the diesel-generator by power 8 kW.

In 1997 under the project developed by experts «Intersolarcenter», in village Krasnoe the wind power plant by power 20 kW has been established. The wind power plant structure is resulted more low:

a) Windmills BWC-EXCEL power of 10 kW everyone - 2 pieces
b) Inverters single-phase power on 4.5 kW - 3 pieces
c) A storage battery in capacity 2100 Ah

Parallel work of a wind power plant and the diesel-generator was not provided. During the summer period the electricity production a windmill makes nearby 300 kWh in a month that provides economy of oil fuel more than 100 litters for the same period. The program of development of power supply of Northern regions provides to establish similar systems in 11 settlements on sea coast of the Arkhangelsk area.

Also in various development stages there are following projects:

1. Leningradskaya wind power plant (Leningrad region)

Power is 75 MW.
The business plan and the feasibility report are finished.

2. Baltic wind power plant (the Kaliningrad area)

Power is 50 MW.
The feasibility report is finished.

3. Yeyskaya wind power plant (Krasnodar territory)

Power is 50 MW (25 windmills x 2 MW).
The designer - “Vetropark Engineering” (part of NGO “Electrosfera”). [10]
The business plan is finished.

Deficiency of the electric power brakes development of the industry and investment activity of Yeysk area of Krasnodar territory. Therefore to solve a power supply problem, at Coast of Azov Sea of it decided to construct a complex of wind-driver power stations. For Yeysk with its strong winds the building of wind power plants is the optimum decision of a problem of shortage of power. The idea of creation of a wind power plant was offered by administration of Yeysk. (Roman Zaikin, 2007)

The complex for measurement of characteristics of a wind is established now in Yeysk. He allows studying a wind rose, to define their force, speed and a direction. It becomes that in a year on the basis of the received information to choose the best place for a wind-driver power station arrangement. (Virtual Eysk, 2007)

In second half of 2010 the Canadian company Greta Energy Inc. intends to start building of three power stations. It is the civil-engineering design of wind power plants first in Russia with power of industrial scale. Wind power plants it is planned to construct in settlements Shirochanka, Mirniy and Oktyabrsky. The area administration has allocated the ground areas for building of wind-driver power stations. The total area of the ground areas makes 700 hectares. Total adjusting power of wind power plants will make 50 MW. It is enough of it for satisfaction of requirement for the city in electric power which population reaches 200 thousand persons. (Virtual Eysk, 2009)

4. Maritime wind power plant (Primorye Territory)

Power is 30 MW.
The feasibility report is finished.

5. Sea wind power plant (Kareliya)

Power is 30 MW.

The feasibility report is finished.

6. Magadanskaya wind power plant (the Magadan area)

Power is 30 MW.

The feasibility report is finished.

7. Chujskaya wind power plant (Republic Altai)

Power is 24 MW.

The business plan is finished.

8. Ust-Kamchatskaya wind-diesel power plant (the Kamchatka area)

Power is 16 MW.

The business plan is finished.

9. Novikovskaya wind-diesel power plant (Republic Komi)

Power is 10 MW.

The business plan is finished.

10. Dagestanskaya wind power plant (Dagestan)

Power is 6 MW.

The business plan is finished.

11. Novorossiskaya wind power plant (Krasnodar territory)

Power is 5 MW.

The feasibility report is finished.

12. Anapskaya wind power plant (Krasnodar territory)

Power is 5 MW.

The business plan is finished.

13. Valaamskaya wind power plant (Kareliya)

Power is 4 MW. (Sodeystvie-XXI century, 2009)

The feasibility report is finished.

14. Wind power station on Russky Island (Primorski Krai). (Itar-Tass, 2009)

Table 5.2. Existent wind power plant in Russia.

| N | Name | Power (MW) |
|---|---|---|
| 1 | Kulikovskaya wind power plant | 5.1 |
| 2 | Anadyrskaya wind power plant | 2.5 |
| 3 | A wind power plant "Tyupkildy | 2.2 |
| 4 | Zapolyarnaya wind-diesel power plant | 1.5 |
| 5 | Bering Island’s wind power plant | 1.2 |
| 6 | Kalmyk wind power plant | 1.0 |
| 7 | Markinskaya wind power plant | 0.3 |
| 8 | Murmanskaya wind power plant | 0.2 |
| 9 | To 1500 small windmills power of 0.1-30 kW | 0.5 |
| Total | | 14.5 |

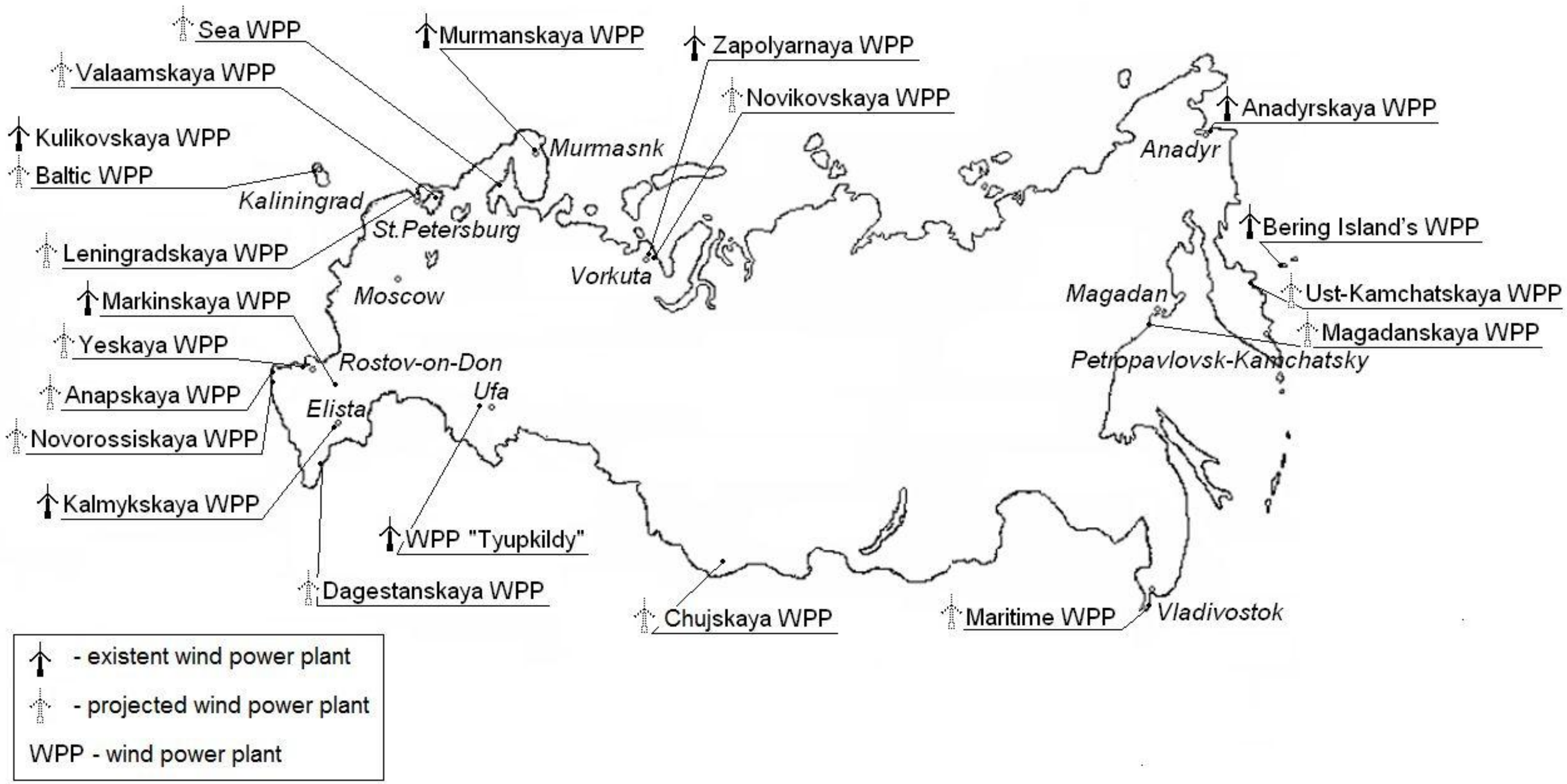



Figure 5.2. Location of wind power plants in Russia

## 5.6. Stimuli and barriers

There is a number of stimulus and barriers on development in Russia wind-power engineering. The following concerns stimulus:

- The well enough investigated and described distribution of a potential of a wind power on territory of Russia;

- Unique system Unified Power System (UPS)

- Unstable deliveries of coal and petroleum for thermal power stations, and also bad reputation of atomic engineering, after events in Chernobyl in 1986;

- A high fuel cost of thermal power stations in the north of the Russian federation, because of difficult delivery;

- Big local capacities for manufacture of components;

It is possible to carry the following to barriers:

- The most important barrier is high enough availability of inexpensive fuel in Russia;

- Presence of unsuccessful experience creation of wind power stations before disorder of the USSR;

- Non-uniform distribution of areas suitable for installation of wind power stations and areas which consume a lot of electric power;

- Small availability of foreign loans and investments because an unstable political situation frightens the foreign companies;

- Wrong representation about a cost ratio of the electric power received by wind power stations (accounts were based on undercharges of fuel, and the overestimated prices for projects of wind power stations);

- Very low level of understanding of ecological benefit from wind power stations. As well as low level of social ecological responsibility of the population.

## 6. CONCLUSION

Russia - the country with huge potential of a wind power which only on rough estimates makes 65166 TWh. Thus to areas with the strongest wind, and according to the greatest potential coastal areas, and also areas of steppes and mountains are: coasts of Silent and Arctic oceans, foothill and mountain areas of Caucasus, Urals Mountains, Altai, Sayan mountains, coasts of Kola peninsula, Primorski Krai, the south of Kamchatka, the Caspian and Azov coasts etc.

Unfortunately, this potential practically is not used owing to the certain economic and political reasons:

- ✓ Insufficient legislative base;
- ✓ Unstable economy and absence of capital foreign investments;
- ✓ Inconstancy of a wind power and complexity inclusion of wind power plants in uniform system of delivery of the electric power;
- ✓ The general national lack of information.

At huge total potential, it is used only 14.5 MW, that makes only a small part from possible use. Thus all operating time and advantages in the given branch, received to disorder of the USSR, are irrevocably lost. And now Russia does not take the lead places on development of a wind power and innovations in the given area. But, despite obviously slowed down rates of creation and development of wind power plants, in comparison with other countries, to Russia many projects, including continue to develop at financial and technological support of the western partners.

In this connection the wind-power engineering future in Russia sees in optimistically tones: projects of new powerful wind power plants are developed, the western technologies are involved and certain legislative steps on wind-power engineering advancement, as future power become. Especially for remote areas, such as the Far North or the Far East.

The main goal of this thesis was to provide a reader with basic information about technical wind energy potential and its usage in Russia. As a result in work the full estimation of a wind energy potential of Russia and the analysis of its use in the most perspective regions is given. In the work beginning have been given concepts about a felt mode are necessary. The separate chapter is devoted methods of an estimation of wind resources (total, technical and economic). Results of an estimation of a wind energy potential according to the considered technique also are brought in work. The separate chapter is devoted consideration modern windmills, reformative kinetic energy of a wind in electric energy. Examples of use of wind energy potential are presented in work as the description of working and projected wind-driven electric power stations. The special attention is given the Russian specificity of development of wind-power engineering. Work is supplied by detailed cards of a wind mode and wind power plants locations, giving evident representation about technical wind energy potential and its use in Russia. The detailed estimation of a technical wind energy potential for each subject of Federation is given in the appendix and is the important part of work.

# REFERENCES


| | |
|---|---|
| (Ageev, 2004) | Ageev V., 2004. *Курс лекций. Нетрадиционные и возобновляемые источники энергии*. [*Course of lectures. Untraditional and renewable energy sources*]. Mordovia: The Mordovian state university of H. P. Ogaryov. Mechanics and power institute. Department of heat energy systems. Available at: http://dhes.ime.mrsu.ru. [Accessed 22nd December 2005]. (Available in Russian) |
| (Andrey Trofimov, 2008) | Andrey Trofimov, 2008. *Как потомки Беринга помогают снижать тарифы на Камчатке.* [*As Bering's descendants help to reduce tariffs for Kamchatka*]. [Online] Petropavlovsk-Kamchatsky: EnergyLand. Available at: http://www.energyland.info/analitic-show-9676 [Accessed 27th Mart 2008]. (Available in Russian) |
| (Anna Kireeva, 2008) | Anna Kireeva, 2008. *Regional governments and private businesses in Russia are aiming for wind energy.* [Online] Bellona. Available at: http://www.bellona.org/articles/articles_2008/strivingfor_wind [Accessed 15th September 2008]. |
| (Anna Kireeva, Rashid Alimov, 2008) | Anna Kireeva, Rashid Alimov, 2008. *After years of research, Murmansk plugs wind power into its grid.* [Online] Bellona. Available at: http://www.bellona.org/articles/articles_2008/murmanks_windmills [Accessed 2nd April 2008]. |
| (Betz, 1966) | Betz, A., 1966. *Introduction to the Theory of Flow Machines.* Translated from German by Randall, D. G. Oxford: Pergamon Press. |

| | |
|---|---|
| (Bezrukih & Bezrukih Jr., 2002) | Bezrukih P.P., Bezrukih P.P (Jr.), 2002. Что может дать энергия ветра. Ответы на 33 вопроса. [That the wind power can give. Answers to 33 questions] . Moscow: IAC Energia. (Available in Russian) |
| (Bezrukih ed., 2007) | Bezrukih P. P. ed., 2007. Справочник – каталог. *Справочник ресурсов возобновляемых источников энергии России.* [Handbook – catalogue. *The directory of resources of renewable energy sources of Russia*]. –Moscow: IAC Energia. (Available in Russian) |
| (Boyle ed., 2004) | Boyle G. ed., 2004. *Renewable energy. Power for a sustainable future*. 2nd edition. Oxford: Oxford University Press. |
| (Bryzgunov Igor, 2006) | Bryzgunov Igor, 2006. *50 mw wind farm on the azov seashore.* [Online] Vetropark Engineering Inc. Available at: http://www.rawi.ru/eng/news/p-eisk.php [Accessed 14th December 2006]. |
| (Cleandex, 2008) | Information-analytic agency Cleandex, 2008. *Ветряная энергетика в России. Итоги 2007 года.* [*Wind energetics in Russia. Resume of 2007*]. [Online] Cleandex. Available at: http://www.cleandex.ru/articles/2008/06/25/wind-energy-russia [Accessed 25th June 2008]. (Available in Russian) |
| (De Renzo ed., 1979) | De Renzo, D.J. ed., 1979. *Wind power. Recent Development*. United States of America: Noyes Data Corporation. |
| (Dmitriy Prokofev, 2008) | Dmitriy Prokofev, 2008. *Первую ветроэнергетическую установку запустят в Калмыкии.* [*First windmill will be started in Kalmikiya*] [Online] Journal “Profession is director”. |

| | |
|---|---|
| | Available at: http://prof-director.ru/index.php?s=2010+2004+400 [Accessed 15th February 2008]. (Available in Russian) |
| (Elistratov & Kuznetsov, 2004) | Elistratov V. V., Kuznetsov M. V. 2004. *Теоретические основы нетрадиционной и возобновляемой энергетики. Часть 1. Определение ветроэнергетических ресурсов региона. Учебное пособие.* [*Theoretical bases of untraditional and renewable energy. Part 1. Determination of wind energy region resources. The manual*]. Saint-Petersburg: Saint-Petersburg State Polytechnical University Press. (Available in Russian) |
| (Elistratov, 2008) | Elistratov V. V. 2008. Использование возобновляемой энергетики. [Using of renewable energy]. Saint-Petersburg: Saint-Petersburg State Polytechnical University Press. (Available in Russian) |
| (Energy, 2009) | *"Energy Saving Now!" journal*, 2009. [Online] Available at: http://deppenschmidt.wordpress.com/2009/02/11/energy-saving-now/. [Accessed 11th February 2009]. |
| (ENIN, 2002) | Krzhizhanovsky Power Engineering Institute (ENIN), 2002. *Russia Renewable Energy Country Profile*. Primary Country Consultant. |
| (Expert RA, 1999) | Rating agency "Expert RA", 1999. *Нетрадиционная энергетика.* [*Untraditional energetics*]. [Online] Moscow: "Expert RA". Available at: http://www.concurs.org/tag/ves [Accessed 27th Mart 1999]. (Available in Russian) |
| (General Energy System of South, | General Energy System of South, 1999. *Калмыцкая ВЭС.* [*Kalmyk wind power plant*]. [Online] General Energy System |

| | |
|---|---|
| 1999) | of South Inc. Available at: http://www.yug.so-ups.ru/Page.aspx?IdP=91 [Accessed 27th January 2009]. (Available in Russian) |
| (GmbH (dena), 2008) | Deutsche Energie-Agentur GmbH (dena), 2008. *Калмыцкая ВЭС получила первые ветроустановки по 1 МВт.* [*Kalmyk wind power plant gave first windmill with power 1 MW*]. [Online] Moscow: RUFO. Available at: http://www.energieforum.ru/ru/archiv_novostej/kalmyckaja_vyes_poluchila_pervye_vetroustanovki_po_1_mvt_460.html [Accessed 26th June 2008]. (Available in Russian) |
| (Itar-Tass, 2009) | Itar-Tass, 2009. *Russia to build wind farm on Russky island by APEC summit-2012.* [Online] Russian agency for support of small and medium business. Available at: http://www.siora.ru/en/node/10407 [Accessed 23rd April 2009]. |
| (Johnson, 2009) | Johnson C., 2009.*Practical Wind Generated Electricity.* [Online]. Available at: http://mb-soft.com/public/wind.html [Accessed 30th April 2009] |
| (Kargiev, et al., 2001) | Kargiev V. M., Martirosov S. N., Murugov V. P., Pinov A. B., Sokolsky A. K., Haritonov V. P. 2001. *Ветроэнергетика. Руководство по применению ветроустановок малой и средней мощности*. [*Wind-power engineering. An application guide of windmills of small and average power*]. Moscow: Intersolarcenter. [Online]. Available at: http://www.intersolar.ru/wind. [Accessed 2nd March 2007]. (Available in Russian and English) |
| (Kavkazki uzel, 2007) | *"Kavkazki uzel" journal*, 2007. *В Калмыкии вводят в строй первую ветроэнергетическую установку.* [*First windmills is installing in Kalmyk wind power plant*]. [Online] Kavkazki |

uzel. Available at: http://armenia.kavkaz-uzel.ru/articles/128412 [Accessed 05th December 2007]. (Available in Russian)

(Krugosvet, 2009) *Кругосвет*. *Онлайн энциклопедия*. [Krugosvet. Online encyclopedia]. 2009. Available online: http://www.krugosvet.ru/enc/nauka_i_tehnika/tehnologiya_i_promyshlennost/VETRODVIGATEL.html [Accessed 04th April 2009]. (Available in Russian)

(Maria Bondarenko, 2009) Maria Bondarenko, 2009. *На Дону не ломают копья.* [*At the Don doesn't break the spears*]. [Online] Rostov-on-Don: NG-Energy. Available at: http://www.ng.ru/energy/2009-01-13/11_don.html [Accessed 13th January 2009]. (Available in Russian)

(Michael Classon, 2007) Michael Classon, 2007. *ГидроОГК реанимирует Калмыцкую ВЭС.* [*HygroOGK resuscitates Kalmyk wind power plant*]. [Online] Moscow: BusinessTime. Available at: http://www.worldenergy.ru/doc_24_38_1204.html [Accessed 05th December 2007]. (Available in Russian)

(Nicolaev, et al., 2008) Nikolaev V. G., Ganaga S.V., Kudryashov Y. I. 2008. *Национальный Кадастр ветроэнергетических ресурсов России и методические основы их определения.* [*National Cadastre wind energy resources of Russia and methodical bases of their definition*]. Moscow: Atmograph. (Available in Russian)

(NIIES, 2006) Public corporation "NIIES", 2006. *Ветроэнергетика: опыт и перспективы.* [*Wind-power engineering: experience and prospect*]. [Online] Rosteplo. Available at: http://www.rosteplo.ru/Tech_stat/stat_shablon.php?id=690

[Accessed 18th September 2006]. (Available in Russian)

(NYSERDA, 2005) NYSERDA, 2005. *Wind Turbine Technology Overview*. New York: NYS Energy Research & Development Authority. Available at**:** www.powernaturally.org. [Accessed 07th October 2005].

(Roman Zaikin, 2007) Roman Zaikin, 2007. *Ветер принесет инвесторов.* [*Wind bring investors*]. [Online] Krasnodar: Delovaya gazeta Inc. Available at: http://www.dgazeta.ru/article/717 [Accessed 4th December 2007]. (Available in Russian)

(RUFO, 2004) RUFO, 2004. Ветропарк „Тюпкильды“, Башкирия. [*Wind power plant "Tyupkildy"*]. [Online] Moscow: RUFO. Available at: http://www.energieforum.ru/ru/vosobnowljaemyje_isstotschniki/wetrjanaja_energetika/projekty_rossija/vetropark_„tupkil'dy“_bashkirija_9.html [Accessed 19th July 2004]. (Available in Russian)

(RUFO, 2007) RUFO, 2007. *Ветропарк Куликово.* [*Kulikovskaya wind power plant*]. [Online] Moscow: RUFO. Available at: http://www.energieforum.ru/prjru_windenerg/morenews.php?iditem=2&lang=ru [Accessed 21st October 2007]. (Available in Russian)

(Russia in Global Affairs, 2008) *"Russia in Global Affairs" journal*, 2008. *Renewable Energy in Russia's Future.* [Online] Russia in Global Affairs Inc. Available at: http://eng.globalaffairs.ru/numbers/24/1219.html [Accessed 9th August 2008].

(Sodeystvie-XXI century, 2009) Fund of innovation and economic technologies "Sodeystvie-XXI century", 2009. *ГидроОГК строит*

| | |
|---|---|
| | *ветроэлектростанции.* [*HygroOGK builds wind power plants*]. [Online] Rostov-on-Don: "Sodeystvie-XXI century". Available at: http://www.concurs.org/tag/ves [Accessed 07th April 2009]. (Available in Russian) |
| (Sokolsky A.,2007) | Sokolsky A.,2007. *Ветроэнергетика в России : вчера, сегодня, завтра.* [*Wind energetics in Russia: yesterday, today, tomorrow*]. [Online] Enecsis. Available at: http://www.enecsis.ru/sokolsky.htm [Accessed 7th May 2007]. (Available in Russian) |
| (Stiebler, 2008) | Stiebler M., 2008 *Wind Energy Systems for Electric Power Generation*. *Green Energy and Technology*. Berlin: Springer-Verlag Berlin Heidelberg. |
| (Virtual Eysk, 2007) | *"Virtual Eysk" journa*l, 2007. *На побережье Азовского моря появится ветроизмерительный комплекс.* [*On the coast of the Azov Sea will set complex for measurement of characteristics of a wind*]. [Online] Eysk: Virtual Eysk Inc. Available at: http://eysk.net/news/20071206204.html [Accessed 6th December 2007]. (Available in Russian) |
| (Virtual Eysk, 2009) | *"Virtual Eysk" journal*, 2009. *В 2010 году в Краснодарском крае начнется строительство ветроэлектростанции..* [*Construction of wind power will begin in the Krasnodar territory in 2010*]. [Online] Eysk: Virtual Eysk Inc. Available at: http://eysk.net/news/20090415310.html [Accessed 15th April 2009]. (Available in Russian) |
| (Vyacheslav Sinyugin, 2005) | Vyacheslav Sinyugin, 2005. *Prospects for the power industry in Russia.* [Online] The Conference de Montreal Press. Available at: http://www.conferencedemontreal.com/fileadmin/images/salle_ |

presse/Vyacheslav%20Y%20Sinyugin%20-%20Power%20Industry%20in%20Russia.pdf [Accessed 31st May 2005].

(Wikipedia, 2005) *Wikipedia. The free encyclopedia*. 2005. Wikimedia Foundation, Inc. [WebSite] Available at: http://en.wikipedia.org/wiki/File:Molen_Wageningen_de_Vlijt_Windmill.jpg. [Accessed 16th October 2005].

(Wikipedia, 2009a) *Wikipedia. The free encyclopedia*. 2009. Wikimedia Foundation, Inc. [WebSite] Available at: http://en.wikipedia.org/wiki/Russia. [Accessed 8th May 2009].

(Wikipedia, 2009b) *Wikipedia. The free encyclopedia*. 2009. Wikimedia Foundation, Inc. [WebSite] Available at: http://en.wikipedia.org/wiki/Inter_RAO_UES. [Accessed 12nd May 2009].

(Wikipedia, 2009c) Wikipedia, 2009. *Ветроэнергетика.* [*Wind energetics*]. [Online] Wikimedia Foundation, Inc. Available at: http://ru.wikipedia.org/wiki/Ветроэнергетика [Accessed 15th May 2009]. (Available in Russian)

Appendix I, 1

**General characteristics of Russia regions. (Bezrukih ed., 2007)**

| The name of the subject of the Russian Federation | The main city | The area. thousand km$^2$ | The population. thousand foreheads | Specific gross potential of a wind power. kWh/m$^2$ in a year |
|---|---|---|---|---|
| 1. The central federal district (the centre – Moscow) | | | | |
| In total | Moscow | 652.8 | 37356.4 | |
| The Belgorod oblast | Belgorod | 27.1 | 1511.4 | 44 |
| Bryansk oblast | Bryansk | 34.9 | 1331.4 | 22 |
| The Vladimir oblast | Vladimir | 29.0 | 1472.6 | 22 |
| The Voronezh oblast | Voronezh | 52.4 | 2313.6 | 22 |
| The Ivanovo oblast | Ivanovo | 23.9 | 1099.9 | 44 |
| The Kaluga oblast | Kaluga | 29.9 | 1014.2 | 66 |
| Kostroma oblast | Kostroma | 60.1 | 708.9 | 66 |
| Kursk oblast | Kursk | 29.8 | 1183.8 | 44 |
| Lipetsk oblast | Lipetsk | 24.1 | 1180.8 | 66 |
| The Moscow oblast | Moscow | 46.1 | 6628.1 | 22 |
| The Orel oblast | Orel | 24.7 | 833.7 | 44 |
| The Ryazan oblast | Ryazan | 39.6 | 1182.0 | 66 |
| Smolensk oblast | Smolensk | 49.8 | 1005.9 | 90 |
| The Tambov oblast | Tambov | 34.3 | 1130.3 | 44 |
| The Tver oblast | Tver | 84.1 | 1406.5 | 22 |
| The Tula oblast | Tula | 25.7 | 1599.8 | 66 |
| The Yaroslavl oblast | Yaroslavl | 36.4 | 1327.8 | 22 |
| Moscow | Moscow | 0.9 | 10425.1 | 22 |
| 2. Northwest federal district (the centre – St.-Petersburg) | | | | |
| In total | | 1677.9 | 13628.3 | |

Appendix I, 2

| | | | | |
|---|---|---|---|---|
| Republic of Karelia | Petrozavodsk | 172.4 | 697.5 | 44 |
| Republic of Komi | Syktyvkar | 415.9 | 985.0 | 66 |
| The Arkhangelsk oblast | Arkhangelsk | 410.7 | 1249.3 | 66 |
| The Vologda oblast | Vologda | 145.7 | 1235.4 | 66 |
| The Kaliningrad oblast | Kaliningrad | 15.1 | 939.9 | 33 |
| Leningrad oblast | St.-Petersburg | 84.6 | 1643.9 | 33 |
| Murmansk oblast | Murmansk | 144.9 | 864.6 | 310 |
| The Novgorod oblast | Novgorod | 55.3 | 665.4 | 110 |
| The Pskov oblast | Pskov | 55.3 | 724.6 | 66 |
| St.-Petersburg | St.-Petersburg | 1.3 | 4580.6 | 33 |
| Nenets Autonomous District | Naryan-Mar | 176.7 | 42.0 | 245 |
| 3. Southern federal district (the centre – Rostov-on-Don) | | | | |
| In total | | 589.2 | 22790.2 | |
| Republic of Adyghe | Maikop | 7.6 | 442.7 | 245 |
| Republic of Dagestan | Makhachkala | 50.3 | 2640.9 | 420 |
| Republic of Ingushetia | Nazran | 4.5 | 486.9 | 245 |
| The Kabardino-Balkaria Republic | Nalchik | 12.5 | 894.0 | 90 |
| Republic of Kalmykia | Elista | 75.9 | 288.7 | 110 |
| Karachai-Cherkess Republic | Cherkessk | 14.1 | 431.5 | 90 |
| North Ossetian Republic | Vladikavkaz | 8.0 | 702.3 | 90 |
| The Chechen Republic | Grozny | 14.8 | 1162.8 | 90 |
| Krasnodar Territory | Krasnodar | 76.0 | 5096.6 | 66 |
| Stavropol Territory | Stavropol | 66.5 | 2710.3 | 175 |
| The Astrakhan oblast | Astrakhan | 44.1 | 994.2 | 66 |
| The Volgograd oblast | Volgograd | 114.1 | 2635.6 | 66 |
| The Rostov oblast | Rostov-on-Don | 100.8 | 4303.5 | 66 |

Appendix I, 3

| | | | | |
|---|---|---|---|---|
| 4. Privolzhsky federal district (the centre – Nizhni Novgorod) | | | | |
| In total | | 1035.9 | 30511.2 | |
| Republic of Bashkortostan | Ufa | 143.6 | 4063 | 44 |
| Republic of Mariy-El | Yoshkar-Ola | 23.2 | 711.5 | 175 |
| Republic of Mordovia | Saransk | 26.2 | 856.8 | 175 |
| Republic of Tatarstan | Kazan | 68 | 3761.5 | 110 |
| Udmurt Republic | Izhevsk | 42.1 | 1544.4 | 88 |
| The Chuvash Republic | Cheboksary | 18.3 | 1292.2 | 660 |
| The Kirov oblast | Kirov | 120.8 | 1442.9 | 44 |
| The Nizhniy Novgorod oblast | Nizhni Novgorod | 74.8 | 3411.0 | 22 |
| The Orenburg oblast | Orenburg | 124 | 2137.8 | 110 |
| The Penza oblast | Penza | 43.2 | 1407.9 | 245 |
| The Perm oblast | Perm | 127.7 | 2597.8 | 22 |
| The Samara oblast | Samara | 53.6 | 3189.0 | 66 |
| The Saratov oblast | Saratov | 100.2 | 2608.3 | 110 |
| The Ulyanovsk oblast | Ulyanovsk | 37.3 | 1335.9 | 110 |
| Komi-Permyak Autonomous District | Kudymkar | 32.9 | 150.4 | 110 |
| 5. The Ural federal district (the centre – Ekaterinburg) | | | | |
| In total | | 1788.9 | 12244.2 | |
| Kurgan oblast | Kurgan | 71.0 | 979.9 | 88 |
| Sverdlovsk oblast | Ekaterinburg | 194.8 | 4409.7 | 245 |
| The Tyumen oblast | Tyumen | 161.8 | 1845.1 | 44 |
| The Chelyabinsk oblast | Chelyabinsk | 87.9 | 3531.3 | 375 |
| Khanty-Mansi Autonomous District | Khanty-Mansiysk | 523.1 | 1478.2 | 110 |
| Yamal-Nenets Autonomous District | Salekhard | 750.3 | 530.6 | 660 |

Appendix I, 4

| | | | | |
|---|---|---|---|---|
| 6. The Siberian federal district (the centre – Novosibirsk) | | | | |
| In total | | 5114.8 | 19676.2 | |
| Republic of Altai | Gorno-Altaisk | 92.6 | 204.4 | 245 |
| Republic of Buryatia | The Ulan-Ude | 351.3 | 963.3 | 90 |
| Republic of Tuva | Kyzyl | 170.5 | 308.5 | 245 |
| Khakass Republic | Abakan | 61.9 | 538.2 | 90 |
| Altay Territory | Barnaul | 169.1 | 2543.3 | |
| Krasnoyarsk region | Krasnoyarsk | 710.0 | 2867.2 | 90 |
| Irkutsk oblast | Irkutsk | 745.5 | 2393.1 | 90 |
| The Kemerovo oblast | Kemerovo | 95.5 | 2838.5 | 420 |
| Novosibirsk oblast | Novosibirsk | 178.2 | 2649.9 | 110 |
| Omsk oblast | Omsk | 139.7 | 2034.6 | 110 |
| Tomsk oblast | Tomsk | 316.9 | 1034.1 | 22 |
| The Chita oblast | Chita | 412.5 | 1054.0 | 90 |
| Agin-Buryat Autonomous District | Agin settlement | 19.0 | 74.2 | 245 |
| Taymyr (Dolgan-Nenets) Autonomous District | Dudinka | 862.1 | 389.9 | 245 |
| Ust-Ordynsk Buryat Autonomous District | Ust-Ordynsk settlement | 22.4 | 133.9 | 90 |
| Evenki Autonomous District | Tura | 767.6 | 17.3 | 22 |
| 7. Far East federal district (the centre – Khabarovsk) | | | | |
| In total | | 6179.9 | 6546.9 | |
| Republic of Sakha | Yakutsk | 3103.2 | 949.9 | 90 |
| Primorye Territory | Vladivostok | 165.9 | 2019.5 | 420 |
| Khabarovsk Territory | Khabarovsk | 788.6 | 1412.3 | 180 |
| The Amur region | Blagoveshchensk | 363.7 | 881.1 | 22 |
| The Kamchatka oblast | Petropavlovsk-Kamchatka | 170.8 | 3260.5 | 660 |

Appendix I, 5

| | | | | |
|---|---|---|---|---|
| The Magadan oblast | Magadan | 461.4 | 171.6 | 310 |
| The Sakhalin oblast | South-Sakhalinsk | 87.1 | 526.2 | 130 |
| Jewish Autonomous District | Birobidzhan | 36. 0 | 186.5 | 90 |
| Koryak Autonomous District | Palana | 301.5 | 23.2 | 370 |
| The Chukchi Autonomous District | Anadyr | 737.7 | 50.5 | 145 |

Appendix II, 1

**Estimations of resources of wind energy on subjects. (Adapted from: Bezrukih, 2008)**

| Federal district | Gross | | Technical | | Economic | |
|---|---|---|---|---|---|---|
| | TWh | m ton of coal equivalent | TWh | m ton of coal equivalent | TWh | m ton of coal equivalent |
| 1. The central federal district | | | | | | |
| In total | 28717 | 9764 | 716.5 | 243.97 | 3.622 | 1.2237 |
| Including: | | | | | | |
| The Belgorod oblast | 1193 | 405 | 30 | 10.2 | 0.15 | 0.051 |
| Bryansk oblast | 768 | 261 | 19 | 6.5 | 0.1 | 0.034 |
| The Vladimir oblast | 638 | 217 | 16 | 5.4 | 0.08 | 0.027 |
| The Voronezh oblast | 1153 | 392 | 29 | 9.8 | 0.15 | 0.051 |
| The Ivanovo oblast | 1052 | 358 | 26 | 8.9 | 0.13 | 0.044 |
| The Kaluga oblast | 1974 | 671 | 49 | 16.8 | 0.25 | 0.084 |
| Kostroma oblast | 3967 | 1349 | 99 | 33.7 | 0.5 | 0.169 |
| Kursk oblast | 1311 | 446 | 33 | 11.2 | 0.17 | 0.056 |
| Lipetsk oblast | 1591 | 541 | 40 | 13.5 | 0.2 | 0.068 |
| The Moscow oblast | 1014 | 345 | 25 | 8.6 | 0.13 | 0.043 |

| | | | | | | |
|---|---|---|---|---|---|---|
| The Orel oblast | 1087 | 370 | 27 | 9.2 | 0.14 | 0.046 |
| The Ryazan oblast | 2614 | 889 | 65 | 22.2 | 0.33 | 0.111 |
| Smolensk oblast | 4482 | 1524 | 112 | 38.1 | 0.56 | 0.19 |
| The Tambov oblast | 1509 | 513 | 38 | 12.8 | 0.19 | 0.064 |
| The Tver oblast | 1850 | 629 | 46 | 15.7 | 0.23 | 0.079 |
| The Tula oblast | 1696 | 577 | 42 | 14.4 | 0.21 | 0.072 |
| The Yaroslavl oblast | 801 | 272 | 20 | 6.8 | 0.1 | 0.034 |
| Moscow | 20 | 6,7 | 0.5 | 0.17 | 0.002 | 0.0007 |
| 2. Northwest federal district | | | | | | |
| In total | 173034 | 58832 | 4326 | 1470.67 | 21.585 | 7.3547 |
| Including: | | | | | | |
| Republic of Karelia | 7586 | 2579 | 190 | 64.5 | 0.95 | 0.322 |
| Republic of Komi | 27449 | 9333 | 686 | 233.3 | 3.4 | 1.167 |
| The Arkhangelsk oblast | 27106 | 9216 | 678 | 230.4 | 3.4 | 1.152 |
| The Vologda oblast | 9616 | 3270 | 240 | 81.7 | 1.2 | 0.409 |
| The Kaliningrad oblast | 498 | 169 | 13 | 4.2 | 0.06 | 0.021 |
| Leningrad oblast | 2792 | 949 | 70 | 23.7 | 0.35 | 0.119 |
| Murmansk oblast | 44919 | 15273 | 1123 | 381.8 | 5.6 | 1.909 |

Appendix II, 3

| | | | | | | |
|---|---|---|---|---|---|---|
| The Novgorod oblast | 6083 | 2068 | 152 | 51.7 | 0.76 | 0.259 |
| The Pskov oblast | 3650 | 1241 | 91 | 31 | 0.46 | 0.155 |
| St.-Petersburg | 43 | 15 | 1 | 0.37 | 0.005 | 0.0017 |
| Nenets Autonomous District | 43292 | 14719 | 1082 | 368 | 5.4 | 1.84 |
| 3. Southern federal district | | | | | | |
| In total | 70633 | 24015 | 1766 | 600.4 | 8.83 | 3.004 |
| Including: | | | | | | |
| Republic of Adyghe | 1862 | 633 | 47 | 15.8 | 0.23 | 0.079 |
| Republic of Dagestan | 21126 | 7183 | 528 | 179.6 | 2.64 | 0.898 |
| Republic of Ingushetia | 1103 | 375 | 28 | 9.4 | 0.14 | 0.047 |
| The Kabardino-Balkaria Republic | 1125 | 383 | 28 | 9.6 | 0.14 | 0.048 |
| Republic of Kalmykia | 8349 | 2839 | 209 | 71 | 1 | 0.355 |
| Karachai-Cherkess Republic | 1269 | 432 | 32 | 10.8 | 0.16 | 0.054 |
| North Ossetian Republic | 720 | 245 | 18 | 6.1 | 0.09 | 0.031 |
| The Chechen Republic | 1332 | 453 | 33 | 11.3 | 0.17 | 0.057 |

Appendix II, 4

| | | | | | | |
|---|---|---|---|---|---|---|
| Krasnodar Territory | 5016 | 1705 | 125 | 42.6 | 0.63 | 0.213 |
| Stavropol Territory | 11638 | 3957 | 291 | 98.9 | 1.5 | 0.495 |
| The Astrakhan oblast | 2911 | 990 | 73 | 24.7 | 0.36 | 0.124 |
| The Volgograd oblast | 7531 | 2560 | 188 | 64 | 0.94 | 0.32 |
| The Rostov oblast | 6653 | 2262 | 166 | 56.6 | 0.83 | 0.283 |
| 4. Privolzhsky federal district | | | | | | |
| In total | 94502 | 32131 | 2365 | 803.5 | 11.77 | 4.016 |
| Including: | | | | | | |
| Republic of Bashkortostan | 6318 | 1380 | 158 | 53.7 | 0.8 | 0.269 |
| Republic of Mariy-El | 4060 | 1559 | 102 | 34.5 | 0.5 | 0.173 |
| Republic of Mordovia | 4585 | 2543 | 115 | 39 | 0.6 | 0.195 |
| Republic of Tatarstan | 7480 | 1260 | 187 | 63.6 | 0.9 | 0.318 |
| Udmurt Republic | 3705 | 4107 | 93 | 31.5 | 0.46 | 0.157 |
| The Chuvash Republic | 12078 | 1807 | 302 | 102.7 | 1.5 | 0.513 |
| The Kirov oblast | 5315 | 560 | 133 | 45.2 | 0.66 | 0.226 |
| The Nizhniy Novgorod oblast | 1646 | 4638 | 41 | 14 | 0.2 | 0.07 |
| The Orenburg oblast | 13640 | 3599 | 341 | 115.9 | 1.7 | 0.58 |

Appendix II, 5

| | | | | | | |
|---|---|---|---|---|---|---|
| The Penza oblast | 10584 | 955 | 265 | 90 | 1.3 | 0.45 |
| The Perm oblast | 2809 | 1203 | 70 | 23.9 | 0.35 | 0.119 |
| The Samara oblast | 3538 | 245 | 88 | 30.1 | 0.44 | 0.15 |
| The Saratov oblast | 11022 | 3748 | 276 | 93.7 | 1.4 | 0.468 |
| The Ulyanovsk oblast | 4103 | 1395 | 103 | 34.9 | 0.51 | 0.174 |
| Komi-Permyak Autonomous District | 3619 | 1231 | 91 | 30.8 | 0.45 | 0.154 |
| 5. The Ural federal district | | | | | | |
| In total | 646795 | 219910 | 16170.2 | 5497.8 | 80.9 | 27.4 |
| Including: | | | | | | |
| Kurgan oblast | 6248 | 2124 | 156.2 | 53.1 | 0.8 | 0.3 |
| Sverdlovsk oblast | 47726 | 16227 | 1193 | 405.7 | 6 | 2 |
| The Tyumen oblast | 7119 | 2421 | 178 | 60.5 | 0.9 | 0.3 |
| The Chelyabinsk oblast | 32963 | 11207 | 824 | 280.2 | 4.1 | 1.4 |
| Khanty-Mansi Autonomous District | 57541 | 19564 | 1439 | 489.1 | 7.2 | 2.4 |
| Yamal-Nenets Autonomous District | 495198 | 168367 | 12380 | 4209.2 | 61.9 | 21 |

Appendix II, 6

| 6. The Siberian federal district | | | | | | |
|---|---|---|---|---|---|---|
| In total | 605192 | 205765 | 15128 | 5144.1 | 75.7 | 25.8 |
| Including: | | | | | | |
| Republic of Altai | 22687 | 7714 | 567 | 192.8 | 2.8 | 1 |
| Republic of Buryatia | 31617 | 10750 | 791 | 268.7 | 4 | 1.3 |
| Republic of Tuva | 41773 | 14203 | 1044 | 355.1 | 5.2 | 1.8 |
| Khakass Republic | 5571 | 1894 | 139 | 47.4 | 0.7 | 0.2 |
| Altay Territory | 18601 | 6324 | 465 | 158.1 | 2.3 | 0.8 |
| Krasnoyarsk region | 63900 | 21726 | 1598 | 543.2 | 8 | 2.7 |
| Irkutsk oblast | 67095 | 22812 | 1677 | 570.3 | 8.4 | 2.9 |
| The Kemerovo oblast | 40110 | 13637 | 1003 | 340.9 | 5 | 1.7 |
| Novosibirsk oblast | 19602 | 6665 | 490 | 166.6 | 2.5 | 0.8 |
| Omsk oblast | 15367 | 5225 | 384 | 130.6 | 1.9 | 0.7 |
| Tomsk oblast | 6972 | 2370 | 174 | 59.3 | 0.9 | 0.3 |
| The Chita oblast | 37125 | 12623 | 928 | 315.6 | 4.6 | 1.6 |
| Agin-Buryat Autonomous District | 4655 | 1583 | 116 | 39.6 | 0.6 | 0.2 |

Appendix II, 7

| | | | | | | |
|---|---|---|---|---|---|---|
| Taymyr (Dolgan-Nenets) Autonomous District | 211215 | 71813 | 5280 | 1795.3 | 26.4 | 9 |
| Ust-Ordynsk Buryat Autonomous District | 2016 | 685 | 50 | 17.1 | 0.3 | 0.1 |
| Evenki Autonomous District | 16887 | 5742 | 422 | 143.5 | 2.1 | 0.7 |
| 7. Far East federal district | | | | | | |
| In total | 987762 | 335839 | 24692 | 8395.9 | 123.4 | 41.9 |
| Including: | | | | | | |
| Republic of Sakha | 279288 | 94958 | 6980 | 2373.9 | 34.9 | 11.9 |
| Primorye Territory | 69678 | 23691 | 1742 | 592.3 | 8.7 | 3 |
| Khabarovsk Territory | 141948 | 48262 | 3549 | 1206.6 | 17.7 | 6 |
| The Amur region | 8002 | 2721 | 200 | 68 | 1 | 0.3 |
| The Kamchatka oblast | 112728 | 38328 | 2818 | 958.2 | 14.1 | 4.8 |
| The Magadan oblast | 143034 | 48632 | 3576 | 1215.8 | 17.9 | 6.1 |
| The Sakhalin oblast | 11323 | 3850 | 283 | 96.2 | 1.4 | 0.5 |
| Jewish Autonomous District | 3240 | 1102 | 81 | 27.5 | 0.4 | 0.1 |

Appendix II, 8

| | | | | | | |
|---|---|---|---|---|---|---|
| Koryak Autonomous District | 111555 | 37929 | 2789 | 948.2 | 13.9 | 4.7 |
| The Chukchi Autonomous District | 106967 | 36369 | 2674 | 909.2 | 13.4 | 4.5 |