



ESTIMATION OF WIND POWER POTENTIAL (ON THE EXAMPLE OF IMERETI)

Earth Science

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ABSTRACT

This issue is important to investigate if considering that the electrical power generated with wind engines is 2 to 3 times cheaper than that generated at thermal power plants, and as an environmental benefit, pollutes the environment less. The issues of use wind power resources are studied quite well in many countries of the world, which work to further improve the wind use. The goal of the study is to identify the wind power potential in Imereti region and to show its territorial distribution and seasonal properties. Long data of 9 weather stations were processed during the study. Based on the data of the weather stations, the empirical provision curves were drafted in the following order: the observation series for each station is classified by the annual duration hours. Putting the different-capacity wind power plants to exploitation in Imereti Region, which is rich in wind power resources, will significantly improve the sustainable operation of the power system of the country and region, particularly in the periods with low water discharge in the rivers (in the second half of autumn and winter) when the hydropower plants fail to operate even with the rated load, while this period is characterized by continuous and intense winds what allows compensating the deficit in the power generation of the HPPs.

KEYWORDS

Wind power potential, Georgia, Imereti.

Introduction

One of the most topical modern problems of the mankind is the exhaustible nature of fossil energy supply. This problem is interwoven with economic problems. As fossil fuel (coal, oil, natural gas) are exhaustible, sometime in the future their price may increase as much as to make their use at thermal power plants, in vehicles or otherwise too expensive to yield profit or economic benefit. Therefore, it is important to look for alternatives.

Today, the world scientists try to widely use the power capacities generated from renewable power sources, such as water, wind, sun, thermal waters and the like, in life. It is this kind of power resources making it possible to substitute the traditional power resources with renewable power plants what will allow us to use renewable natural power sources, which are ecologically pure. In this respect, it is very important to study and estimate the power potential of wind, an inexhaustible natural resource, in concrete regions.

This issue is important to investigate if considering that the electrical power generated with wind engines is 2 to 3 times cheaper than that generated at thermal power plants, and as an environmental benefit, pollutes the environment less. The issues of use wind power resources are studied quite well in many countries of the world, which work to further improve the wind use.

If looking at the present situation of using the renewable energy sources, we will see that these resources are underused in Georgia, which more accents other, nonrestorable resources. It is true that they started to generate and use wind energy in Georgia, but in too small scales. The wind, if used efficiently in Georgia, may generate 1-1,5 million KW.hr electrical power [Imereti region..., 2012] what will be a great contribution to the power system of the country.

However, as Georgia is rich in wind power resources, wind must be used in larger scales. However, to do this, a scientifically proved basis must be developed.

At present, this issue is not thoroughly studied in Georgia, but there are only few works dedicated to this problem (Zedgenidze, Svanadze et al. 2014). The situation is further complicated by the scarcity of the data about the wind. More detailed and accurate data about the questions of identifying the power capacity and use of wind are needed.

The goal of the study is to identify the wind power potential in Imereti region and to show its territorial distribution and seasonal properties.

Study Area

Imereti is located in the eastern part of Georgia. Its area is 6.4 thousand sq.km making 9.2% of the total area of the country. Imereti includes 3 large orographic units: the Great Caucasus, Lesser Caucasus and the intermountain plain between them.

The eastern part of the territory is mountainous, and the western part is hilly, which merges with the eastern part of Kolkheti Lowland.

Georgia is in the active zone of influence of solar energy. An average value of solar radiation in this zone of the Earth is 3 KW.hr/m² a day what makes the country rich in wind power resources. This is particularly true with Imereti region. 2% of the solar energy is transformed into wind energy equaling to 2,661016 KW.hr a year (Todradze 2017).

The wind energy in Georgia is 3,651012 KW.hr. Even if using 1% of it, we will gain 3,651010 KW.hr power a year. At present, this resource is virtually unused, while in the developed countries of the world, the use of wind energy is 10 to 20% (Mrtskhulava, Chomakhidze 2014).

Imereti is the region in the center of Georgia with a much favorable geographical location and clear natural borders. It is bordered by Racha Ridge from the north, by Meskheti Ridge from the south, by Likhi Ridge from the east and by the Tskhenistkali River from the west. Imereti is bordered by mountains from three sides and by the eastern part of Kolkheti Lowland from the west, which gradually merges with north and south hilly zones. The northern and north-eastern parts are presented by hills and mountains. Due to such a relief, the wind direction, velocity and frequency in different areas of the region vary greatly.

Western and eastern winds prevail in Imereti. The seasonality is clearly seen in the annual flow of the wind direction: winds blowing from the east prevail in winter months, and on the contrary, the winds from the west are dominant in summer. The number of windy days in the mentioned period reaches its maximum. The action of frequent western winds is augmented by local winds, the breezes, and that of eastern winds is augmented by foehn winds. The river Rioni gorge and the crest area of Likhi Ridge are distinguished for strong winds.

Research Methods and Initial Data

Long data of 9 weather stations were processed during the study. Based on the data of the weather stations, the empirical provision curves were drafted in the following order: the observation series for each station is classified by the annual duration hours. Empirical provision is calculated by a famous formula:
$$P_n = \frac{m}{n+1} \cdot 100\%$$

where m is the number of a member in a given series of stations ($m=1, 2, 3, \dots, n$); and N is the value of the series.

As the series is less than 50 ($n=9$ in our case), value $n+1$ is taken as a denominator in the formula to improve the reliability of the calculation.

The coordinates of the provision curve were calculated by various speed and relevant durations based on the observation data for wind speed: V3 m/sec, V5 m/sec, V8 m/sec and V10 m/sec.

In addition, the percentage values of the provision of wind duration were calculated in different periods of the year.

The data of the weather stations located in the regional centers are useless to describe the territories of the villages distanced from the center. Therefore, it is necessary to study wind power resources of such areas and correlate them to the data of the regional center, and the method proposed by us is designed to solve this problem. The essence of our method is as follows:

In order to study the wind intensity (velocity), conditionally, we must take any of the regional centers as the basic observation center. For instance, let us conditionally take the following gradations of wind velocity in the basic center: 5 m/sec; 10 m/sec; 15 m/sec; and 20 m/sec. In case of fixing the given gradations of wind velocity in the basic center (e.g. wind velocity of 10 m/sec), under the given plan, the wind speed in the selected points (in villages) are identified (measured) simultaneously by using an instrumental method. These field-expedition works will be accomplished mostly in the basic fixed areas selected in advance where wind velocity must be calculated from the basic center (from Kutaisi).

Main Results

Circulation atmospheric processes on the territory of Georgia. The circulation atmospheric processes on the territory of Georgia are mostly determined by Iceland Minimum, Siberian Anticyclone and Azores High. In winter, the whole area is influenced by one branch of Siberian Anticyclone, anticyclones formed on the territory of Eastern Europe and Iceland Minimum, while no impact of the Siberian Anticyclone is the case in the warm period of the year. However, on the other hand, the action of Azores High becomes stronger. It is these circulation processes of the atmosphere resulting in the regime and intensity of the winds. In addition, due to instable winter temperature regime, the wind pressure and wind regime consequently, change a lot. Therefore, the wind regime in this period of the year varies more than in summer.

Depending on the wind regime, the territory of Georgia is divided into 3 regions: west, east and South Georgia (Elizbarashvili, Matchavariani, Nikolaishvili 2000). In west Georgia, in the cold period of the year, eastern downbursts prevail, which do not cause precipitations, while in the warm period of the year, west anabatic winds prevail. Sea winds, the breezes are common in summer traveling to 130-135 km inland. As a result, large areas of west Georgia receive abundant precipitations. For almost all the year, western and north-western downbursts blow in east Georgia not bringing precipitations with them. The wind velocity in South Georgia is low. In winter, an anticyclone situation is more common here with prevailing western and south-western winds, while in summer, a cyclone situation is more common with the winds of opposite direction developed.

Territorial and seasonal peculiarities of the wind power potential distribution on the territory of Georgia. It is known that wind power plants are installed where average annual wind velocity exceeds 4 m/sec. Georgia has many such locations covering quite vast areas. Provided they are thoroughly exploited, 4.5 milliard KW.hr electrical power is possible to generate (Elizbarashvili, Matchavariani, Nikolaishvili 2000).

Wind velocity differs in different regions of Georgia. It reaches its maximum over Great Caucasus and Lesser Caucasus – in high-mountainous, subnival and nival zones. Average wind velocity over the slopes of mountain Mkinvartsveri is 6.3 m/sec sometimes reaching 45 m/sec (Imereti Region... 2012). Maximum average wind speed are

also registered over Likhi ridge and crest zones of Samsara and Javakheti Ridges. Therefore, generating wind power is particularly beneficial over high mountains and passes, e.g. in the environs of Kazbegi where the annual number of days with winds with the velocity of over 15 m/sec is 98 and in the environs of mount Sabueti, where the same value is ¹⁴².

The number of days with strong winds (with the velocity of over 15 m/sec) varies a lot. It is minimum (0.2 days on average) in Racha Basin (Chrebalo weather station) and it is maximum (162 days) across Likhi Ridge (mount Sabueti). The power potential of wind is maximum at these locations. There is also a high wind power potential in the intermountain plain of Georgia, which is a kind of a climatic "corridor" along the gorges of the rivers Mtkvari and Rioni.

The wind resource values are low in deep gorges and intermountain basins. For example, average wind velocity across the plains and in the deep gorges and basins of East Georgia (gorges of Borjomi, Liakhvi, Ksani, Aragvi, Iori, Alazani, upper reaches of Kodori and basins of Ajara, Racha, Zemo Svaneti and Kvemo Svaneti), which are confined to orographic barriers, is low. However, there are some exceptions even with the plains of Georgia. Generating wind energy is particularly beneficial in the areas with many days with the winds of over 15 m/sec speed (the river Rioni gorge near the city of Kutaisi, the river Mtkvari gorge where Tbilisi starts). The number of such days in Kutaisi is 88 a year and it is 132 in Tbilisi. Maximum number of days with strong winds is fixed in winter, i.e. when maximum power is needed.

In the coastal and lowland regions of Kolkheti in the warm period of the year, the winds blowing from sea to land (western) prevail (constituting 30-60 %), while in the cold period, eastern and north-eastern winds dominate (45-60 %). At the same time, breezes (sea winds) of a monsoon nature are common in summer. Their influence spreads deep inland up to 130-135 km [Maruashvili, 1964]. Due to the monsoon nature of the winds, in the warm period of the year, Kolkheti and western slopes of mountainous regions are humidified too much what has a negative impact on agricultural crops. Dry and hot winds – the foehn winds may also be considered a negative phenomenon, as they damage the agricultural crops in West Georgia. Eastern or south-eastern winds are common to the mountains and piedmont of West Caucasus in the warm period of the year (30-49 %) and northern or north-eastern winds prevail in the cold period of the year (25-45 %).

In the lowland of East Georgia, western and north-western winds prevail all over the year (30-60 %), with eastern winds being less common. Alazani Valley is an exception where eastern and north-eastern winds prevail (30-60 %). In the cold period of the year, north-western and south-eastern winds prevail in the lowland of Georgia (25-50 %) and north-western and western winds dominate in Alazani Valley (20-40%). Eastern spring and autumn dry winds have a negative impact on agricultural crops production (Reference book 2004; Reference Book of the Climate of the USSR 1968).

Mountain and gorge winds blow over the most territory of Georgia, which, in an agro-climatic respect, are considered as a positive phenomenon for the territory of the lowland of West Georgia (as it takes excess moisture from the soil) and as a negative phenomenon for the territory of the lowland of East Georgia (as, in terms of humidity deficit, it causes drying of soil by taking the amount of moisture from it needed by the agricultural crops).

Maximum wind speed is fixed in the high-mountainous subnival and nival zones and in the crest zones of Likhi, Samsara and Javakheti Ridges. The winds with the least speed are typical for the lowland zone of East Georgia and deep and closed gorges (some sections of Chkhaltia-Sakeni, Enguri, Rioni, Tskhenistskali, Liakhvi, Ksani, Aragvi, Iori, Alazani, Acharistskali and Borjomula river gorges) (Maruashvili, 1964).

Knowing the common speed of the wind, so called working velocity and its duration, is very important in estimating wind power resources. If considering that the multi-blade, low-speed wind plants need the winds with the velocity of more than 3 m/sec to run (the wind working velocity is considered to be $V=3$ m/sec), while winds with the velocity of more than 4,5 m/sec are needed by high-speed plants, it will be clear that for most of the year (50-70 %), high-efficient winds blow in many regions of Georgia (intermontane plain, Javakheti Plateau,

Tskhratskaro Pass, environs of Mamisoni and mount Sabueti).

Wind regime on the territory of Imereti. Due to the mountainous relief, the direction, velocity and frequency of winds vary a lot in the region. A great role in wind formation in this area is played by the Black and Caspian Seas and seasonal distribution of pressure over the Eurasian Continent, as well as the direction (exposition) of the ridges and gorges.

During the penetration of wind masses from the west, the air temperature reduces and the weather is commonly cloudy and wet. When traveling across the Black Sea, the wind absorbs much moisture and takes abundant atmospheric precipitations mostly to West Georgia; however, the amount of atmospheric precipitations is much less in the zone of Imereti Lowland due to its location in the extreme eastern part. Penetration of air masses from the west takes place all year long, but is more typical in the warm period of the year. The penetration of air masses from the east, what is most typical in the cold period of the year, has less impact on the territory of Imereti.

The climatic peculiarities of Imereti Region are greatly influenced by high orographic barriers – the Caucasus mountains preventing the cold air masses from penetrating from the north and Likhi Ridge, preventing the distribution of humid western air masses in East Georgia. This is why the high locations of Likhi Ridge are quite wet.

Uneven warming of landmass and sea and alternating series of ridges and gorges result in the winds of different directions and speed.

Eastern winds prevail in winter, and on the contrary, western winds, or breezes, prevail in summer in the western regions. Eastern foehn winds often blow in the region.

Peculiarities of the territorial distribution of wind power resources in Imereti. Based on the data of nine weather stations of the region, the duration provision for wind speed of V3 m/sec, V5 m/sec, V8 m/sec and V10 m/sec was calculated by using the method of mathematical statistics.

Duration of wind velocity on the territory of Imereti. Imereti is outstanding not only for wind speed, but their duration, as well (Table 1). As the studies have demonstrated, winds with the velocity of over 30 m/sec have quite high percentage provision. In particular, 7000 hours are provided by 10% and 2550 hours are provided by 90%. The value of percentage provision of the winds with the velocity of 5 m/sec or more is also high (Fig. 1).

Table 1. Duration of wind velocity

Wind velocity, m/sec	Duration, hrs.	Provision
> 3	2550-7000	7000 hours are provided by 10%, 2550 hours are provided by 90% and 3100 hours are provided by 50%.

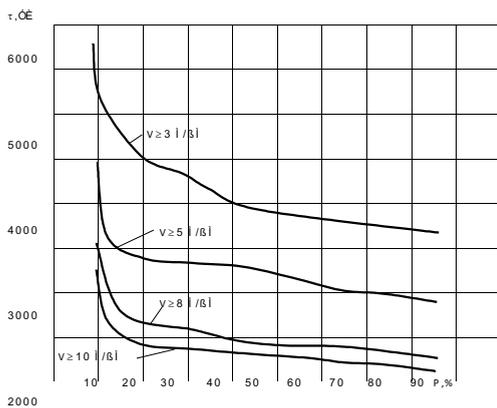


Fig. 1. Correlation curves between the annual duration of wind working velocity (v) and its provision (P) (in Imereti)

The studies have demonstrated that when wind velocity V3 m/sec, the duration varies from 680 to 1720 hours. =1720 hrs. are provided by 10% and =680 hours are provided by 90%. 940 hours are provided by 50%. When wind velocity V5 m/sec, the duration varies from 400 to 1140 hours. =1140 hrs. are provided by 10% and =400 hours are provided by 90%. 540 hours are provided by 50%. Wind speed of V8 m/sec and V10 m/sec are non-profitable.

The situation is different in different seasons. In spring, when wind velocity V3 m/sec, the duration varies from 780 to 1870 hours. =1870 hrs. are provided by 10% and =780 hours are provided by 90%. 1000 hours are provided by 50%. When wind velocity V5 m/sec, the duration varies from 320 to 1320 hours. =1320 hrs. are provided by 10% and =320 hours are provided by 90%. 580 hours are provided by 50%. Wind speed of V8 m/sec and V10 m/sec are non-profitable.

In summer, when wind velocity V3 m/sec, the duration varies from 470 to 1880 hours. =1880 hrs. are provided by 10%. When wind velocity V5 m/sec, the duration varies from 145 to 1135 hours. =1135 hrs. are provided by 10% and =145 hours are provided by 90%. 300 hours are provided by 50%. Wind speed of V8 m/sec and V10 m/sec are non-profitable (Fig. 2).

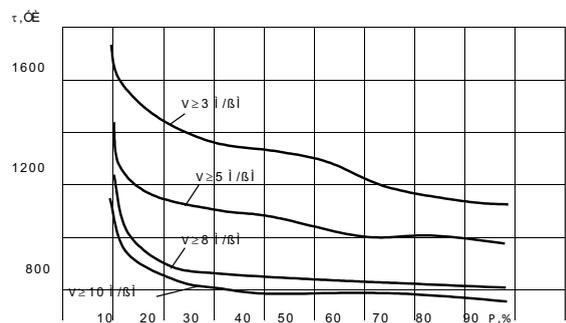


Fig. 2. Correlation curves between duration of wind in winter working velocity (v) and its provision (P) (in Imereti)

In autumn, when wind velocity V3 m/sec, the duration varies from 607 to 1727 hours. =1727 hrs. are provided by 10% and =607 hours are provided by 90%. 760 hours are provided by 50%. When wind velocity V5 m/sec, the duration varies from 333 to 1210 hours. =1210 hrs. are provided by 10% and =333 hours are provided by 90%. 440 hours are provided by 50%. Wind speed of V8 m/sec and V10 m/sec are non-profitable.

Average annual and monthly wind speed. General level of wind velocity at different locations is measured by using the weathercock data obtained as a result of long-term observations of average wind velocity. These data give us certain understanding about the efficiency of using wind power. However, estimating and using their value is impossible without considering wind structure and regime. The data of average annual wind velocity in individual areas and map of its geographical distribution show that in Imereti, depending on the relief and degree of protection of the locations, the wind velocity and direction often change.

In Imereti region, winds of maximum speed (4.1-6.0 m/sec) are most common in Kutaisi region, on mount Sabueti and sometimes in other regions, too.

The seasonal movement of wind velocity all over the territory of Imereti is thoroughly studied with the help of weather stations and posts. Maximum monthly wind speed is fixed in winter (i.e. in the cold period of the year) and in the second half of autumn (in particular, in November, December, January, February and March). This period brings frequent continuous winds to the territory of Imereti. From May through August, the average annual wind velocity reduces to minimum what is caused by the absence of mountains and valleys at high altitudes. In summer, the currents of western wind prevail, while the dynamics is opposite in winter.

In the environs of mount Sabueti, average annual wind velocity is 9.1 m/sec, and average monthly wind velocity is more than 8.0 m/sec. The duration of working wind velocity of V3 m/sec reaches 4000-7000 hours. This region offers good prospects to develop low- and high-speed wind power plants. The recurrence of wind working speed of V3 m/sec and V5 m/sec here is 75 and 48%, respectively. As mentioned above, the total duration of working speed is over 7000 hours making 81 % of the total annual hours, with 56 % (4900 hrs.) of V5 m/sec wind velocity.

Average continuous duration of working wind speed on mount Sabueti is 37 hours. Continuous duration of 12 hours or more has a 78 % provision and changes within the limits of: =0,30,35 for low-speed wind engines and =0,350,45. for high-speed wind engines.

Zoning the territory of Imereti depending on wind power potential. As a result of the data analysis, a map of distribution of the duration of average annual wind velocity (V3 m/sec) was drafted (Fig. 3). The map allows identifying the reference areas where the exploitation of wind facilities will be profitable. The data of weather stations on the territory do not give a realistic picture, as they are mostly located in the populated, central areas, and the application of the data obtained at the posts to the adjacent areas is often not correct due to the varying natural conditions. Besides, the orography of the territory of Imereti significantly changes the picture of wind distribution in space and time. Therefore, the map can be used to select the reference areas only.

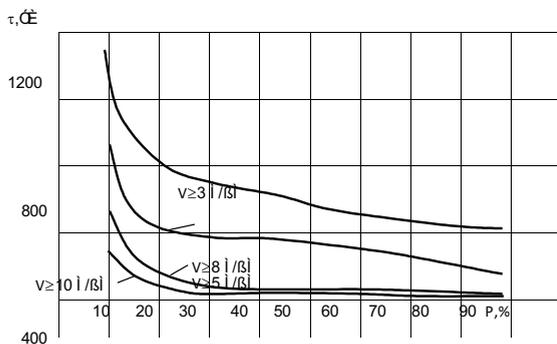


Fig. 3. Correlation curves between duration of wind in summer working velocity (V) and its provision (P) (in Imereti)

The following reference areas were selected in 10 administrative regions:

- 1) Bagdati Region - an area of 815,54 km², 22 villages. The most distant villages form the regional center: Sakraula (21 km) and Khani (23 km);
- 2) Vani Region - an area of 577 km², 41 villages. The most distant villages form the regional center: Ukhuti (24 km), Pereta (18 km) and Saprasia (21 km);
- 3) Zestaponi Region - an area of 423,7 km², 57 villages. The most distant villages form the regional center: Shrosha (20 km) and Rodinauli (19 km);
- 4) Terdjola Region - an area of 357,4 km², 45 villages. The most distant villages form the regional center: Godogani (27 km), Kvakhchiri (28 km) and Chognari (20 km);
- 5) Samtredia Region - an area of 364 km², 48 villages. The most distant villages form the regional center: Zemo Abasha (28 km) and Gormagali (25 km);
- 6) Sachkhere Region - an area of 768,5 km², 45 villages. The most distant villages form the regional center: Korbouli (17 km) and Chalovani (34 km);
- 7) Tkibuli Region - an area of 478,2 km², 45 villages. The most distant villages form the regional center: Kursebi (29 km) and Orpiri (25 km);
- 8) Kharagauli Region - an area of 913,9 km², 78 villages. The most distant villages form the regional center: Boriti (28 km), Goresha (33

km) and Khunevi (35 km);

9) Khoni Region - an area of 428,5 km², 39 villages. The most distant villages form the regional center: Kveda kinchkha (25 km) and Kveda Gordi (19 km);

10) Tskaltubo Region - an area of 700,1 km², 49 villages. The most distant villages form the regional center: Dgnorisa (63 km), Mekvena (54 km), Opurchkheti (31 km) and Opshkviti (34 km);

11) Chiatura Region - an area of 542 km², 61 villages. The most distant villages form the regional center: Shua Gezrula (25 km) and Mandaeti (20 km).

Conclusion

Putting the different-capacity wind power plants to exploitation in Imereti Region, which is rich in wind power resources, will significantly improve the sustainable operation of the power system of the country and region, particularly in the periods with low water discharge in the rivers (in the second half of autumn and winter) when the hydropower plants fail to operate even with the rated load, while this period is characterized by continuous and intense winds what allows compensating the deficit in the power generation of the HPPs.

The weather stations in Georgia, in Imereti in particular, were mostly located in the administrative centers, failing to cover all the areas around them (the villages). The plain areas are transformed into hilly or mountainous gorges, gorges with a forest cover, plateaus or lowlands in the peripheries. Using the data of the weather station located in the center to estimate the changes in the wind velocity in the areas with a complex relief distanced from the center by 25, 30 or 40 km will be less realistic. Therefore, the areas selected for assessment, in respect of changes in the wind dynamics, are to be studied and identified. As for the obtained data, they must be correlated to the data fixed in the center. Studying such a problem will allow establishing a correlation between the wind speed fixed in the center and measured in the adjoining areas distanced from it.

Imereti region is confined to geographically clear natural borders and is bordered by Racha Ridge from the north, by Meskheti ridge from the south, by Likhi Ridge from the east and by the river Tskhenistkali from the west. Following its complex location, studying the wind power resources on its territory it necessary for the areas distanced from the central points (regional centers).

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