Mechanical Testing and Diagnosis
ISSN 2247 – 9635, 2016 (VI), Volume 1, pp. 20-28

STUDY OF THE VARIABILITY OF WIND ENERGY RESOURCES IN ROMANIA

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ABSTRACT

The main objective of the present work is to provide an extensive and more comprehensive picture of the wind patterns in Romania. The wind conditions were evaluated in order to cover large areas of the Romanian lands and, also, areas belonging to the Romanian nearshore. Moreover, a direct comparison between these areas was performed. The wind conditions are mainly evaluated by considering the AVISO satellite measurements, which correspond to the time interval 2010-2015. This data set is also completed by 15-year period of reanalysis of the wind data (2000-2014) coming from the European Centre for Medium-Range Weather Forecasts. The main conclusion of this work is that the Romanian lands, as well as its nearshore, are appropriate for the wind energy extraction. Moreover, it seems that the future of the renewable energy extraction is in the coastal environment. This is because the wind energy is higher in the marine areas, it can be combined with some other sources as the wave energy in hybrid approaches and, finaly, the marine energy farms can also help in the coastal protetction, which represents, in fact, a very challenging issue.

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Keywords: wind power, renewable energy, Romania, mountain areas, nearshore

INTRODUCTION

Nowadays, in the current context of the exploitations of fossil fuel reserves, their rising prices and the EU requirements on reducing emissions, the development and use of alternative energy sources has become a priority in Romania.

The use and promotion of renewable energy sources are essential. Their exploitation contributes to environmental protection and sustainable development. According to Directive 2009/28/EC of the European Parliament and Council to promote electricity generation based on renewable energy sources by the year 2020, Romania, as all European community countries, will have to produce 20% of all electricity from renewable sources [1].

Renewable energy sources in Romania have important theoretical potential. The utilizable potential of these sources are much lower, due to technological limitations, economic efficiency and environmental restrictions. Table 1 shows the main renewable energy sources in Romania.

Table 1. The potential of the renewable energy in Romania [2](tep - tons of equivalent petroleum)

Source of renewable energy	*The annual energy potential*	*Economic equivalent energy (tep)*	*Application*
Solar energy			
thermal	60x106 GJ	1433.0	Thermal energy
photovoltaic	1200 GWh	103.2	Electrical energy
Wind energy	23000 GWh	1978.0	Electrical energy
Hydropower			
- over 10 MW	40000 GWh	3440.0	Electrical energy
- below 10 MW	6000 GWh	516.0	Electrical energy
Biomass	318x10^6 GJ	7597.0	Thermal energy
Geothermal energy	7x10^6 GJ	167.0	Thermal energy

WIND ENERGY

Wind energy is one of the most sustainable forms of energy. This resource is abundant, inexhaustible and totally clean. Though wind turbine production technology is well developed and constantly improved, we should mention that there is a negative impact on the environment, wind turbines are making noise. For this reason it is necessary for them to be located in a reasonable distance from inhabited areas not to pollute the sound. Another signal is the discomfort caused by moving shadows caused by propellers.

One of the problems is that they can adversely affect the natural habitat of birds. They can be killed by turbine blades when flying near windmills. Although they found evidence in this regard, a study by the National Coordinating Committee of the Wind (NWCC) has shown that the effects are small and they do not represent a real threat.

In the areas of hill and mountain wind farms would destroy the natural beauty of places. On the other hand placing turbines in the plains uses more land than in hilly or mountain ridges. Hence the questions arise regarding the use of land for the construction of wind farms.

According to studies done in the United States National Renewable Energy Laboratory, it was found that large wind farms using between 12 and 60 ha MW production capacity. But less than 0.4 ha/MW is always busy and 1.4 ha/MW are temporarily employed during wind farm arrangement. The remaining land can be used for agriculture or tourism [3, 4].

This next figure (Fig. 1) represents the main capacity of the renewable energy facilities in Romania.

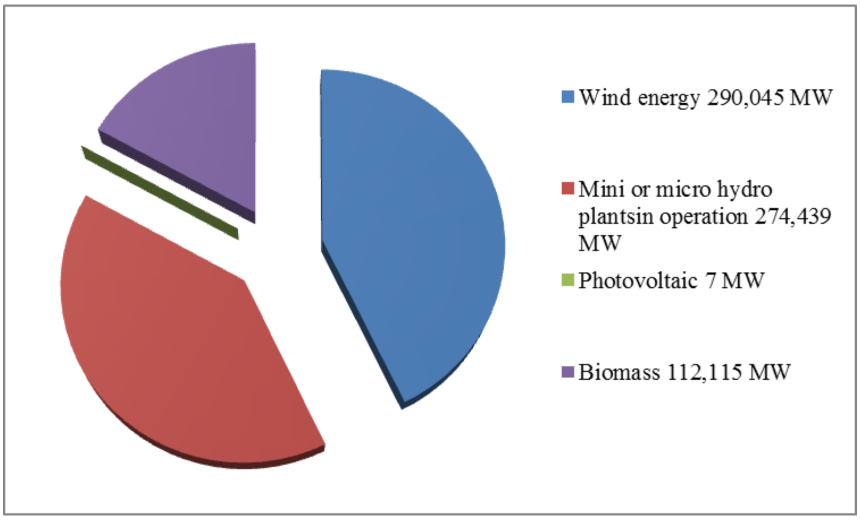

Fig. 1. Capacity of renewable energy facilities in Romania

WIND CONDITIONS IN THE MOUNTAIN AREAS

North Atlantic Oscillation (NAO) is one of the most important modes of large scale variability in the Northern Hemisphere. It occurs especially during boreal winter (when the atmosphere is dynamically the most active), while the NAO summer signal is quite null. The phenomenon has been defined as an anomaly in the sea level air pressure (SLP) distribution with centers of action near the Icelandic low and the Azores [5]. Conventionally, the index of the NAO is based on the difference of the standardized sea level pressure (SLP) anomaly measured at Lisbon, Portugal and at Stykkisholmur, Iceland. In Romania, positive thermal anomalies are associated with positive NAO phases due to the prevalence of zonal circulation over the Northern and Central Europe and negative thermal anomalies over Romania are associated with negative NAO phases. The winter precipitation pattern over Romania is indirectly related to the NAO. The study of NAO projection on temperature and precipitation regime in Romania show that the winter NAO related signal is stronger in the extra-Carpathian regions, due to the orographic effects imposed by the Carpathian Mountains on the atmospheric flow.

The distribution of the mean wind speed over the Romanian territory revealed the influence of the Carpathian chain on the regional response to the large scale atmospheric circulation. The South-Eastern Carpathians represent a roughness element for the atmospheric flow, acting as a complex barrier. In order to quantify the effects of altitude upon wind speed, a correlation between altitude and mean wind speed was computed for 10 mountain meteorological stations placed in wind-exposed areas at altitudes higher than 1200 m in Figure 2. As a consequence, the regions between the Carpathians branches (Ardeal) and the intra-mountain and sub-mountain depressions present small annual wind speed values (1-2 m/s), moderate values (2-4 m/s) for the extra-Carpathians regions (Moldova, Muntenia, Oltenia, Dobrogea, Banat, Crişana) while the mountain wind-exposed areas have the highest values (5-9.3 m/s). For the Aeolian energy, the most suitable locations have to record high speeds and low turbulences which are rare in Carpathians (especially restricted to wide plateaus: Muntele Mic, Godeanu, Semenic), but frequent in the coastal zone and on the exposed areas of the Moldavian and Dobrogea tablelands or in Bărăgan. Over the Romanian territory, the position of the Carpathians Mountains induces a high variability for the spatial distribution of the wind parameters characteristics and influences the local response to the NAO variability. Thus, the extra (intra-) Carpathian regions are characterized by high (medium to low) correlation coefficients between the NAO index and wind anomalies.

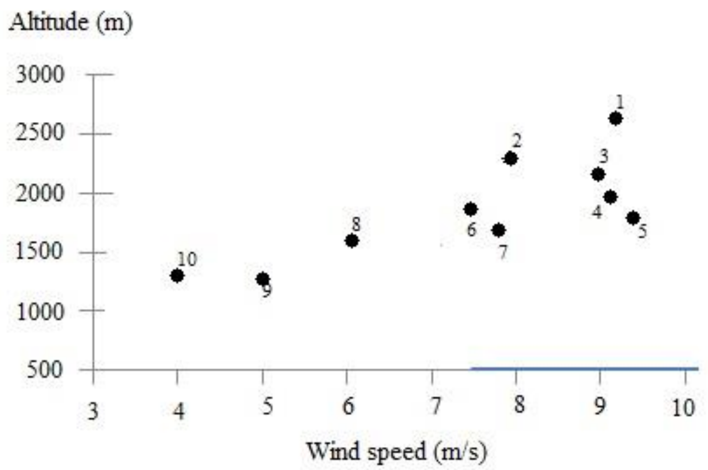

Fig. 2. The influence of altitude on the mean wind speed (wind-exposed areas)
1-Vf. Omu, 2- Babele, 3- Țarcu, 4- Călimani, 5- Ceahlău Toaca, 6- Vlădeasa,
7- Lăcăuți, 8- Postăvaru, 9- Semenic, 10- Fundata;

WIND ENERGY ALONG THE ROMANIAN LANDS

For a wind aggregate to work, the wind should blow with at least 3m/s, on average, a speed capable to generate energy (the so-called energy speed). The notion of energy speed designates the average speed obtained by summating active wind frequencies at speeds of 3m/s observation times, blowing every meter, referred to the number of possible cases over the year. So, it is a question of hourly speeds necessary to keep the aggregate working continuously.

The calculated annual frequency of active wind speeds (over 3 m/s) indicates a north-to-south frequency increase throughout the study region: 34.2% at Botoşani, 39.8% at Iaşi, 41.3% at Galaţi.

During the year (Table 2), the highest monthly average wind speed is registered in the cold season, values differing from north to south: in the north of Moldavia, at Botoşani, the highest frequency occurs in February (43.8%); in central and southern Moldavia in March (Iaşi 96.2%, Bacău 51.6% and Galaţi58.1%)

The highest active speed frequencies in the day-time usually occur between 10:00 a.m. and 7:00 p.m., when temperature convection stimulates the development of air currents both on the vertical and the horizontal. The lowest frequencies are registered at night, between 10:00 p.m. and 5:00 a.m. because morning cooling enhances temperature inversions stabilizing air temperature. It follows that daily active speed amplitudes are higher in summer and autumn than in winter.

The value differences throughout Romania's eastern territory depend on the times of the year, when the general atmospheric circulation intensifies in February, in connection with the activity of the Polar Anticyclones and the East-European Anticyclone which come into contact with the Mediterranean and Pontic cyclones; in March-April with atmospheric disturbances generated by changes in the general atmospheric circulation from east in winter to west in summer; in November-December with the intensified activity of the Mediterranean and Pontic cyclones.

Table 2. Wind speed, Source: ANM Archive, Bucharest. Calculated average values

Months	**Stations**			
	Botoșani	***Iași***	***Bacău***	***Galați***
January	37.7	37.6	34.6	43.5
February	**43.8**	46.2	39.6	55.1
March	43.0	**96.2**	**51.6**	**58.1**
April	35.0	42.2	35.0	19.4
May	40.9	34.4	35.4	46.3
June	39.5	38.9	22.2	36.1
Julie	31.1	19.9	17.0	44.6
August	18.9	15.1	14.0	28.5
September	21.2	17.2	18.3	33.3
October	29.6	24.2	20.5	31.1
November	33.8	65.8	38.4	42.7
December	36.0	39.8	35.5	56.5
Averages	34.2	39.8	30.2	41.3

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WIND CLIMATE IN THE ROMANIAN NEARSHORE

Since the industrial revolution started, worldwide energy process was mainly supported by burning fossil fuels, which on a large time scale has the effect to reduce these resources and to produce a negative impact on the environment. As a consequence to these changes, a new industrial revolution is under progress in which a large range of energy systems are considered to convert the natural resources into usable energy.

The kinetic energy from the movement of the atmospheric air is an important source of renewable energy already used in various regions of the world and the regions near coastlines are typically considered good places to develop wind projects. Thus, the marine environment represents a large repository of renewable energy the main sources being the waves and the wind. In the same time, the wave energy is denser and can be predicted with a reasonable accuracy with the numerical wave models [6]. The Black Sea in general, presents moderate wave energy resources although the Romanian coastal environment is usually characterized by slightly higher energetic conditions, see for example the detailed studies presented in [7-9]. On the other hand, the Romanian nearshore regions present relative high wind speed values (4.2-6.95 m/s) due to the complex connections between the Atlantic storm track, the cycle genesis activity over the Mediterranean area and the atmospheric circulation over Black Sea [10-12].

Figure 3 illustrates the target area of the nearshore wind analysis, which is located in the northwestern part of the Black Sea, more precisely in the vicinity of the Romanian sector. In order to assess the local wind conditions of the entire coastal area, four reference points were defined nearshore.

This AVISO measurements from Figure 4 were processed for the time interval September 2009-August 2015, being defined by one measurement per day which indicates only the wind speed.

Fig. 3. Nearshore observation points (figure processed from Google Maps)

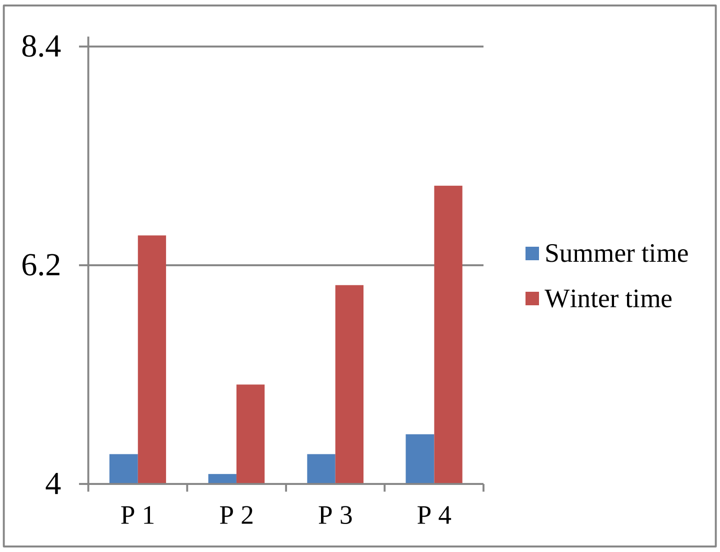

Fig. 4. Wind speed in the observation points
data processed from [13]

It has to be also mentioned that in the present work the winter time is considered the period between October and March while the summer time represents rest (between April and October). A complete analysis of the wind conditions is presented in Table 3, considering various statistical parameters.

Table 3. Statistical analysis of the wind conditions illustrated by the ECMWF dataset, for the interval 2000-2014 structured on summer and winter time, data procesed from [14]

Results	Period	Points			
		P1	**P2**	**P3**	**P4**
≥3 m/s (%)	Summer time	78.1	76	77.7	79.7
	Winter time	88.4	86.9	89	90.4
≥12.5 m/s	Summer time	0.516	0.304	0.442	0.672
	Winter time	3.57	1.9	2.37	3.37
Maxim (m/s)	Summer time	17.2	16.3	17	18.9
	Winter time	18.9	18.1	19.5	20.1
Std (m/s)	Summer time	2.37	2.23	2.36	2.49
	Winter time	3.01	2.74	2.82	2.92

Figure 5 presents a direct comparison between the two data sets, considering the distribution of this parameter for the summer and winter time. Can be mentioned that the ECMWF values are much higher, with the exception of the winter time when the points NP2 and NP3 present more consistent values for the AVISO data.

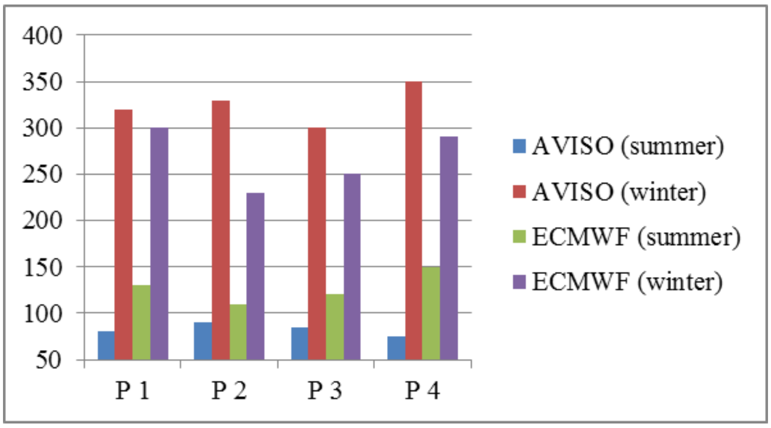

Fig. 5: Distribution of the wind power density (W/m2) based on the AVISO and ECMWF dataset (September 2009-August 2015)

Since the wave energy might be considered also quite relevant in the target area, hybrid energy farms obtained by co-locating the wind and wave farms can also be taken into account and such approaches can play an active role also in the coastal protection, see for example the studies [15, 16].

CONCLUDING REMARKS

The present work presents a picture of the wind energy conditions over the Romanian areas. This analysis was performed mainly from the perspective that although its first professional wind farm projects were only developed a few years ago, Romania's wind energy sector is currently undergoing dynamic changes and beginning to play an increasingly important role. Moreover, it is expected that in the coming years, Romania will undoubtedly have a real chance to become one of the leading users of this form of renewable energy in Europe. From this perspective the present analysis was structured in three parts, the mountain areas, the lands and the nearshore. Although the wind power in the mountain areas and over the Romanian lands can be considered both important and relevant it seems that the future belongs to the nearshore areas, where the wind is stronger and also where it is enough space to develop large energy farms. The work is still ongoing and a future work direction taken into account is to compare various data sources that can provide reliable information on the wind climate on medium to long term. Thus, at this moment three sources are mainly considered for performing extended studies of the wind variability in time and in the geographical space. These are the data provided by the European Centre for Medium Range Weather Predictions (ECMWF), those from the US National Centers for Environmental predictions (NCEP) and also satellite data. It has to be also highlighted the fact that this last data source (satellite data) becomes in the last years more and more important with increasing accuracy and geographical coverage.

ACKNOWLEDGMENT

This work was supported by a grant of the Romanian Ministry of National Education, CNCS – UEFISCDI PN–II–ID–PCE–2012–4–0089 (project DAMWAVE).

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