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Wind Energy Potential in the World and in Serbia and Montenegro

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Abstract: Today, wind energy participates by not more than 0,5 % in the gross world production of electric energy. However, according to the presently existing world trends and due to the fact that the world's wind energy potential is immense, it can be predicted that in the following decades this low percentage might become thirty times larger. Unfortunately, not one modern wind generator has yet been installed in our country, although conditions are favourable in this respect. Experiences the world has had so far impose the necessity of analyzing technical possibilities for the construction of wind generators and the necessity to incorporate wind energy into the strategic model of the development of energetics in Serbia and Montenegro (SM). In this paper we analyze the availability of wind energy on the global scale, in Europe and in SM. We show in this paper that in SM wind is the energy resource about 10 000 MW (20 TWh/year) whose activation would greatly enlarge already installed capacities, increase the diversity of types of energy sources and reduce the dependance on the importation of raw energy sources.

Keywords: Wind energy potential, resources, wind generators, electric energy.

1 Introduction

It is not surprising how great the interest in wind is because its usage has many advantages. Wind energy is renewable and clean. It neither pollutes air, nor emits carbon-dioxide and it does not bring acid rains. Besides, it does not radiate and does not destroy the ozone layer and no waste materials are left behind. To make use of wind, one does nod need mines or river waters. In the world, wind energy

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Table 1. Installed power of wind generators in the world (january 2005)

	[MW]	[%]
Germany	16 629	35.1
Spain	8263	17.5
United States	6740	14.2
Denmark	3117	6.6
India	3000	6.3
Italy	1125	2.4
Netherlands	1078	2.3
United Kingdom	888	1.9
Japan	874	1.8
China	764	1.6
Top Ten-Total	42478	89.7
Rest of the World-Total	4839	10.3
WORLD TOTAL	47317	100.0

potential that can be utilized technically is immense (over 100 000 TWh/year). It is many times greater than hydro potential (about 15 000 TWh/year) and it exceeds total global needs for electric energy to a great extent (currently about 17 500 TWh/year).

The upward trend in the utilization of wind energy in the world is amazing. There is less construction work on farms of wind generators than on conventional electric power-plants, while at the same time the prices of one installed kW are today compatible even when compared with gas power-plants. Wind generators farms at sea have become very attractive and they are our reality. An intensive work is being put into the development of turbines which will use very low velocity winds or undersea currents.

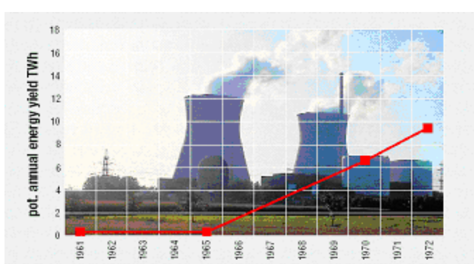


Fig. 1. First eleven years of commercial utilization of nuclear energy (1961-1972)

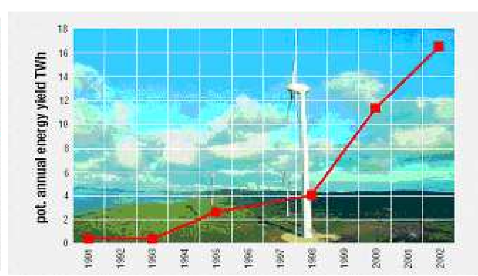


Fig. 2. First eleven years of commercial utilization of wind energy (1991-2002)

Today, wind energy participates by not more than 0.5 % in the gross world

Table 2. The dynamics of the development of wind energetics in the world based on the study Wind Force 12

Year	Average annual growth rate [%]	Annual new capacity [MW]	Cumulative new capacity [MW]	Annual wind electricity production [TWh]	Projected world electricity demand [TWh]	Wind power penetration of world electricity [%]
2002	25	7 227	32 037	64.5	16 233	0.40
2003	25	9 034	41 071	86.3	16 666	0.52
2004	25	11 292	52 363	110.1	17 110	0.64
2005	25	14 115	66 478	139.8	17 567	0.80
2006	25	17 644	84 122	184.2	18 035	1.02
2007	25	22 055	106 177	232.5	18 156	1.26
2008	25	27 569	133 746	292.9	19 010	1.54
2009	20	33 083	166 829	365.4	19 517	1.87
2010	20	39 699	206 528	452.3	20 037	2.26
2011	20	47 639	254 167	556.6	20 532	2.71
2012	20	57 167	311 333	763.6	21 040	3.63
2013	20	68 600	379 933	931.9	21 560	4.32
2014	20	82 320	462 253	1133.8	22 093	5.13
2015	15	94 668	556 922	1366.0	22 639	6.03
2016	15	108 868	665 790	1633.0	23 198	7.04
2017	15	125 199	790 988	1940.1	23 771	8.16
2018	10	137 718	928 707	2277.9	24 359	9.35
2019	10	151 490	1 080 197	2649.5	24 961	10.61
2020	0	151 490	1 231 687	3021.1	25 578	11.81
2030	0	151 490	2 592 424	6358.7	31 524	20.17
2040	0	151 490	3 082 167	8099.9	36 585	22.14

production of electric energy. In 50 countries (primarily in Europe and in the USA) by the beginning of 2005 the installed capacity was about 47 500 MW. However, trends show that in the following decade this percentage might become thirty times larger (Table 2), [1]. In the year 2004, the world production of electric energy based on wind was about 110 TWh. This is sufficient to satisfy the needs for the consumption of electric energy of about 20 million average European and about 10 million American households. Wind energetics is the most expansive of the industries in Europe and in the world (growth rate in the period 1998 – 2004 is 32 %) and approximately 50 billion euros have so far been invested in it.

Generally speaking, our country is defficient in energy sources. Domestic pro-

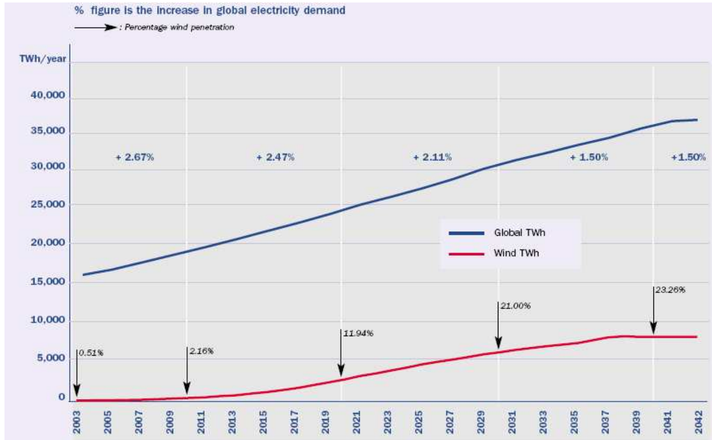


Fig. 3. Projected global electricity consumption and wind electricity output

duction of oil covers only 15 % of total needs and the production of gas is only 20 % of the gross consumption. The analyses show that it is necessary to make available about one billion euros per year for the importation of indispensable raw energy sources, where 800 million euros out of this sum go for the importation of oil and its derivatives. The exploitation of domestic coal of relatively low heating capacity will be more and more restricted, because coal is the source of carbon-dioxide and other gases which influence the greenhouse effect, thus causing climatic changes on earth and global heating. One should also have in mind that in keeping with the necessity to improve the pace of the industrial development the consumption of energy in SM will continue to rise in the following period, despite the fact that the efficiency with which energy is used increases. The exploitation of the existing reserves of fossil fuels will be greater and it will be more difficult to meet the demand for energy in our country.

The state of the power system in SM is far from promising. Although measures have been taken to increase the efficiency with which energy is used and to revitalize the production facilities and national grid, deficit in electric energy has been permanently present in EPS and EPM since 1997. In 2003 this deficit amounted to approximately 5.5 TWh, i.e. 10 % of the gross national consumption, which at that time amounted to app. 40 TWh. In Serbia, at some instants of winter peak load, the power system suffers from a shortage of ca 900 MW of power, while the daily shortages of electric energy are in average 2 GWh in summer and 20 GWh in winter (data for 2003), [2]. Lack of balance between the production and the consumption of electric energy in the previous period was solved by the importation of expensive electric energy and by restrictions in the delivery od electric energy.

These problems can be solved by means of installing wind generators of (2000-2 500) MW total power, because wind is a renewable source of energy which is highly available in SM.

2 Models for the Estimation of Wind Energy Potential

Wind is an inexaustable source of energy but its capacities are limited with respect to power. In order to be able to determine exactly technically utilizable wind energy potential of a region, it is necessary to know the exact histogram of wind velocity at the altitude at which the wind turbine is placed. Because wind properties at altitudes where modern wind generators are installed (up to 120 m) are greatly dependant on the exact positions of the micro locations, for the precise determination of wind potential it would be necessary to have an enormous number of measuring systems for continuous measurement over a rather long time horizon (2-3 years). It is practically impossible to carry out such measurements over a wide region. Therefore, estimates based on meteorological data are often made in practice. However, because meteorological stations give parameters for the relatively small number of locations in a region (at the altitude of 10 m), various complex mathematical models are developed, for the purpose of simulating wind over wider areas by using as input the meteorological data and terrain topography. These models differ greatly with respect to the way in which wind energy potential is determined. As a result, big variations appeared in the estimate of wind energy potential of a certain region (country). Main reason for these differences lies in high sensitivity of wind energy to the velocity, which is a function of a great number of meteorological as well as topographical parameters. Incorrect estimate of any of the parameters could lead to a sequence of errors in the estimation of wind energy potential. *Ten percent error in the velocity measurement introduces an error greater than thirty percent in the calculation of wind power*, [3]. Errors in power estimation are cumulatively reflected upon the estimates of electric energy that can be obtained annualy from wind. It is important to say that only a small portion of the total kinetic energy of wind can be converted into electric energy, because the maximal utilization coefficient of wind is about 0.40, [4, 5]. This is illustrated in Fig. 5.

Authors of this paper concluded that the estimations of global wind potential which are based on standard meteorological data and on models relying on these data are unreliable. Implementations of various models lead to different conclusions concerning wind energy potential in the world. Even the best known papers in this field in the world literature are to a certain extent contradictory. This shows that there does not exist a reliable theoretical model for the estimation of wind potential. In favour of this statement is a fact that countries where wind energetics is

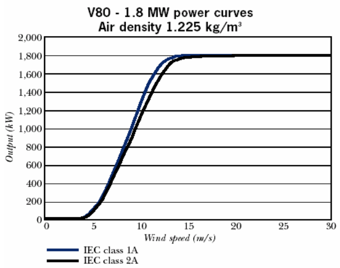


Fig. 4. Input-output characteristic for a wind generator of 1800 kW rated power.

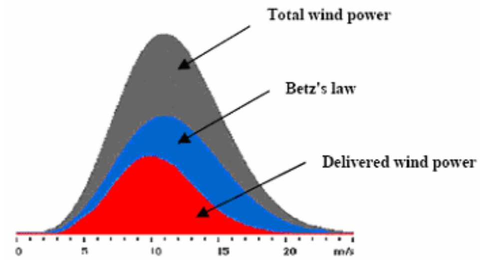


Fig. 5. Illustration of the utilization of wind power and the distribution as a function of wind velocity.

most developed corrected their initial estimates many times.

Since in the beginning of 2005 Denmark was the first in the world with respect to the participation of wind energy in the gross production of electric energy – nearly 20 % (installed capacity app. 3 117 MW) and because Germany was the first with respect to the installed wind energy potential (installed capacity app. 16 629 MW , at present 5 % of the gross consumption of electric energy is obtained from wind generators), basic idea in this paper is to make an analysis of their experience, to try to establish certain geographic, topological and demographic similarities and make an estimate of the wind energy potential in SM on the basis of such analysis. This approach is relatively simple and superficial, but it is based on the results verified in practice and this gives this method certain reliability. Since Denmark and Germany, who have built significant facilities based on wind energetics, have the greatest experience in the field of wind energetics, as well as in the verification of estimates of their total wind energy potential, authors of this paper during their research tried to establish certain similarity between wind energy potential in these two countries, which can be considered sufficiently reliable, and the wind energy potential in SM. It is known that the great dependance of wind properties on micro locations causes errors that are inevitable in these comparisons. Since the main objective of this paper is to make an estimate of the total wind potential in SM, this approach provides an estimate which is more reliable than those based only on meteorological data and theoretical models.

3 State of Wind Energetics and Wind Energy Potential in Serbia and Montenegro

There are great regional differences in the availability of wind energy in SM and significant differences are present even at small distances. The availability of wind energy in Serbia is greater in lower areas than in higher ones. Northeastern part of Serbia is characterized by a strong local southeast wind – košava. The descending component of this wind is stronger that it's ascending component, which appears at the same time. The fact that košava most often blows during colder parts of the year underlines how important it would be for Serbia to couple mutually the utilization of solar and wind energy. During warmer parts of the year more dominant influence has west wind – northwest and southwest wind (thirty years ago it attained the peak velocity of 170 km/h). In this period, the available wind energy is much lower than in winter, but the consumption of electricity is also lower. It happened only exceptionally that some variant of a tornado blew through these parts. This was the case in summer 1977, in Negbone village, near Nova Varoš.

In SM there are no installed modern wind generator capacities nor have been carried out any large specific measurements of wind for the purpose of determination of the country's total wind potential. Rare analyses and studies of wind potential in SM are fully based on the data recorded by anemographs in meteorological stations. As we have concluded that such data cannot be used directly for estimations of total wind potential, a completely different approach is used in this paper, where hydrometeorological data about wind are used for the estimation of the degree of similarity of our winds with winds in Denmark and Germany. Comparative analysis certainly introduces some errors which are the consequence of the adopted method itself, and also of the fact that technically usable wind energy potential is related only to winds whose average annual velocity at 10 m above the ground is greater than 5.1 m/s. It is thus necessary to consider only these winds in the comparative analysis. This approach, i.e. model, can be used only for the estimation of total wind potential, while for the identification of suitable microlocations it is necessary to carry out special measurements in SM. Comparative analysis of relevant parameters for Denmark, Germany and SM is given in Table 3.

Wind potential in Denmark is contained in mainland (*onshore*) winds and in sea (*offshore*) winds in seaside regions. Besides 3 117 MW built capacity in wind generators, Danish government has approved the construction of additional 4 000 MW till 2010, and long term plans (till 2020) include the construction of 10 000 MW in total that would produce approximately 50 % of the national demand for electric energy. On the basis of these plans, which are based on the real wind energy resources, it can be concluded that the wind energy resources in Denmark are about 20 000 MW, 50 % of which are concentrated in sea winds and 50 % in mainland winds. This figure can be taken as reliable, because it comes as a result of a longtime experience and extensive measurements, which were corrected on the basis of practical experience.

If wind maps of Denmark, [5] and SM, [3] are analyzed and compared, it can

Table 3. Comparative analysis of parameters relevant for the analysis of wind energy potential for Denmark, Germany and Serbia and Montenegro (january 2005)

	Denmark	Germany	Serbia and Montenegro
Area [km^2]	43 000	357 000	102 000
Population density [inh/km^2]	120	230	100
Average wind velocity [m/s]	(5-8)	(4-7)	(4-6)
Total installed power of electric power system [MW]	10 000	120 000	9 000
Total production of electric energy [MWh]	36 500	504 000	35 000
Total consumption of electric energy [MWh]	35 500	500 000	40 500
Power installed in wind generators [MW]	3 117	16 629	0
Portion of wind energy in the total produced electric energy [%]	20	5	0

be concluded that mainland winds in SM are about (20-30)% weaker, that is

$$\begin{aligned} v_{av(SM)} &\sim (0.7-0.8)\cdot v_{av(D)} \Rightarrow P_{av(SM)} \sim \left(0.7^3-0.8^3\right)\cdot P_{av(D)} \\ P_{av(SM)} &\sim (0.343-0.512)\cdot P_{av(D)} \sim 0.4\cdot P_{av(D)} \end{aligned} \tag{1}$$

The number of wind generators which can be constructed in a certain region depends on the amount of unoccupied area at suitable locations. For the reason of mutual compatibility it is necessary to provide the adequate distance between wind generator units, so that the number of wind generators per 1 square km of unoccupied area is not greater than 8-12 (Figure 7), depending on wind generator's diameter, which corresponds to 10 MW of installed power per 1 square km of unoccupied area. If unoccupied area is taken as the criterion, then, in comparison to Denmark, that has 10 GW of technically utilizable mainland wind potential, SM would have 25 GW mainland wind potential if winds would be of the same quality

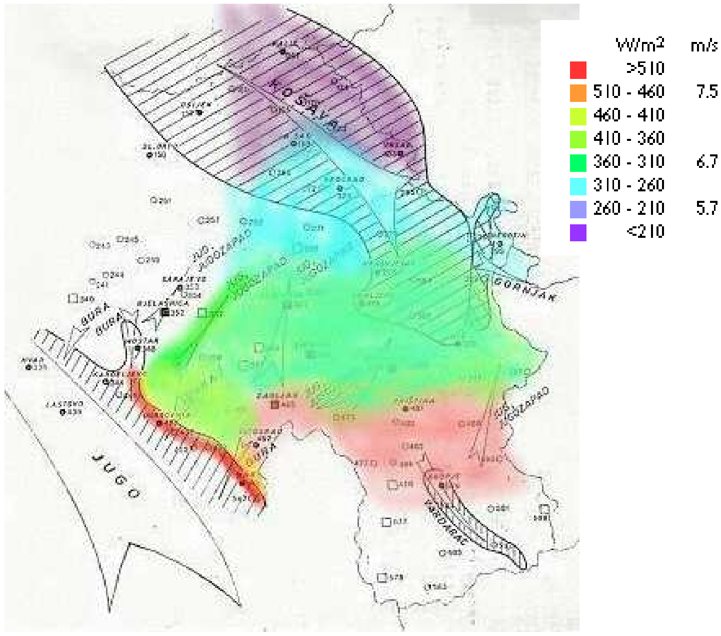


Fig. 6. Map of wind energy resources for winds in Serbia and Montenegro

as those in Denmark:

$$
\begin{aligned}
WP_{(SM)} = & WP_{(D)} \frac{A_{(SM)}}{A_{(D)}} \left(\frac{v_{av(SM)}}{v_{av(D)}} \right)^3 \\
& = 10 \frac{102000}{43000} (0.75)^3 \approx 10GW
\end{aligned} \tag{2}
$$

Therefore, estimates can be made which show that technically utilizable wind potential in SM is about 10 GW.

If wind maps of Germany, [6] and SM, [2] are analyzed and compared, it can also be concluded that the intensities of average annual wind velocities are quite similar. On the assumption that wind velocities in SM are (10-20)% lower than in Germany, we get:

$$
\begin{aligned}
& v_{av_{(SM)}} \sim (0.8 - 0.9) \cdot v_{av(G)} \Rightarrow P_{av(SM)} \sim \left(0.8^3 - 0.9^3\right) \cdot P_{av(G)} \\
& P_{av(SM)} \sim (0.512 - 0.729) \cdot P_{av(G)} \sim 0.6 \cdot P_{av(G)}
\end{aligned} \tag{3}
$$

In the study on wind energy potential of mainland winds in Germany, German Ministry of Economy presented data showing that the total technically utilizable mainland winds potential in Germany is about 64 000 MW of installed wind generator power. On the basis of this data and on the previous analysis, it can be concluded that wind energy potential of mainland winds in SM is

$$\begin{aligned} WP_{(SM)} &= WP_{(G)} \frac{A_{(SM)}}{A_{(G)}} \left(\frac{v_{av(SM)}}{v_{av(G)}} \right)^3 \\ &= 64 \frac{102000}{357000} (0.85)^3 \approx 11.2 GW \end{aligned} \quad (4)$$

Fig. 7. Distance between wind generators.

Consequently, two completely independent analyses gave similar estimates of total wind potential in SM. According to the data presented in the European Wind Atlas, [5], southern Adriatic falls into the category of seas whose windiness is medium. From this aspect, it would thus be possible to install in SM significant capacities at sea (offshore). The limiting factor in this undertaking may be depth of the sea in the coastal belt, because today's technology of laying column foundations in sea is at such level that it is economically justified to build wind generators only in shallow waters.

It can be concluded that the total technically utilizable wind energy potential (mainland + sea) in SM is as follows: $WP_{av(SM)}$ =(8.000÷15.000) MW

If wind generators would work with average factor of utilization $\eta_{av} = 0.23$ they would be able to produce electric energy:

$$W = \eta_{av} \cdot P \cdot t = 0.23 \cdot 10GW \cdot 8760\,h \approx 20\,TWh/year \quad (5)$$

what makes about 50 % of today's demand for electric energy in SM. One of the possible scenarios for the construction of wind generators in SM is to install in the following fifteen years 100 MW/year. At the end of this period these wind generators would provide about 10 % of the electric energy in the ecologically most acceptable way.

It is important to say that even at today's level of development wind generators have become competitive in relation to classical sources of electric energy both with respect to price and with respect to the quality of the produced electric energy (Figure 8).

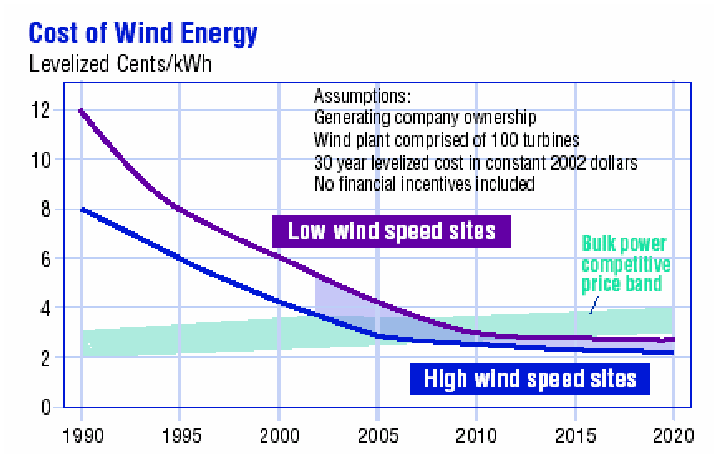


Fig. 8. Price of the ecologically clean electric energy produced by wind generator.

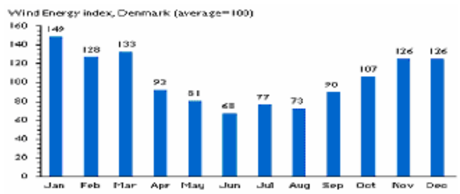
4 Regions in Serbia and Montenegro Suitable for the Construction of Wind Generators and Possibilities of Utilizaton of Wind Energy in the Production of Electric Energy

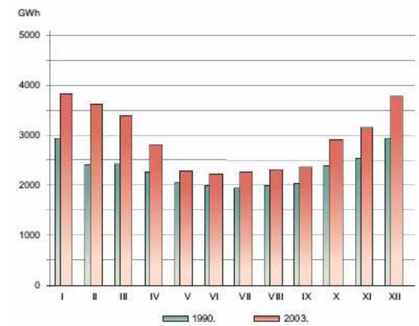
The structure of electric power systems in SM is favourable in regard to the integration of wind generators. The existance of the reversible hydroelectric power-plant Bajina Bašta makes possible the takeover of surplus of electric power in the conditions of strengthened wind, that is, when wind generators are producing electric energy. Stable hydro potential (Djerdap hydroelectric power-plants) can also provide the efficient regulatory reserves and by this the stable work of the system, even in the conditions when variations in the production by wind generators are great. As a rule, wind generators are connected to the distributive systems, thus relieving significantly national grid of its load. Besides these advantages, losses in the grid would be lowered on the account of the decentralization of production. Voltage conditions would also be improved as distributive systems would be able to manage the production of active and reactive energy of wind generators which are practically located at the door-step of consumption. In our country winds are generally mostly present when the demand for the electric power is the greatest and analyses of wind variations made at daily level show that even wind daily variations follow the consumption diagram. Therefore, both at a daily or annual level, energy obtained from wind would in the conditions prevailing in our country have the character of peak energy.

Regions in SM with locations potentially suitable for the construction of wind generators are:

1. Eastern parts of Serbia - Stara Planina, Ozren , Vlasina, Rtanj, Deli Jovan, Crni Vrh, etc. There are locations in these regions with average wind velocity $v_{av} > 6$m/s, which corresponds to the power of P_{av}=(300-400) W/m^2. This area covers about 2000 km^2 and in the future about 2000 MW of installed wind generator power might be built here;
2. Pešter, Zlatibor, Žabljak, Bjelasica, Kopaonik and Divčibare are mountain regions which abound in winds, where measurements may be taken and appropriate suitable micro locations found (at altitudes over 800 m) for the construction of wind generators;
3. Pannonian Plain, north of Danube, i.e. wider region of the territory where košava wind blows also abounds in winds. This area covers about 2000 km^2 and is suitable for the construction of wind generators because the basic infrastructure already exists, from roads to electricity grid, and also because of the vicinity of big centers of electric energy consumption, and the like. In future, it would be possible to install there about (1500-2000) MW of wind generator capacities;
4. Montenegrin seaside region, that is, belt along the coast from Ulcinj to Herceg Novi 20 km wide, whose area is about 1000 km^2. Average wind velocity in this area is $v_{av} > 7$m/s and average wind power is P_{av}=(400-600) W/m^2. This area is also from some other aspects suitable for the construction of wind generators (it is not wooded, proximity of the grid, absence of problems concerning visual influence on the environment, and the like). This shows that about (1000-1500) MW of wind generators power coud be built here. Along the Montenegrin seaside region there are many mountain-ridges and hills (sites above Budva, Tivat, Kotor, and so on) where the average wind power at altitudes of 50 m may be over 1000 W/m^2. There are also areas in western parts of Montenegro which are potentially suitable for the utilization of wind.

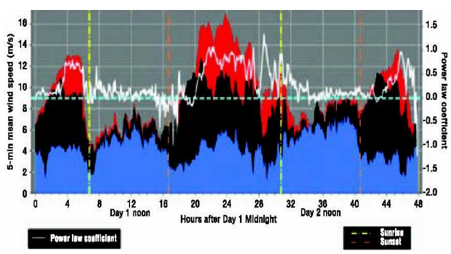
Wind generators have a great number of applications. Concerning the utiliza-

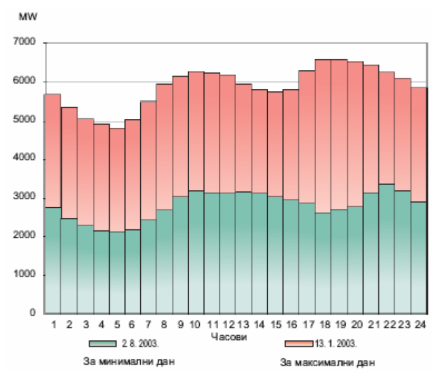




(a) (b)

Fig. 9. (a) Typical monthly variation of mean wind velocity (values denote percentages of mean annual wind velocity) for the particular location in SM. (b) Monthly consumption of electric energy in EPS in 1990 and in 2003.





(a) (b)

Fig. 10. (a) Typical daily variations of mean wind velocity for the particular location in SM. (b) Daily diagram of gross consumption of electric energy in EPS in 2003.

tion of wind energy, systems of wind generators can be classified according to their power. Thus, it can be said that there are systems based on big wind generators which are connected to the national grid (systems of generators of up to 4500 kW). Second group of wind generators is comprised of systems of medium size wind generators in hybrid power systems, combined with other energy sources (photovoltage, hydro, diesel sources), or of systems which are used as a power supply for water pumps, or for recharging accumulators, and so on. Because their power is between 10 and 150 kW, it is not economical to connect them to the national grid. Third group of wind generators consists of small stand alone wind generators of up to 10 kW, which are used for recharging accumulators, as a power supply for water pumps, for heating, etc. It is only a question of time when will in SM be installed the first modern wind generator for the purpose of producing electric energy. However, before this happens, certain conditions must be met: the state has to define clear policy on renewable sources of energy, law must allow individual legal and physical entities to take part in the production of electric energy.

5 Conclusions

The structure of electric power systems in SM is very favourable for the construction of wind generators. Their construction should be done in phases, in the course of which it would constantly be necessary to monitor the technical efficiency and economy of already built capacities and accordingly correct the future dynamics of the construction of wind generators. It is shown in this paper that the wind energy potential in SM is about 10 000 MW (20 TWh/year) and that there are many locations in SM where individual wind generators of medium to high power can be put, and at least 50 good locations where wind generators farms could be installed. These farms, which would include wind generators of about 20 MW (50×20 MW=1000 MW), could be realized in the next 10-15 years. One of the possible scenarios for the construction of wind generators in SM is to install in the following fifteen years 100 MW/year. At the end of this period these wind generators would provide about 10 % of the electric energy in the ecologically most acceptable way. Regardless of the chosen strategic model of the development of electric power systems, there will always be a need present and probably also an obligation for the utilization of ecologically clean sources ("green energy"). If our global objective is the integration into the European Union, then it is clear that the reform of the energetics sector must be conducted in a way where all processes in the development of energetics in EU must be followed. Most of the European states have had the experience which shows that it is necessary to include wind energetics in the national strategy for the development of energetics in SM. In relation to this, the first step could be to determine wind energy potential and suitable locations for the construction of future modern wind generators which will produce electric energy in SM.

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