Particular Review on SODAR and LIDAR Measurements of Bora Wind in Mostar, Bosnia and Herzegovina

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***Abstract* - Recently, Bosnia and Herzegovina has been falling behind the countries of SE Europe in all segments of power industry. Besides other energy resources (coal and water are the most significant), huge potential lies in renewable energy sources, primarily wind, small hydropower, sun and biomass. Unfortunately, these potentials are not used sufficiently. This paper discusses basic characteristics of the wind energy in Bosnia and Herzegovina, with a specific emphasis on estimation of the wind potential on the complex terrains and under diverse conditions of the Bora wind, as well as the discussion on presented results of the research on wind characteristics by using specialized equipment (SODAR and LIDAR) at the locality of Podvelezje (Mostar). Availability of LIDAR obtained data was considerable better as compared to SODAR ones. Results for wind direction correspond relatively well. The increase of wind speed with height is very small, which can be caused by the complexity of the wind conditions. That was the very first handling of this equipment under local conditions in Bosnia and Herzegovina. Presented results of the measurements are significantly useful, although they have certain imperfections. Additionally, it gives a brief reference to the complexity of the wind potential research under complex conditions of wind type in Bosnia and Herzegovina, giving in this way a contribution to a more realistic estimation of economically feasible potential, which will consequently help to create required strategic documents in Bosnia and Herzegovina.**

***Index Term*-- wind energy, SODAR, LIDAR, Bora wind, Mostar, Bosnia.**

I. INTRODUCTION

Bosnia and Herzegovina's energy import is low as 38%, indicating that the country significantly uses domestic energy from the coal, wood and hydropower. However, the country is 100% import dependent for oil and gas [1] and import volumes are increasing. If electric power sector has been evaluated, than can be concluded that Bosnia and Herzegovina is an exporter of electricity.

Total installed capacity in electric power plants is 3 536.2 MW, with a planned annual production of 13 166.3 GWh in 2012. Out of this amount, the maximum installed powers of the power transmission network is 2 030.6 MW in 14 hydropower plants or 57.4% out of total capacity, with planned annual production of ca. 4 820 GWh in the transmission network or 36.6% out of total planned production in 2012. The total maximum installed power of 4 thermo-electric power plants in the transmission network is 1 505.6 MW or 42.6% out of total capacity, with planned annual production of 8 346 GWh or 63.4% out of total planned annual production in 2012 [2].

The production of electric power is at the level of pre-war production in 1990. In the final consumption of electric power households participate with 43.9%, industry 7%, and 20.4% all other consumers including construction industry, traffic and agriculture in 2010 [2].

An increase in electric power consumption is expected to reach an annual rate of 3.3% in the forthcoming period until 2020 [3,4].

Bosnia and Herzegovina consumes 30% - 40% of energy less and ca. 25% less electric power as compared to the consumption average in countries of SE Europe. The energy intensity is high as in other SE Europe countries, and utilizes a lot of energy per GDP (GDP/C about 3 300 € in 20105), which is about four times more than in 25 countries of the European Union (without Romania and Bulgaria) [3,4,6,7]. Therefore, Bosnia and Herzegovina is behind SE European countries when it comes to all of the energy industry segments.

These indicators clearly show that economy is ineffective in energy using to reach an adequate GDP, which is manifested through the ratio between energy costs, and a GDP, as well as high energy intensity. This proves that Bosnia and Herzegovina is an underdeveloped country, with an ineffective system of primary energy conversion and energy consumption in general. New energy sources would contribute to a faster and stronger economic development. However, that makes sense only with parallel measures for increased technical and social energy usage efficiency.

Since Bosnia and Herzegovina is facing amalgamation to the EU, the country is under obligation to meet certain EU standards, i.e. has to adjust its regulations and legal system. This applies to the energy sector as well. Also, it should be noted that Bosnia and Herzegovina has no formal national or regional energy policy or reform plans although its energy industry has to develop the strategy of energy industry until 2020. The Study of Energy Sector in Bosnia and Herzegovina [4] and Strategic Plan and Program of the Energy Sector Development of Federation of Bosnia and Herzegovina [3] will serve as a starting point for an energy industry development strategy.

The basic potential of renewables represents: biomass, wind, sun and small hydro power [3,4,8]. The RES action plan has to be developed as in other SE European countries with own RES goals. At the same time, there is “fear” within certain companies that renewables will represent a huge problem when it comes to their integration into the existing electric-power system, its management, etc.

This paper describes the wind energy resources in Bosnia and Herzegovina, with a specific emphasis on diverse conditions of the Bora wind. This paper will also compare and analyze results of the research on wind characteristics by using the measurement mast and specialized equipment (SODAR and LIDAR) as well as equipment behavior under harsh meteorological conditions at the locality of Mali grad (Mostar). This equipment has been used first time in the area of Bosnia and Herzegovina.

II. MEASUREMENTS OF WIND CHARACTERISTICS AND ESTIMATION OF WIND ENERGY POTENTIAL

The systematic observations and measurements of wind characteristics in Bosnia and Herzegovina have been performed for over 120 years. However, the first measurements with adequate equipment and technology aimed at determining of the wind energy potential, started in April 2002 at the location of Sveta Gora – Podvelezje (Mostar). In the previous period wind characteristics have been measured at 12 meteorological stations. In addition, mostly these stations have been installed within big urban areas and inadequately equipped for the wind potential estimation. This data is being digitized as part of FP6 project SEEWIND [9] (see more at www.seewind.org). This situation, as well as the terrain complexity and diverse wind conditions resulted in the lack of appropriate data base for accurate wind atlas production, i.e. determining wind potential for the electricity production. Thanks to analysis of this information and satellite snapshots [9,10,11], the area of south Bosnia and Herzegovina has been recognized as an interesting region for wind power plants installation (Figure 1) [9].

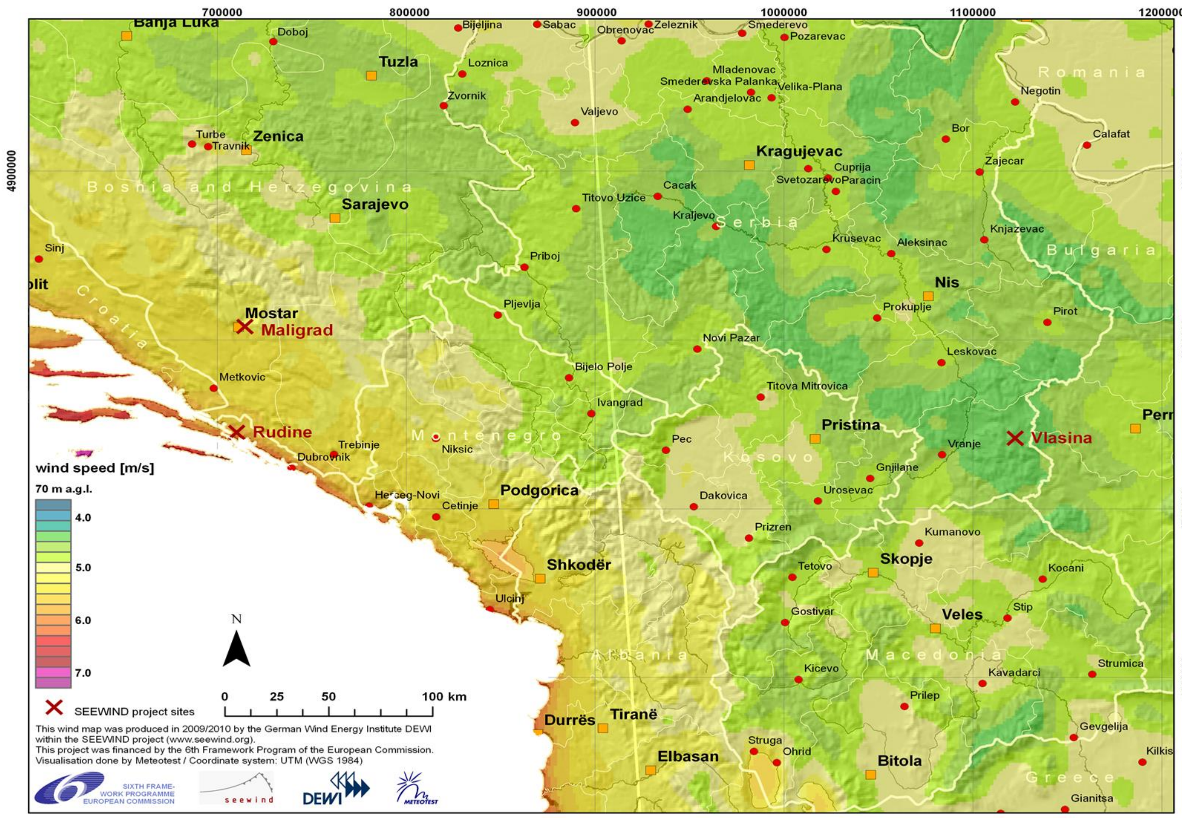

Fig. 1. Wind map at height 70 m above ground.

Therefore, the first analyses, research and investigations of the wind power potential were related to the area of south Bosnia and Herzegovina. A total of 39 locations with measuring equipment have been installed at 18 different areas prior to 31st December 2008 (A map of locations shown in [11]). The exact number of locations where the measuring was performed is difficult to determine at the moment, due to the undefined base in the register of projects on RES for the entire Bosnia and Herzegovina. At these locations the wind speed and direction have been measured at different heights (6, 10, 25, 30, 40 and 50 m) by using the anemometers and the wind vanes with a 10-minute measuring average. The measurement period lasted for 6 months and longer. The information acquired from these measuring stations could be considered as a representative and useful for further analysis. The analyses have revealed that some locations have good potentials, but the others not. Based on this research, several wind farms have been already planned, with an installed power of about 200 MW, and with a high energy efficiency coefficient [11].

First measuring and research have resulted in new discoveries. In other words, it was necessary to develop and implement a “particular” research model due to distinctive features of the area and the wind conditions [12-14]. The terrain and wind Bora [15-18] (local language Bura) complexity required a greater number of measuring locations in an area of interest (see [19]), therefore, the measurements were performed at 12 locations in a relatively small area of Podvelezje (about 60 km^2).

There were number of factors that influenced the precise estimation of the potential construction of wind power plants, deficiency of the local spatial plans, as well as many other factors. Additionally, it demands a certain number of the representative input data. Considering the terrain complexity and wind characteristics, it is necessary to carry out more measurements within a longer measurement period. Only after that and after completion of the analysis it is possible to talk precisely about the potential for the wind farm construction. According to the existing analyses, economically feasible potential should be 1 000 – 1 200 MW [11].

Independent System Operator in Bosnia and Herzegovina (ISO BH), with financial support from the European Bank for Reconstruction and Development (EBRD), has started a study that was finished in 2011, which was used to estimate the level of wind farms integrity into the transmission network until 2022 [20]. According to this study, it is possible, with minimum investment, to install up to 350 MW of wind farms, yet higher values would demand a considerable reconstruction of the network.

According to the Indicative Plan of Production Development for the period 2013-2022, 48 wind parks have been registered, with an unbelievable total amount of 2 804 MW, [2] which pointing out to the unregulated area. Interestingly, the author estimation is a great success that applies to the potential installment of 50 MW until the end of 2015.

III. Vertical Wind Speed Profile and Turbulence Intensity of the Bora Wind

Strictly speaking, measured data of the wind speed at a particular location, in the calculation of wind energy, are applicable for the location where the measuring unit was installed to measure wind characteristics. Also, several questions are raised, such as: which equipment to use, what type of mast and what mounting arrangements should be evaluated, when to measure and for how long, how many locations to measure, to use remote sensing equipment or not, checking the level of continual data quality, etc.

Application of measured data in a wider area requires methods of the transformation of measured values for that region. That means it is necessary to set a comprehensive model for the vertical and horizontal extrapolation or the extrapolation of measured data and to estimate of wind potential. These models are based on physical principles of an air flow in the border area of atmosphere and they take into account different influences of the terrain and influences caused by constructions or other obstacles, as well as the issue of wind speed change caused by different height characteristics around the measuring station.

The measurement of the wind speed is best to perform at the hub height, but in the first phase of the project it is unknown which turbine type and which performances would be chosen. Also, the permanent increase of turbine mast height should be taken into consideration. The knowledge on the shape of the vertical wind profile is crucial for energy yield calculations. Mounting of a higher mast with more anemometers requires considerably higher costs. For this reason, conversion of wind speed is done at a higher height. The standard IEC 61400-1 [21]. defines the vertical profile or wind speed change with heights:

$$v(z) = v_{hub}\left(\frac{z}{z_{hub}}\right)^{\alpha} \tag{1}$$

where are: $v(z)$ the mean wind speed at the height z above the ground, v_{hub} is the mean horizontal wind speed at the height of rotor hub, z_{hub} and α is an exponent of vertical wind profile.

For onshore locations, it is recommended 0.20 for α [21], while the value of α for open sites was 0.14 in [19] and [22]. Such a value often causes deviations that depending on the terrain itself and the wind, which can be considerable. These deviations are especially visible in the complex areas. Thus, measurements of vertical profile are of great importance.

Also, Ref. [21] provides parameters necessary for the estimate of a location and selection of a wind turbine type. Turbulence intensity (I, %) is ratio of the wind speed standard deviation (σ) to the mean wind speed (v) that is determined from the same set of measured data samples of wind speed, and taken over a specified period of time [21]. It can be written as follows:

$$I = \frac{\sigma}{v} \tag{2}$$

The Bora is a strong cold katabatic wind (with the top speed of 248 km/h - measured at the Maslenicki most, Croatia), which mostly blows from north to north – east, starts suddenly and decelerate slow. There are anti-cyclonal (dry) and cyclonal (with clouds) Bora. Furthermore, there are several conditions needed for Bora (mountain massifs, different values of temperature and pressure in the heights and lowlands, etc.). Certain number of researchers investigated dynamics and structure of impact of the Bora in northern and southern Adriatic [15-17,23-27]. However, there has not been studies or research conducted on Bora in other areas where it appears, such as in Bosnia and Herzegovina.

The wind rose by directions and wind speed distribution for the height of 30 m for the locality of Plocno (Mostar) are shown in the Figure 2. The diagram shows the prevailing wind directions that are E, NNE and W.

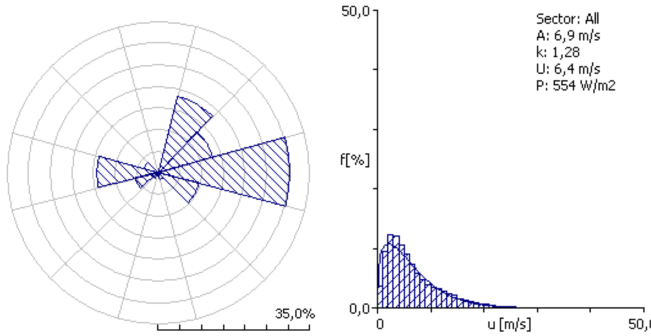

Fig. 2. Wind rose and distribution of wind at site Plocno (height 30 m).

By analyzing measured data from the same period of time, in surrounding stations with calibrated equipment of the same type and mounted at the same height, it can be noticed that there is a significant deviation in the favor of dominant winds in relation to the data from the measuring station at Plocno. The air distance between the above mentioned stations is about 7 km and locations are mutually visible. Also, the data on dominant wind directions from the measuring station Plocno are vary from the Bora wind impact direction. Further, the analysis during the period of measurement at Plocno, along with multiple checking's of the wind direction (at the location by using compass), and other characteristics of measurement during inspection of the equipment at the location, did not reveal any incorrect measuring. Thus, these described and shown characteristics of the measured wind direction are detailed by local topography and complexity of the terrain Plocno location.

IV. Equipment and Measurement Configuration

To calculate a vertical wind profile, turbulence intensity, and later to assessment wind energy potential and micrositing at certain location, one usually uses a program package which utilize measurements acquired with anemometer(s) and wind vane(s) at the mast (Figure 3, left), according to the standard IEC 61400-12-1 [28] and MEASNET (Measuring Network of Wind Energy Institutes) [29]. Recently, for complex terrains, combined equipment at the mast and SODAR and/or LIDAR are used (Figure 3, right and the middle), and their values are then compared. Measurements are performed in the periods of at least three months, in characteristic seasons. The wind speed at the mast should be measured at three different heights at least. In the next period, probably beginning from 2014, the standard IEC 61400-12-1 is expected to be changed, and a new IEC 61400-12-1 will include remote sensing techniques like the SODAR and LIDAR as well as the sonic anemometers.


Fig. 3. Measuring mast, SODAR and LIDAR at the location of Mali grad – Mostar.

SODAR (Sonic Detection and Ranging) is based on Doppler shift principle. SODAR enables measuring of all the three wind components at the height of up to 1 000 m, with an altitude resolution from 5 to 10 m. Depending on temperature field (stratification), number of missing data increases with height, which is especially visible for the speeds higher than 15 m/s. Some other imperfections that can be pointed out are big energy consumption and possible damage during transport. SODAR, also, produces noise that sometimes can negatively influence environment. To install SODAR, it is not necessary to obtain location and building permits, and its advantage is a fast data download. The accuracy of the SODAR measurement data depends, besides the already mentioned influences, on the environmental influences (noise sources, obstacles, power-transmission lines etc.). For these reasons, SODAR can show wind speed that differ from real ones, [30,31]. There are different variants of this device. Quality of equipment is reflected in its processing of the signals, i.e. in a possibility that software will recognize and filtering negative impacts.

LIDAR (Light Detection and Ranging) uses a similar principle to SODAR, with a difference that it uses light rays. It is good for determining of vertical wind profile for the heights up to 150 m. Its advantages are: better preciseness and data availability, easy transport and installation, energy saving, as well as the fact that it doesn't affect the environment. Its disadvantages are: low wind registration (under 2 m/s), influence by clouds, rain, fog and snow, slow data download and high price (five times more expensive than SODAR). Some studies point at good behavior of LIDAR [32,33], but numbers of these studies are insufficient. According to light emission, there are two types of LIDAR: continues and pulsed.

It is difficult to find "independent" evaluator, which compare LIDARs and SODARs under similar conditions, and furthermore, comparisons and field tests yet do not give enough statistical information for their proper handling. Recently, as more relevant, LIDAR is used more than SODAR.

Within project SEEWIND [9] at the location Mali Grad – Podvelezje, the measurements were performed by using special equipment SODAR and LIDAR aiming to define the vertical wind profile and analyze the mentioned equipment at sites in complex terrain and under harsh conditions of the wind Bora. This has been only usage of this equipment in the area of Bosnia and Herzegovina.

The wind speed, wind direction and turbulence intensity have been analyzed for the period when all instruments were available and functioning (22nd November 2007 – 9th December 2007). The wind speed has been measured at the mast, at the heights of 12 m and 30 m (cup anemometers Thies Classic), on SODAR (Aerovironment 4000 miniSODAR, ASC) at the heights of 30 - 15^0 m at each 10 m, and on LIDAR (ZephIR, Natural Power, continues) at 30 m, 60 m, 80 m, 100 m and 150 m. These heights correspond to the heights of wind vane, except to the point at 12 m on the mast. The averaging measuring interval was 10 minutes.

V. SITE DESCRIPTION

Mali grad is a location positioned 6-7 km east from the city of Mostar. This location is about 730 m above the sea level, while that height is for the city of Mostar about 50 m. Meteorological station Mostar is 99 m above the sea level. The mountain Velez is east of Mostar, over 1 900 m above the sea level. As it can be seen in the Figure 4, the terrain is very complex (surrounding terrain that features significant variations in topography and terrain obstacles that may cause flow distortion) [29].

Fig. 4. City of Mostar and Mali grad site.

Figure 5 shows results from the measurement mast for the height of 30 meters on the location of Mali grad. In the diagram, it can be seen that the dominant wind direction comes from the sector 15-45^0 and 165-195^0 what complies with a general activity of wind Bora what differs from the values obtained in the Figure 2.

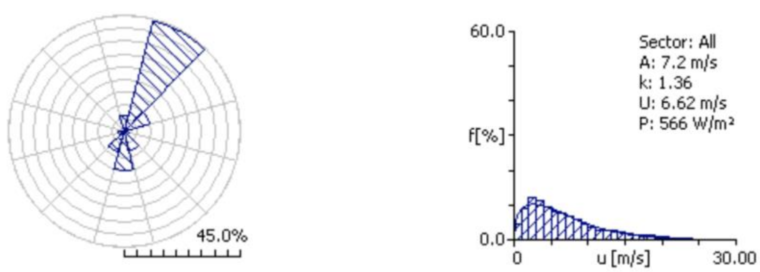

Fig. 5. Wind rose and distribution of wind at height 30 m for the Mali grad.

VI. RESULTS AND DISCUSSION

In particular time intervals data availability of the LIDAR and SODAR was different. The SODAR data availability significantly decreases with height. For the height of 60 m availability for the SODAR is 79%, for the height of 80 m it is 68% and for 100 m it is only 54%, while for the LIDAR data availability for the height of 60 m is 88%, for 80 m availability is 87%, and for 100 m it is 85% [34].

Figure 6 shows the comparison of the time series of the measured wind speeds for the height of 30 m for the SODAR (green), the mast (red) and the LIDAR (blue) for 10-min averages. Values of wind speeds read at cup anemometers and the LIDAR correspond well. While wind speed values from the SODAR in particular time intervals, especially for velocities over 15 m/s differ considerably, especially in the sector 165-195^0. Here it should be emphasized that at the time of this measurement campaign, measuring equipment at the mast was not calibrated, according to [29].

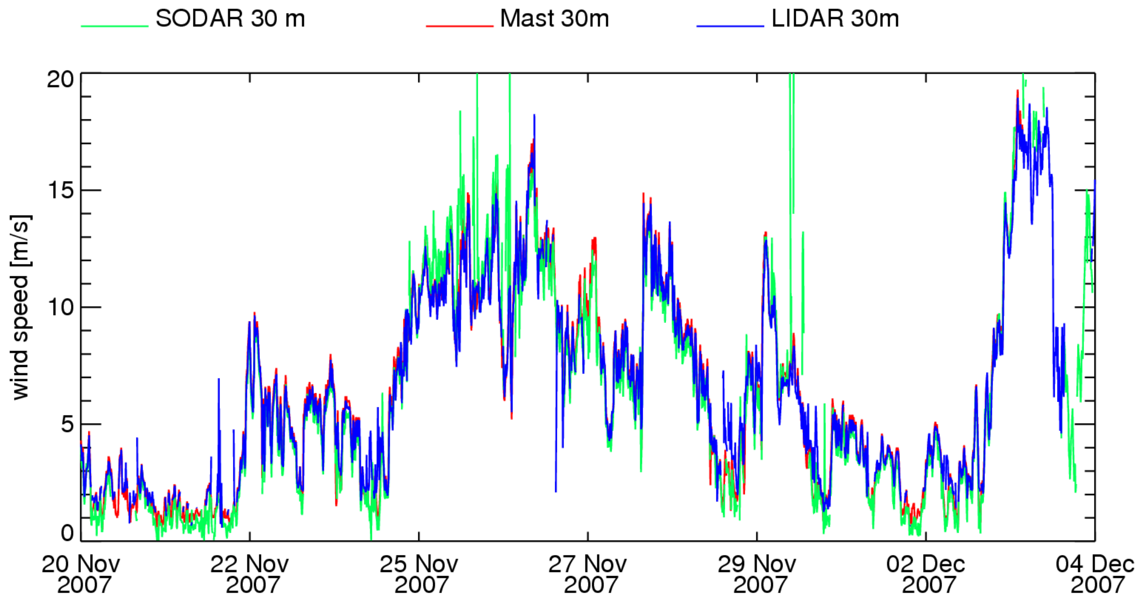

Fig. 6. Comparison of 30 m wind speeds from cup anemometer (Mast), LIDAR and SODAR.

Figure 7 shows the comparison the time series of the measured wind directions for the height of 30 m for the SODAR (green), the mast (red) and the LIDAR (blue) for 10-min averages. By analyzing processed data, it is visible that the data correspond well. However, there are periods during which both remote sensing systems have different values of wind direction compared to the cup anemometer.

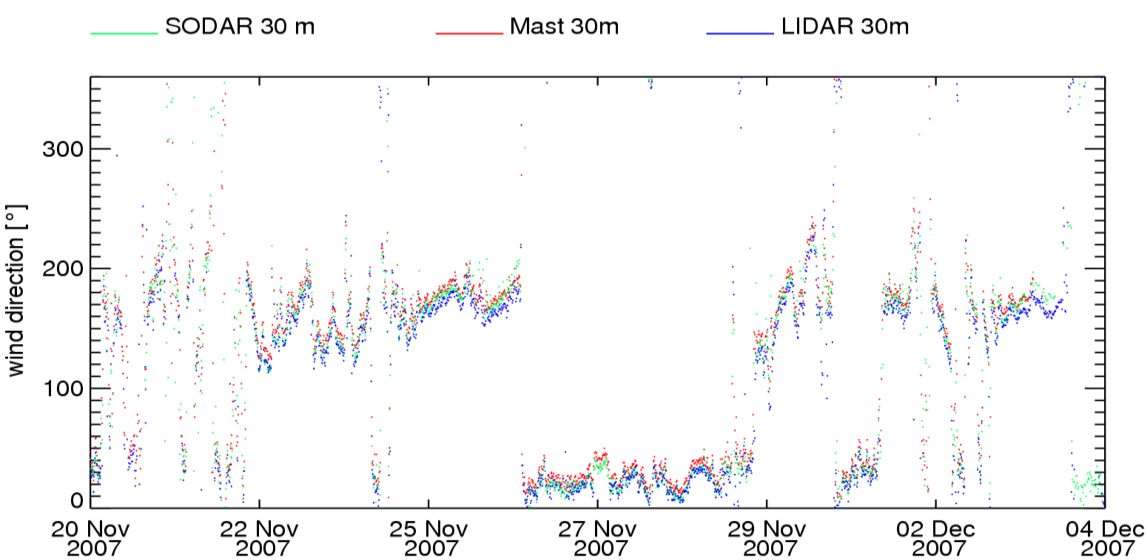

Fig. 7. Comparison of 30 m wind direction

Figure 8 shows normalized data for 60 m the vertical wind profile of the wind speed for dominant sectors. Blue color relates to the SODAR obtained, and red one to the LIDAR obtained data. By further analysis it is visible a good correspondence of the measured data obtained from the LIDAR and SODAR. It is also visible that the wind speed increase with height is bigger for the south sector (165-195^{0}), especially for the SODAR, as compared with north-north-east sector (15-45^{0}), but in total, values of the wind speed increase with height are rather small for the height up to 100 m.

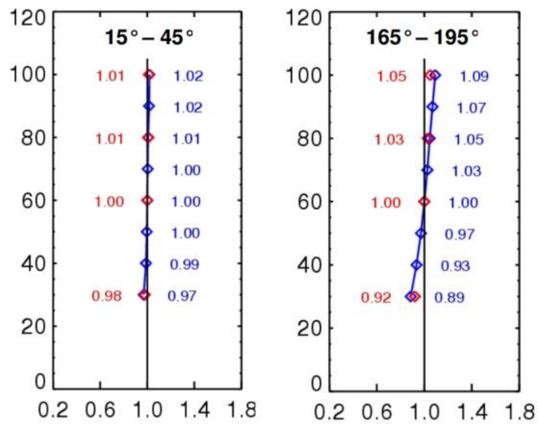

Fig. 8. Vertical wind profile.

Ref. [35] shows comparison of normalized data with LIDAR results, with results of CFD program package WindSim for sector (15-45^{0}), where profiles correspond well.

Turbulence intensity decreases with increased height at the location of Mali grad, as can be seen in the Figure 9. Data obtained by using cup anemometer. This provides additional information on the specific qualities of this location and wind conditions.

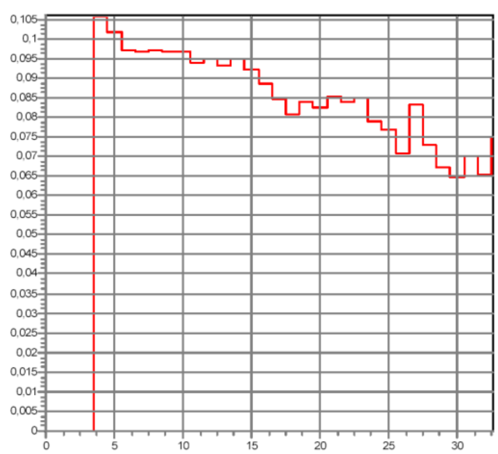

Fig. 9. Turbulence intensity at the location of Mali grad.

LIDAR and SODAR turbulence measurements are quite complicated. In addition to that, the obtained data often deviate from the real ones. Ref. [24] and [25] showed analyses of the turbulence intensity values (calculated turbulence intensity) for the two observed sectors at the height of 30 m. Only wind speeds above 4 m/s are considered. Measurement results prove that turbulence intensity is higher in the north sector (15-45^{0}), as compared to the south sector, but it is still under the class of A and B according to the standard IEC [16]. However, certain deviations exist based the data obtained by the LIDAR and SODAR as compared to anemometer in the north sector, but it is significant in the south sector (165-195^{0}).

VII. CONCLUSIONS

Bosnia and Herzegovina has considerable potentials in RES. It applies to: small hydropower, wind energy, biomass and solar energy. However, there is an obvious stoppage in implementation of RES based projects. For a successful implementation of these potential projects, it is necessary to have unambiguous political support for defining objectives, legislatives, introducing scientific – research institutions in the process, making favorable economic climate, preparation of national production capacities for equipment production, etc.

At the moment, it is impossible to discuss precisely about the real potential for the wind farm construction. Research is still incomplete and limited by the complexity of terrain, by the wind type „Bora", as well as by non-existence of necessary strategic documents and regulations on renewables. According to the rough estimation, the economically feasible potential should be around 1 000 – 1 200 MW. In any case, it would be a success to install 50 MW before the year of 2015.

Using the remote sensing equipment at the location of Mali grad (Podvelezje), Mostar has resulted in new discoveries. The knowledge of the vertical wind profile and the turbulence intensity on Bora's dominated sites will provide important information on the impact on the wind turbine operating under such conditions.

The LIDAR and SODAR functioned "relatively well" in complex conditions of the terrain and wind characteristics of Bora.

Availability of the LIDAR obtained data was considerable better as compared to the SODAR ones. For example, for the height of 100 m availability for the SODAR was only 54%, while for the same height the LIDAR data availability was 85%. Data quality obtained from the SODAR for the wind speeds higher than 15 m/s decrease considerably depending on the sector.

Results for the wind direction correspond well, but in certain southern sectors there were some deviations, especially for the data from the SODAR.

The vertical wind profile, obtained by using the LIDAR and SODAR correspond quite well. At the measuring site, the increase of wind speed with height (vertical wind profile) was very small, which could be caused by the complexity of the terrain and wind conditions, which all results in incompetence of certain program packages and values of the exponent of vertical profile α, in Eq. (1), to estimate the wind potential in complex terrains and Bora wind conditions.

The turbulence intensities for both prevailing wind directions are below class A and B of the IEC 61400-12-1, which was not increased at a higher wind speed.

It should be stressed again, that this was the very first usage of remote sensing equipment in these complex terrains and specific work conditions so in addition to a large number of missing data, especially obtained by the SODAR, low heights of not calibrated cup anemometer (30 m) with limited time intervals of the combined equipment functioning (15 days) and all weaknesses in usage of such equipment, these obtained data should be used with reserve. That requires installed mast with cup anemometer at the height of 80 m, whose results are expected in the forthcoming period. For more relevant observance of Bora characteristics and behavior of the equipment in a complex location like this one, it is necessary to carry out measurements in a longer period of time (at least 3 months) and in different seasons.

ACKNOWLEDGMENTS

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