Regular paper

Wind Power Utilization

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***Abstract*—This paper briefly describes reasons for the wind utilization development recently and physics of wind power utilization as well. Also, recent statistic data concerning temporary installed capacities, distribution of wind power among European countries, predictions for the future and likely scenarios in next years are presented. The paper explains reasons for tendencies toward large wind farms with emphasis on offshore wind farms, i.e. their main characteristics, advantages and disadvantages as well. There are some facts about first projects of wind power utilization in B&H and Republika Srpska.**

***Index Terms*—Wind Power Utilize, Offshore Wind Farms, Stričići Wind Farm Wind Power, Wind Power Installed Capacity, Wind Turbines.**

I. Introduction

Wind power exploit was introduced long time ago but real breakthrough has begun from the end of 20th century. There were two main reasons for that:

A. First

The demand for energy, especially for electricity, has increased in the last years significantly, and thus environmental impact of the energy production increased seriously, also. CO_2 emission has already reached critical level and the energy production turn to environmental friendly production could be way to decrease a CO_2 emission. Politicians and most of country governments were faced with dangerous data about environment future in a case if pollution remains in same amount. So, many governments began to subsidize environmental benign energy production. Also, *green forces* have started to protest and demand more and more for some real action in global manner.

B. Second

The technology has increased on that level that production of large scale wind turbines (in MWs) was available with reasonable costs. From the early beginnings there were turbines with few KWs, nowadays there are available turbines up to 5 MW installed power with huge blade span and large heights.Potential investors have recognized wind power as profitable, so financials weren't problem any more. The first wind farms have already launched (up to 160 MW of installed power). The installation of bigger ones is just logical step forward. As the consequence of above mentioned, wind is temporary the fastest growing energy source, especially in Europe, with predictions to become dominant industry in next decades.

The global benefits of wind power [9]:

- Reduces climate change and other environmental pollution
- Creates employment, regional growth and innovation
- Fuel source is free, abundant and inexhaustible
- Global wind resource is bigger than global power demand
- Diversifies energy supply, eliminates imported fuels
- Reduces poverty through improved energy access
- Modular and rapid to install

II. The Physics of Utilizing Wind Energy

An air mass moves due to different thermal conditions of the mass.

The power of the wind, flowing at velocity v through an area A is:

$$P_{wind} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3$$

where,

- P_{wind} is the wind power [W],

- ρ is the air density [kg/m^3],

- A is the swept area [m^2],

- v is the wind speed [m/s].

From the equation above, it is obvious that the wind speed has the greatest impact on wind power, with third power.

The power in the wind is converted into mechanical-rotational-energy of the wind turbine rotor, which results in a reduced speed of the air mass. The power in the wind cannot be extracted completely by a wind turbine, as the air mass would be stopped completely in the intercepting rotor area.

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The theoretical maximum power extracted from the wind is determined by the Betz optimum. According to the Betz, the

theoretically maximum that can be extracted from the wind is:

$$P_{Betz} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot C_{PBetz_z}$$

where,

- C_{Pbetz} is the maximal power coefficient and it is equal 0.59.

That means, the 59% of wind power is the maximum power that a wind turbine can utilize. Taking into account and trailing rotational wake, the theoretical maximal power is even less then one from Betz, about 0.55. With new blade design the efficiency of energy conversion approaches the Betz optimum.

Wind energy conversion systems can be divided into those that utilize either aerodynamic drag or aerodynamic lift. The modern wind turbines are predominately based on the aerodynamic lift, due to fact that turbines utilizing the aerodynamic drag have a very low power coefficient.
The horizontal-axis turbine based on an aerodynamic lift is the approach that dominates within conventional wind turbine applications. Horizontal-axis wind turbines use a different number of blades, depending on the purpose of the wind turbine. Two or three bladed turbines are usually used for electricity power production. Turbines with twenty or more blades are used for mechanical water pumping. Turbines with more blades have high starting torque and, therefore, require a high solidity of swept area [1], [7].
Three bladed turbines dominate the wind power market. They have better moment distribution on the rotor and mechanical parts. Three blade turbines produce less noise and they have ”better” visual impact on environment comparing to two bladed. Mechanical loads are better distributed using three blades. But the two bladed turbines have fewer blades what make them cheaper. Note that the costs for a three-bladed rotor are about 20 % of wind turbine's total costs [1]. So, fewer blades makes turbine’s cost cheaper significantly.

III. Wind Power Nowedays and Predictions for Future

Wind power has already been approved as the dominant source of environmental friendly energy production. Leading EU countries seriously plan to have great amount of wind energy in total energy needs.

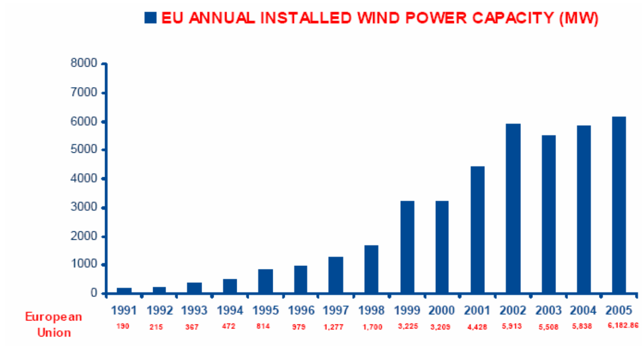

Fig. 1. Installed wind power through last years [3].

Over the last ten years, cumulative wind power capacity in the EU has increased by an average 32% per year over the ten year period from 1995 to 2005. In terms of annual installations, the European market has grown by an average 22% over the same period. In 2005, the European market grew by 6%, to 6,183 MW (from 5,838 MW in 2004). The growth was achieved despite a combined reduction in installations of more than 500 MW between Germany and Spain [3]. Progression of wind power over last years is presented in *Figure 1*.
The top five European wind energy markets in 2005 were Germany (1,808 MW), Spain (1,764 MW), Portugal (500 MW), Italy (452 MW) and the UK (446 MW). In cumulative installed capacity, two countries have more than 10 GW (Germany 18,428 MW and Spain 10,027 MW) and seven countries have more than 1GW (Denmark 3,122 MW, Italy 1,717 MW, UK 1,353 MW, Netherlands 1,219 MW and Portugal 1,022 MW, as well as Germany and Spain) [3]. These data are tabulated in *Table I*.

TABLE I
WIND POWER PROGRESSION IN EU IN 2005 [2]

EU CAPACITY (MW)

	Total at end 2004	Installed Jan-Dec 2005	Total at end 2005
Austria	606	218	819
Belgium	96	71	167
Cyprus	0	0	0
Czech Republic	17	9	26
Denmark	3,118	22	3,122
Estonia	3	27	30
Finland	82	4	82
France	390	367	757
Germany	16,629	1,808	18,428
Greece	473	100	573
Hungary	3	14	17
Ireland*	338.5	157	495.5
Italy	1,265	452	1,717
Latvia	27	0	27
Lithuania	7	0	7
Luxembourg	35	0	35
Malta	0	0	0
Netherlands	1,079	154	1,219
Poland	63	10	73
Portugal	522	500	1,022
Slovakia	5	0	5
Slovenia	0	0	0
Spain	8,263	1,764	10,027
Sweden	442	58	500
UK	907	446	1.353
EU-15	**34,246**	**6,122**	**40,317**
EU-10	**125**	**61**	**186**
EU-25	**34,371**	**6,183**	**40,504**

* Ireland: Installation figures do not include December 2005

Note: Due to previous-year adjustments, project decommissioning of 50 MW, and rounding, the 2005 end-of-year cumulative capacity total does not exactly match the year-end 2004 total plus the 2005 additions.

In Denmark, wind power already satisfies 20% of electricity consumption.
In Spain the installed wind capacity already exceeds nuclear and combined cycle gas, and will this decade overtake coal and large hydro.
In northern Germany, the federal state of Schleswig-Holstein gets 30% of its power supply from the wind [8].

By 2010, wind energy in Europe is predicted to have saved over 500 millions tones of CO_2 [6]. Today, wind power installed in Europe is saving over 50 million tones of CO_2 a year and on track by 2010 to deliver one third of the EU's Kyoto commitment [4].

At the Earth Summit and the UN climate negotiations in India in 2002, European Wind Energy Association (EWEA) launched its industry strategy-*Wind Force 12 - a blueprint to achieve 12% of the world's electricity from wind power by 2020*. The feasibility study demonstrates that there are no technical, economic or resource limitations to achieve this goal, but that political and policy changes are required in order for the industry to reach its full potential. By 2020 the industry is capable of installing 1,260,000 MW of wind energy throughout the world.
Wind Force 12 outlines that by 2010 the industry is capable of installing 230,000 MW of wind energy worldwide, 100,000 MW in Europe. By 2010 the global wind industry could be worth a cumulative €133 billion [5].

One of the conditions to fulfill above predictions is switch from small and medium size turbines to large wind turbines. Installation of higher turbines with significant bigger swept area, comparing with the ones from the end of last century, in large wind farms is giving serious role of wind energy in energy market. The development of wind turbines' sizes over years is presented in *Figure 2*.

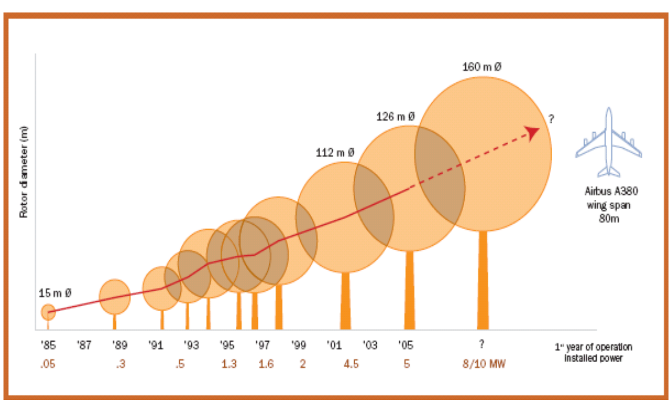

Fig. 2. The size progression of wind turbines. Mid 2005 the largest wind turbine had a diameter of 126 meters and an installed power of 5 MW [6].

Most of EU counties are already running out of available onshore sites for installation new turbines. Getting all necessary permissions for new installation locations has begun a tough job, often more complicated and more demanded than installation itself. So, replacing small turbines with bigger ones is just a logical consequence of temporary condition. The tendency of replace small turbines with bigger ones has already started but the real breakthrough is expected to begin in following years. A prediction for more power from fewer turbines in figures is presented in *Figure 3*. In order to reach these figures and expectations the governmental support and subsidies are necessary. These subsidies in some countries are reflected in a higher selling price of clean energy.
This prediction is based on assumption that new turbines units will be in MWs and installed in large wind farms, mostly in offshore wind farms. Also, such approach is considered to be more profitable for prospective investors.
According to [8], in Europe will be 75 000 MW by 2010, 180 000 MW by 2020 and 300 000 MW by 2030.

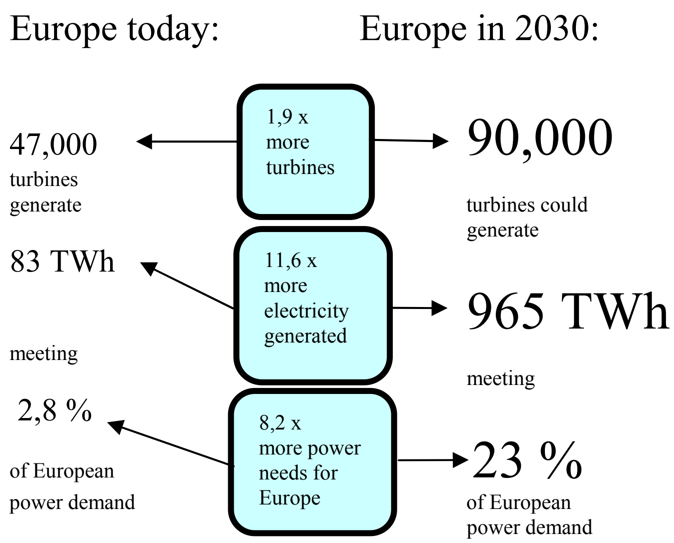

Fig. 3. Prediction for wind energy production in Europe in 2030 with bigger turbines [8].

IV. SWITCH FROM ONSHORE TO OFFSHORE

The *Figure 2* shows nowadays turbines in huge sizes. Installation of such turbines at appropriate sites can result in high energy yield. As mentioned above many EU countries are already running out of available onshore sites for installation of new turbines. Land use limitations in areas with high population density are slowing the installation of new wind farms. In some countries in Northern Europe, the public will no longer accept a significant increase in onshore wind power capacity.
Offshore, however, there are both abundant space and dense wind. Wind speeds tend to increase as you move offshore. This means that turbines built further offshore should capture

more wind energy. Unfortunately, as the distance to land increases and water depth, the cost of building and maintaining the turbines and transmitting the power back to shore also increase significantly, limiting the distance out to sea at which offshore wind projects will be built [7].

There are some advantages of offshore sites what make them preferable for wind farms installations.
An average annual wind speed is higher 20 % at least offshore; wind turbulence is less, not significant visual impact, depends on distance from shore.
From another side, rigid installation conditions like salt in air, waves, sea ice; installation is limited on few calm months; poor weather conditions and remote locations
jeopardize maintenance; connection issues are main disadvantages offshore wind farms [7].
In spite all above mentioned the first small-scale offshore wind farms were built between 1991 and 1997 in Sweden, Denmark and Netherlands. After that many wind farms were erected and for the distant future, plans have been developed for gigawatt-sized plants that employ multi-megawatt machines at sites as far as 100 km from the shore and in water depths up to 40 m [10].
The *EWEA* in [11] predicts, in EU-15 by 2010, 10 000 MW of offshore wind power installed, and 70 GW by 2020. There are 5 countries already launched offshore wind farms into operation with totally 331 turbines and 612 MW total capacity, with annual production of 2 190 000 MWh [12].

Installation of such big wind farm imposes one very important operating problem. A wind farm is not dispatchable plant as conventional one, i.e. wind velocity is very hard to predict precisely. A trip of such large wind farm or sudden increase in energy production due to decrease/increase in wind speed could make to system operators great difficulties in a power transmission system. Due to that, wind farms should behave against to power transmission system similar to conventional HPPs or TPPs. In order to prevent such difficulties it is assumed installation of reactive elements (inductors and capacitors) controlled by power electronics, at the connection point to transmission system. These devices should register disturbances from a grid and react in such manner to simulate response of conventional power plants (who have regular generator excitation what wind turbine's generators don't have).

Besides great investment and installation costs, a connection installation stands as one of the greatest limitation factors for offshore wind farms deployment. Almost each site near to shore has a weak transmission grid what increase connection costs and hence overall investment costs, also.
Offshore wind farms are supposed to be connected to shore by submarines cables, either HVAC or HVDC cables. Many reasons influence on chosen connection technology, so every project has to be evaluated individually to be able to find the most effective connection solution. Not many studies concerning connection solutions studies have been performed so far. In [7] and [13] there can be find evaluation studies of connection solutions for large offshore wind farms (up to 1000 MW) and at long distances from shore in sea (up to 300 km) for both solutions, HVAC and HVDC.
These works partially have been sponsored by *"DOWNVInD" (Distant Offshore Windfarms with No Visual Impact in Deepwater)* project. Within this project, at the beginning, it has been planned to build two demonstration wind turbines (each of 5 MW rated power) in the Moray Firth (Scotland offshore) at a depth of 40 meters. It is situated 24 km from the shore and there already exist Beatrice oil platform with 4 platforms. These two turbines will be first ones at such deep water and at such distance. So far, all offshore wind farms are installed up to 18 meters of water depth and up to 20 km from shore [7]. This demonstration project will test technologies for deepwater wind farms distant from the shore, with no visual impact. The results will help determine if large-scale developments of this type are a practical and economic source of renewable energy. The project will include the design, construction, installation and operation of two prototype turbines.
The *DOWNVInD* started in summer 2004, with the demonstration turbines for installed in 2005. Total project duration will be 54 months. For these five years of project duration, test data and useful experience from such offshore conditions should be collected. If successful, the *DOWNVInD* demonstration project could be the precursor to large offshore wind farms being built by its main sponsors in the Moray Firth offshore UK and the Midsjöbanken, offshore Sweden [7].

Comparing the HVAC and HVDC, HVAC can be considered as better solution for shorter distances, while for longer distances reactive production of submarine cable(s) are so excessive that transmission capacity for active power is decreased significantly. This solution, for large offshore wind farms, requires also offshore platform for transformer necessary to step up voltage to transmission level. For better distribution of reactive power produced by its cable, reactors have to be necessary at each cable end. Using rectors of same sizes, same reactive power is drained at each cable end [7].
HVDC solution is better for longer transmission distances. This solution requires converter stations at each cable ends what make it more expensive. From another side, using these converters enable better operational possibilities and make a wind farm more resistible from grid disturbances [13].
The comparison of HVAC and HVDC is presented in paper [14], where transmission losses are taken as criteria only.

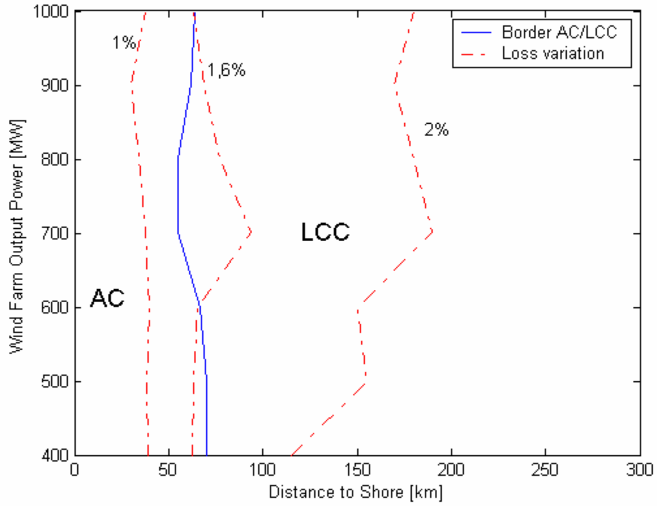

Fig.4. "*MW-km*" plane, comparison HVAC-HVDC LCC for different wind farm size (400-1000 MW) and different distances to shore (0-300 km) for average wind speed of 9 m/s [14].

Figure 4 defines border between HVAC and HVDC solutions in "MW-km" plane where overall transmission losses were taken for criteria only. As mentioned above HVAC solution has lower losses at shorter distances while HVDC solution is better for longer distances. Within HVAC transmission solution almost all losses are in transmission cable(s) (above 85 % of total transmission losses) while for HVDC solution transmission losses are mostly in power converter station (about 80 % in both converter station onshore and offshore)[14].

V. Wind Power in B&H and Republika Srpska

It is very hard to evaluate precise wind conditions in B&H since there weren't organized wind measurements. There are some data from previous measurements of meteorological stations but they weren't performed according to standards necessary to have reliable information for possible investment in wind power. Usually, these measurements have to be performed in 2-3 years to be sure in data reliability.

It is supposed that good location for wind farm installations are: some parts of Velež mountain, valley of river Neretva, highland Kupres, Glamoč. All locations are remote from the transmission lines (110 kV and higher voltages) except valley of river Neretva. Recently, the wind measurements have started on Velež and Kupres, so that first results've proved excellent wind conditions. Consequently, first request for connection permission from Power Transmisssion company of Bosnia and Herzegovina has already arrived.

Also, there are few locations in Republika Srpska supposed to have good wind conditions. These are, among others, wide area of Trebinje city and Herzegovina, some parts near to Sava river, Manjača highland and more. Herzegovina area has advantage that many transmission lines have already installed so connection problem should not be a problem.
These predictions of proper good wind conditions, in areas above mentioned, have to be proved by appropriate wind measurements, After that, it can be estimated wheather these areas are profitable for wind power utilize, either small turbines or large wind farms, or not.

The first wind turbines in Bosnia and Herzegovina are installed near to Posušje as additional supply of the PVC Factory at the road Posušje-Tomislavgrad, 7 km from Posušje. Two Lagerwey 18/80 wind turbines were installed. Nominal output power is 80 KW; the blade span is 18 meters; 2 blades; hub height 32 meters. Output voltage of asynchronous generator is 0.4 kV; there is AC/DC/AC converter as interface between generator and grid. This solution provides asynchronous work of a wind generator with grid, i.e. generator frequency is independent of grid frequency. That enables wind turbine to produce power in wide range of wind speeds. The cut in wind speed is 3 m/s, cut out 25 m/s and nominal wind speed is 12 m/s. Power curve of Lagerwey 18/80 is presented in *Figure 5*.
Investors predict annual average wind speed of 10 m/s at hub height what could give 378 MWh annually from one turbine.

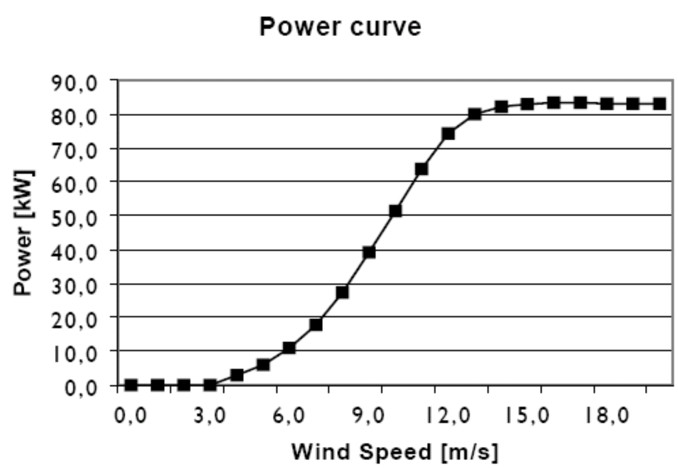

Fig.5. Power curve of Lagerwey 18/80

The first wind turbines in Republika Srpska are planned to be installed in Stričići at Manjača highland. The connection permission from local distribution company and concession approval from the Government were already applied. This small wind farm should consist of six Lagerwey 18/80 turbines connected at 20 kV transmission line Banja Luka 5 – Dobrinja. The wind farm should be connected to this line by 630 KVA 20/0.4 kV transformer. The distance between turbines is 60 m and each turbine is connected to transformer station by 0.4 kV underground cable. This solution is more expensive then connection between turbines but much more reliable. In a case of failure of one 0.4 kV cable just one wind turbine is tripped. Produced power is injected in transmission line by one 20 kV underground cable connecting 20 kV transformer side and 20 kV transmission line. Overall, all wind farm has six 0.4 kV underground cables and one 20 kV underground cable. According to measurements, performed periodically from 2003, the average wind speed should be 6 -

8 m/s at least. This wind speed should yield 160 – 283 MWh annually from one wind turbine, i.e. 960 - 1698 MWh from six wind turbines. Since turbines are situated relatively close to each other, 60 m, it is supposed that all turbines are affected with same wind speed, i.e. produce same output power. Generally, in large wind farms, distance between adjacent turbines should be 8-9 times blade diameter in order to avoid wake effect and have same air mass conditions for each turbine. In this wind farms that should be 8 - 9 x 18 meters equals 144 – 162 meters. These distances should increase cables lengths in total and investment costs significantly so distances are shortened.

So far, there are none wind turbines installed in all Republika Srpska and this attempt in first one. If succeed this wind farm will give first reliable wind measurements at this area and give first results from wind power utilize in this part of Republika Srpska.

Since, this is first such project in Republika Srpska, local authority is expected to recognize importance of it and support it in a manner of necessary permissions, at least.

Temporary, there is no precise legislation to lead such projects towards final realization like for conventional power plants but first steps are made. In many EU countries, the government's subsidy such clean energy what in our case is not even proposed.

It is expected that first results will present this energy production as ecologically and economically viable. In that case, wind power expansion and investments in much bigger projects are logical step further, what happened in European countries at the end of last century.

VI. Conclusion

Wind power expansion has started from the end of last century and main reasons for that were recognize from governments and politicians and last technological progress in materials. New blade design already reached Betz optimum and turbines are growing towards big units, up to 5 MW. In future, less number of turbines is supposed to give much more energy as consequence of replacing small units with big ones. Onshore sites, available for wind farm installation is already running out, so wind farms sites are moving to offshore where are abundant space and wind. It is expected that first large wind farms (up to 1000 MW) should be installed offshore. In spite of big investment necessary for offshore installation large offshore wind farms are expected to be profitable during their normal exploit life.

Wind power utilization in Bosnia and Herzegovina and in Republika Srpska has begun recently. After first serious wind measurements and first KWhs from few small already installed turbines the real breakthrough is expected. Also, parallel with this first steps, legal regulation has to be adjusted as well as governmental subsidy and subsidy from local authorities, similar to other countries with advanced wind industry.

VII. References

[1] Gasch R., and Twele J., 'Wind Power Plants: Fundamentals, Design and Operation', Solar praxis AG, Germany, 2001.

[2] www.ewea.org, June 2006. Available: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/statistics/2005statistics.pdf.

[3] www.ewea.org, June 2006, Available: http://www.ewea.org/fileadmin/ewea_documents/documents/press_releases/2006/060201_Statistics_2005.pdf.

[4] www.ewea.org, June 2006, Available: http://www.ewea.org/fileadmin/ewea_documents/documents/press_releases/2005/0630_-_Windforce_12_-_FINAL.pdf.

[5] www.ewea.org, June 2006, Available: http://www.ewea.org/fileadmin/ewea_documents/documents/news_releases/ewea/021113-europeanwiindenergyachieves_40percgrowthrate.pdf.

[6] www.ewea.org, June 2006, Available: http://www.ewea.org/fileadmin/ewea_documents/documents/projects/SRA/SRA_final.pdf.

[7] Todorovic J., 'Losses Evaluation of HVAC Connection of Large Offshore Wind Farms', Master Thesis, Royal Institute of Technology, Stockholm, Sweden, December 2004.

[8] www.ewea.org, June 2006, Available: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/briefings/no_fuel_lo_res_72dpi.pdf

[9] www.ewea.org, June 2006, Available: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/wf12-2005.pdf

[10] Ackermann T. *"Transmission Systems for Offshore Wind Farms"*, IEEE Power Engineering Review, December 2002

[11] www.ewea.org/, "*Wind Energy The Facts: An analysis of wind energy in the EU25"*, *http://www.ewea.org/documents/Thefacts_Summary.pdf*, September 2004

[12] www.offshorewindenergie.novem.nl, Available: *http://home.wxs.nl/~windsh/offshore.html,* September 2004

[13] Barberis Negra N., 'Losses Evaluation of HVDC Solutions for Large Offshore Wind Farms', Master Thesis, Royal Institute of Technology, Stockholm, Sweden, January 2005.

[14] N. Barberis Negra , J. Todorovic and T. Ackermann, "Loss Evaluation of HVAC and HVDC Transmission Solutions for Large Offshore Wind Farms" presented at *Fifth International Workshop on Large-Scale Integration of the Wind Power and Transmission Networks for Offshore Wind Farms*, April 2005, Glasgow, Scotland

[15] www.windenergysolutions.nl, Available: http://www.windenergysolutions.nl/wes18/index.htm#MEAP, July 2006

VIII. Biographies

Mr. Jovan Todorović was born in Zenica, B&H, in 1971. He received the B.Sc. degree (Dipl.-Ing.) in electrical power engineering from Belgrade University, Belgrade, Serbia in 1999 and the M. Sc. Degree in electrical power engineering from Royal Institute of Technology (KTH) in Stockholm, Sweden in 2004.

He is with Power Transmission Company of Bosnia and Herzegovina from 1999 in the Department of Power System Control.
He took participate at the *Fifth International Workshop on Large-Scale Integration of the Wind Power and Transmission Networks for Offshore Wind Farms* in Glasgow, Scotland in April 2005 where he was presented results of his master thesis in paper "Loss Evaluation of HVAC and HVDC Transmission Solutions for Large Offshore Wind Farms".

Dr. Mićo Gaćanović was born in 1952. He is recognized and known internationally as a scientist in the field of applied electrostatics, where he has given his contribution through original solutions, which are patented in 136 countries throughout the world and applied in production.

He received many prestigious world-known awards and certificates for his creative work. Hence, he is included in the work of world groups of creativity, research and new technology in Brussels, Moscow, Pittsburgh and other world cities. He is also involved in research projects from the field of theoretical electrical engineering in Germany, Belgium and Russia.