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Sea wind farms

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Key words: wind velocity, efficiency of wind turbine, power of wind turbine, mounting sea wind turbines, floating wind turbines, design analyses of wind turbines

Abstract
Wind is such an element of sea environment, from which it is relatively easy to obtain energy. Wind parameters over both seas and oceans are more favorable than those on land (due to variability of landform features). Moreover, also sea wind turbines exercise comparatively smaller negative effect on people than on land. Therefore, sea wind farms are ahead of us, as further development of wind energy. The article presents basic parameters of wind turbines, possible installations on sea bed, as well as future designs of large floating sea farms. The article presents also an example of design analyses of wind turbine, using computational fluid dynamics (CFD).

Introduction

Two basic elements of sea environment: air and water are in constant motion throughout a major part of the year. Air travels over the sea surface in the form of wind, and water in the form of sea currents and tides as well as waves (however the movement of water particles is here totally different than in sea currents or wind). The area covered by seas and oceans constitutes approx. 71% of the surface of the Earth [1], it is therefore easily conceivable, that energy resources of wind, sea currents and waves are really abundant. However, there is mainly a technical problem of obtaining such energy, as well as the effectiveness and productivity of this process.

Research into retrieving at least part of energy from sea environment has been carried out for a number of years. Major achievements can be observed in retrieving energy using the speed from travelling air (wind) to propel wind turbines. First such turbines were built on land, and later on also on sea.

The paper presents wind turbines installed on sea, their efficiency and productivity as well as their possible further developments.

Wind

A horizontal component of air mass movement of a turbulent character is called wind. The turbulent nature of this process is caused by air travelling from the area of higher pressure to the area of lower pressure. For this reason, wind is a complex random process both in space and time.

For air travelling over sea area, whose size and depth are large in relation to wind turbine dimensions, the Reynolds number, is defined by the formula:

$$\mathrm{Re} = \frac{\bar{V}_A \cdot L_A}{\nu_A} \tag{1}$$

where:

$\bar{V}_A$ – average wind velocity;
L_A – sea length;
ν_A – coefficient of air kinematic viscosity,

reaches large values even at a really small mean wind speed $\bar{V}_A$. The Reynolds number (Re) is then larger than critical, and air flow over free sea surface or around wind turbine is turbulent.

Wind is characterized by three basic parameters: velocity, direction, and gust coefficient.

Horizontal air velocity has two components: mean speed value of a constant direction and value, and speed pulsation of changeable direction and value. Instantaneous wind speed therefore equals:

$$V_A(t) = \overline{V}_A + u_A(t) \tag{2}$$

where:

- $\overline{V}_A$ – mean wind speed, whose value depends on mean time lapse and height above the sea level (the influence of height and mean time is presented, among others in [2]);
- $u_A(t)$ – component of the wind speed pulsation around mean value, concordant with the wind direction.

Maximum wind speed, exceeding mean value, is the wind speed blowing in gusts.

Direction of wind action, is the direction from which the wind blows. In terms of values, wind direction is determined either in an angular system (degrees) or a 16-direction system, called the wind rose. It is often that the wind rose contains information on probability of wind occurring from a given direction (in some cases the total probability from a given direction is divided into probabilities for separate sections of mean wind speeds from that direction, Fig. 1).

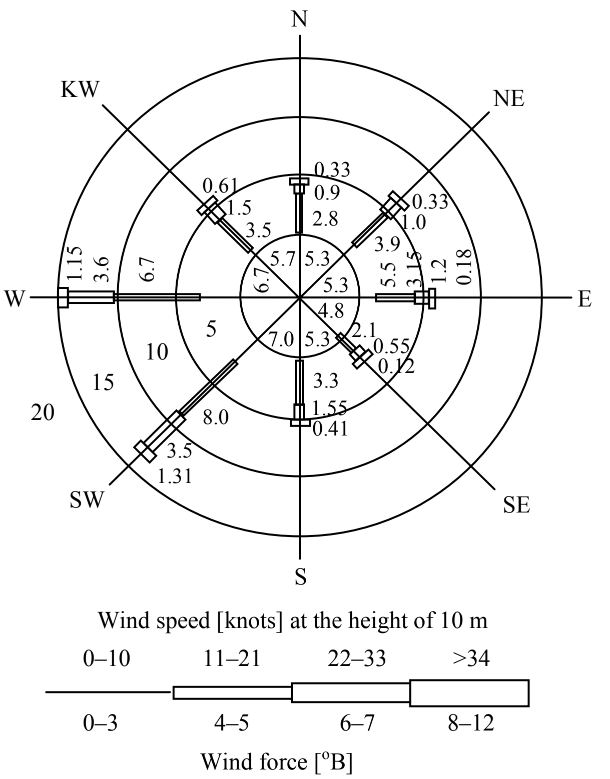

Fig. 1. Wind rose showing occurrence probability of speed $\overline{V}_{10A}$ and direction (numeral values in this figure determine how often velocity $\overline{V}_{10A}$ in [%] can occur from given direction)

Wind gustiness is characterized by a mean gust coefficient k. Instantaneous gust coefficient equals:

$$k = \frac{V_{A\max}}{\overline{V}_A} \tag{3}$$

where $V_{A\max}$ is a maximum mean wind speed in a short period of time, e.g. 0.5 s. Mean gust coefficient is a random value and decreases with an increase of height above sea (surface).

The value of mean wind speed changes in accordance with the height above sea (surface) at which this speed is measured, resulting in the so called wind velocity profile (Fig. 2 – wind reaches full velocity above 22 m above sea surface). The dependence of mean wind speed on height can be approximated by the following equations:

$$\frac{\overline{V}_{AZ}}{\overline{V}_{A10}} = \frac{\ln \frac{z}{z_0}}{\ln \frac{10}{z_0}} \tag{4}$$

$$\frac{\overline{V}_{AZ}}{\overline{V}_{A10}} = \left(\frac{z}{10}\right)^{\alpha} \tag{5}$$

where:

- $\overline{V}_{A10}$ – mean wind velocity at the height of 10 m above sea level;
- $\overline{V}_{AZ}$ – mean wind velocity at the height z;
- z_0 – sea "roughness" level (wind speed at this level equals zero); $z_0 \approx (0.2 \div 0.5)$ cm;
- z – the height above sea level, for which speed V_A is calculated;
- α – exponent, usually $\alpha = 0.1 \div 0.15$.

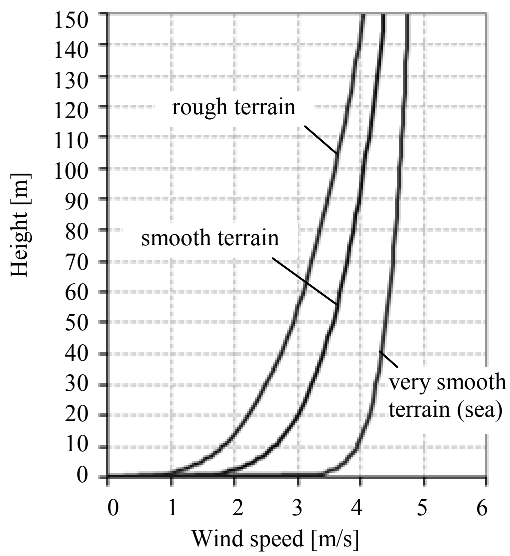

Fig. 2. Change in wind speed in the function of height above sea surface (wind speed profile) [3]

Measurements of long-lasting mean wind speeds are kept in order to install sea wind turbines (as well as land ones). These measurements show very good wind conditions in the southern Baltic Polish region (Fig. 3).

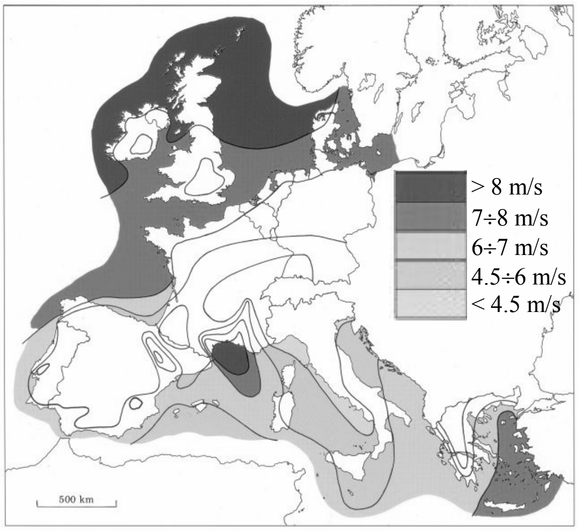

Fig. 3. An overview of European wind resources on open sea, on the basis of [4]

Efficiency and power of wind turbine

Air flow through wind turbine results in emergence of aerodynamic forces on the blade of a turbine. One from components of the resulting aerodynamic force – the component tangent to the rotor surface – causes rotations of the turbine rotor. Air stream flowing through turbine rotator, decreases its speed due to rotor rotations (Fig. 4).

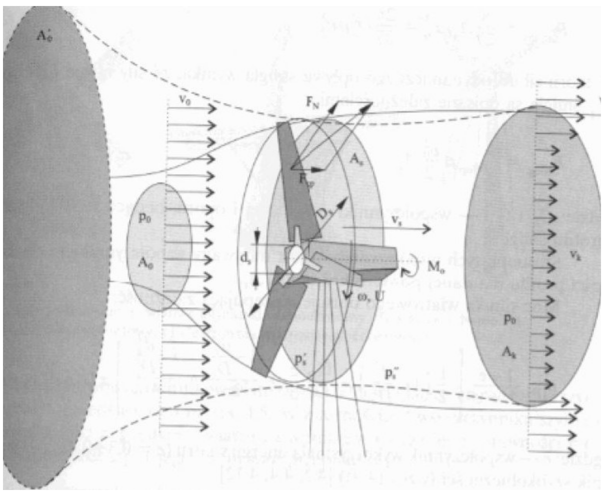

Fig. 4. Air flow through turbine [5]

If the speed of air stream behind the rotator fell to zero, it would mean that all energy of the airflow was taken up by the turbine rotator. It is not possible in practice, and best results, e.g. turbine efficiency can be achieved when air speed behind the turbine equals approx. 1/3 of the speed in front of the turbine [6].

Power output of an ideal turbine equals:

$$P_u = \frac{1}{4} A \cdot \rho_p \cdot \left(V_0^2 - V_2^2\right) \cdot \left(V_0 + V_2\right) \tag{6}$$

and efficiency:

$$\eta = \frac{P_u}{P_w} \tag{7}$$

where:

A – circle surface area of turbine rotator;
ρ_p – air density;
V_0 – air stream velocity in front of turbine rotator;
V_2 – air stream velocity behind turbine rotator;
P_w – air stream power in front of turbine rotator

$$P_w = \frac{1}{2} A \cdot \rho_p \cdot V_0^3 \tag{8}$$

Theoretical efficiency of an ideal turbine equals $\eta_t = 0.59$. Efficiency of a real turbine depends on:

- degree of air stream homogeneity flowing through turbine rotator [7];
- profile, surface and length of turbine blades (there is an optimal profile and surface area of rotator blades for a given wind speed) [8];
- power load on turbine rotator (the lower the load, the better efficiency);
- energy loss resulting from friction and transfer of the rotator torque on (electric) current generator.

In order to increase turbine efficiency:

- it (a turbine) is installed on such height, as to make the flowing air stream as homogenous as possible (Fig. 2);
- the diameter of turbine rotator is increased, as to decrease the component of power load on turbine rotator.

The increase of rotator diameter is, however, restricted by a maximum linear speed, tangent to the top ends of turbine blades (Fig. 5):

$$V_K = R \cdot \omega < \text{the speed of sound} \tag{9}$$

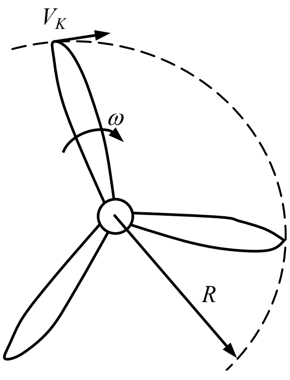

Fig. 5. Linear speed of a top end of a turbine blade

A wind turbine has a maximum efficiency at a given wind speed. Such turbine works within a range of wind speeds, hence its power (and its efficiency to certain extent) changes as well (Fig. 6 and 7).

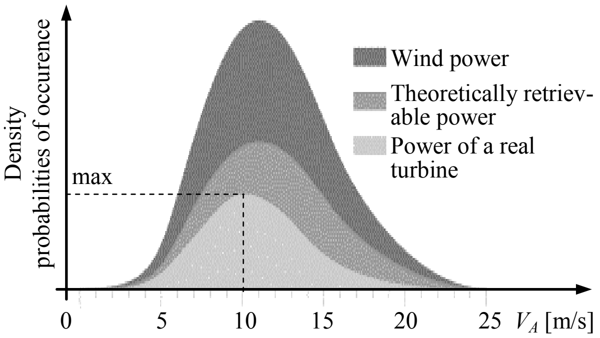

Fig. 6. Distribution of turbine power density in the function of wind speed [5]

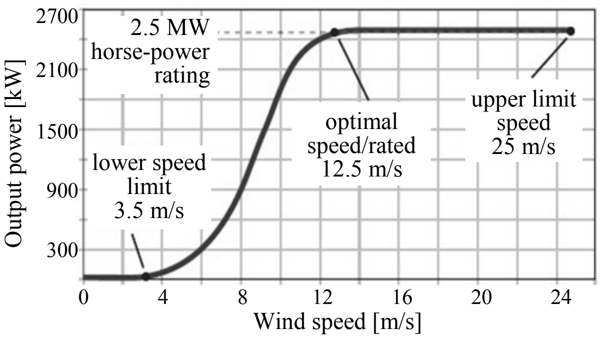

Fig. 7. The speed range of turbine work 2.5 MW GE – Energy [9]

Sea wind turbines

Sea wind turbines are similar in built to the land ones. On smaller water depths areas they are seated on seabed.

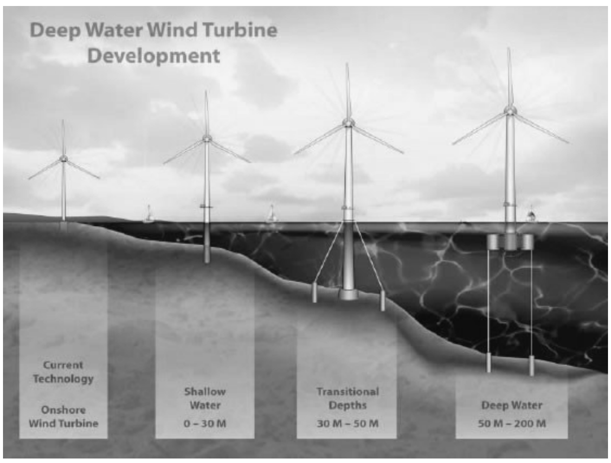

Fig. 8. Possible ways of mounting wind turbines depending on sea depth [10]

Floating turbines are designed and built for larger depths, moored to seabed with elastic anchoring systems (Fig. 9). A floating moored turbine, can move (up and down and to the sides) on waves, which results in a small decrease of its efficiency and power in comparison to the turbine rigidly mounted on seabed.

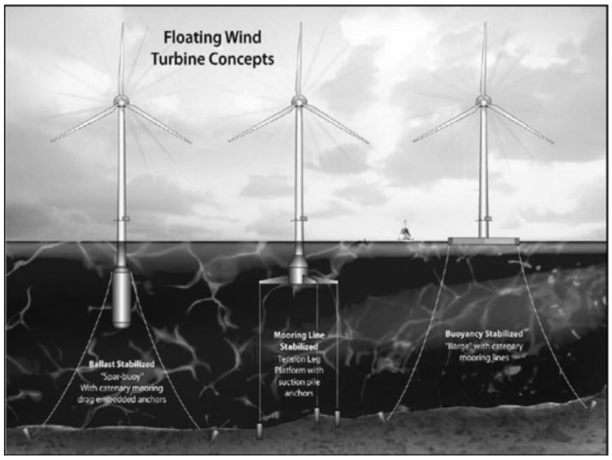

Fig. 9. An example of three design concepts of floating wind turbines [11]

Striving to increase power or diameter of wind turbines installed at larger depths, resulted in emergence of new designs e.g. of floating structures, on which several (up to twenty) wind power stations would be simultaneously installed (Fig. 10).

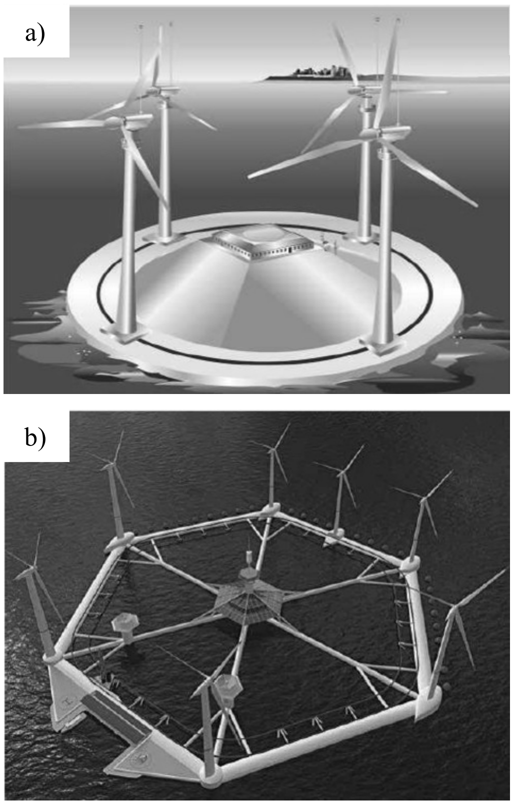

Fig. 10. An example of floating platforms with a larger number of wind turbines [12, 13]: a) a concept proposed by Stansbury Resources, b) a solution offered by a Swedish company Hexicon

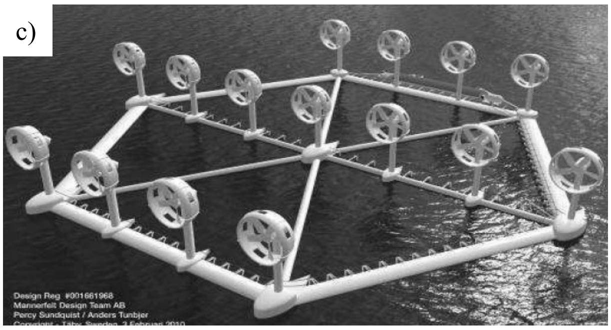

Fig. 10. c) a joint concept of two companies Innowind and Hexicon

An example of design analyses of a wind turbine

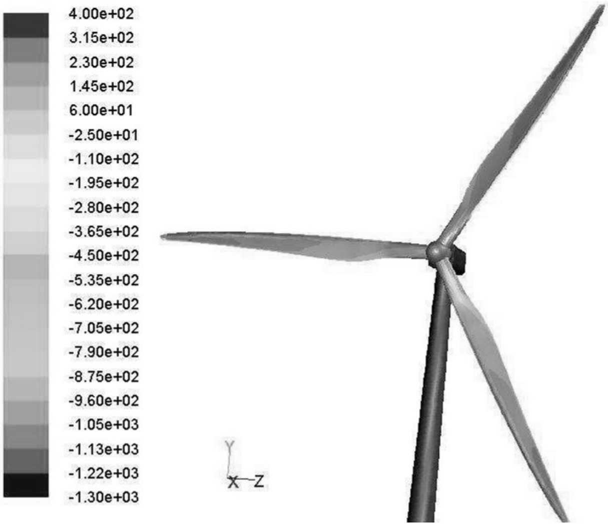

Fig. 11. Distribution of pressures on the thrusting side of the rotator for a rotational speed of 13 rpm

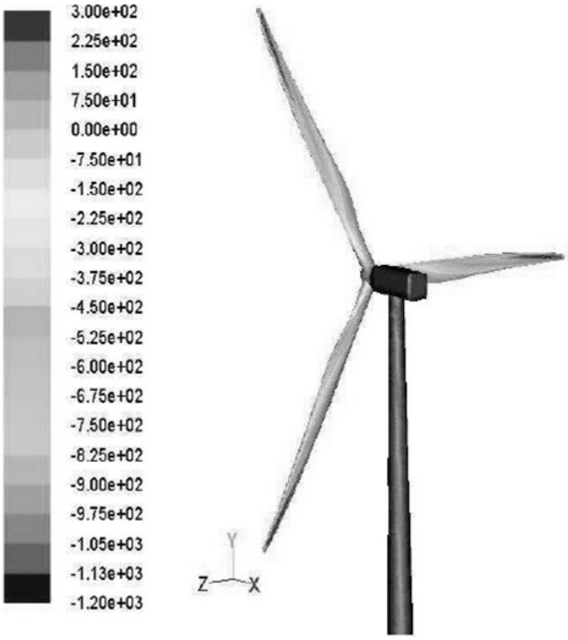

Fig. 12. Distribution of pressures on the thrusting side of the rotator for a rotational speed of 15 rpm

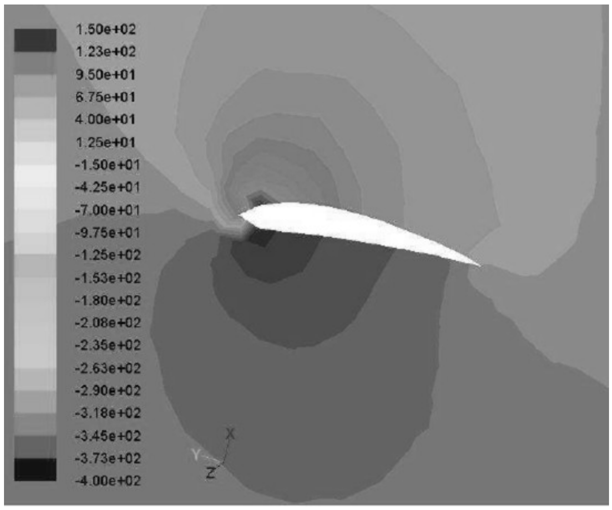

Fig. 13. Distribution of pressures around the profile of wind turbine blade for a rotational speed of 15 rpm

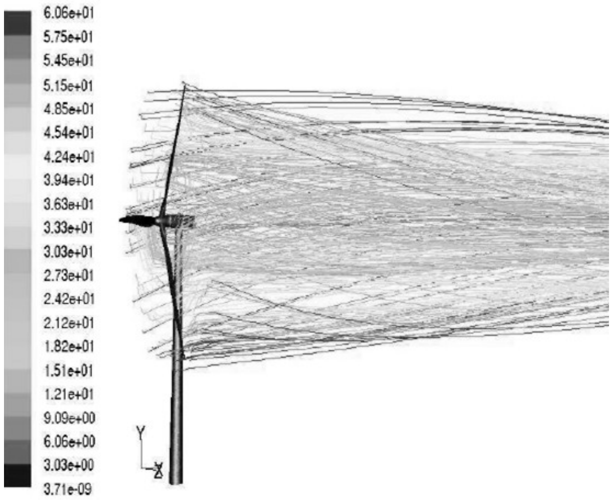

Fig. 14. Current lines behind the profile of a wind turbine

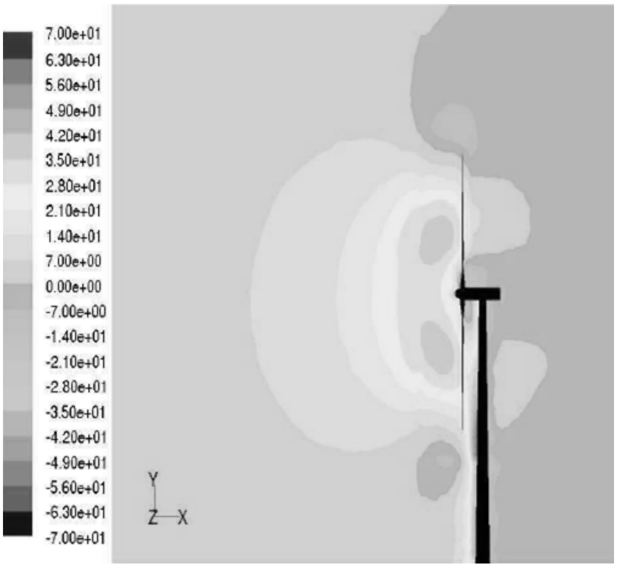

Fig. 15. Pressure distribution around turbine

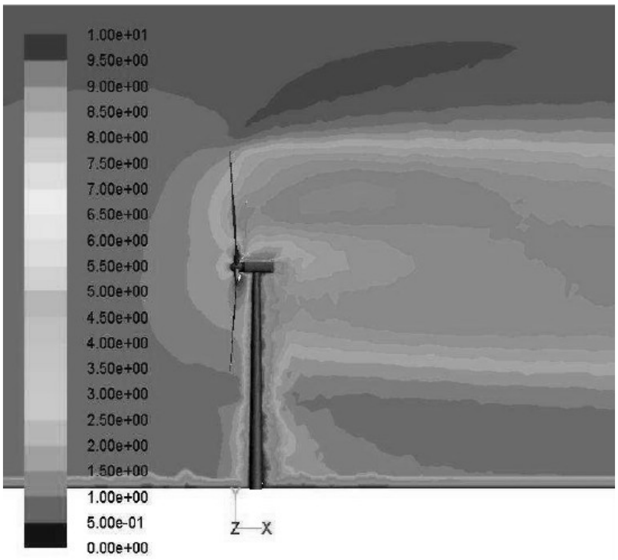

Fig. 16. Distribution of wind speeds around turbine

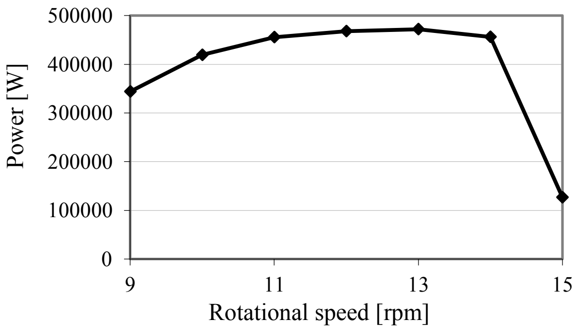

Fig. 17. The relationship between turbine power and rotational speed

The figures 11–17 presents an example of design analyses of wind turbine, using computational fluid dynamics (CFD).

Conclusions

Wind conditions present in the southern Baltic are very favourable for wind power industry.

Sea wind turbines can achieve slightly better efficiency due to a more homogenous airflow above the sea surface.

Adverse influence of wind turbines on natural environment is smaller on sea than on land.

Sea offers better conditions for building large wind power stations, also floating at larger sea depths.

References

1. DUXBURY A.C., DUXBURY A.B., SVERDRUP K.A.: Oceany świata. Wydawnictwo Naukowe PWN, Warszawa 2002 (in Polish).
2. Environmental Conditions and Environmental Loads. Det Norske Veritas, No. 30.5, March 2000.
3. www.green-power.com.pl – firma Green Power Development zajmująca się projektowaniem turbin wiatrowych [access 12.06.2014]
4. www.windatlas.dk – duński serwis zawierający mapy wietrzności wybranych krajów świata [access 12.06.2014].
5. LEWANDOWSKI M.W.: Proekologiczne odnawialne źródła energii. Wydawnictwo Naukowo-Techniczne, Warszawa 2003 (in Polish).
6. DĘBIŃSKI A. (Red.): Młody technik. Wydawnictwo AVT, 2005 (in Polish).
7. WOLAŃCZYK F.: Elektrownie wiatrowe. Wydawnictwo KaBe, Krosno 2009 (in Polish).
8. MĘŻYK A., JURECZKO M.: Optymalizacja wielokryterialna łopat elektrowni wiatrowej ze względu na minimalizację drgań. Wydawnictwo Politechniki Śląskiej, Gliwice 2006 (in Polish).
9. www.controlengpolska.com – artykuł poświęcony turbinom wiatrowym [access 12.06.2014]
10. www.globaloffshorewind.wordpress.com – strona poświęcona tematyce dotyczącej energii wiatrowej [access 12.06.2014]
11. www.large.stanford.edu – artykuł poświęcony turbinom wiatrowym [access 12.06.2014]
12. www.hexicon.eu – firma Hexicon zajmująca się projektowaniem turbin typu offshore [access 12.06.2014]
13. www.pesn.com – serwis poświęcony energetyce wiatrowej [access 12.06.2014]