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Conversion of Wind Energy into Rotational-Mechanical and its Impact on Wind Power Generators

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Abstract: *Presented is the conversion of wind energy into rotational mechanical in the use of wind turbine generators (WTG). Power density G depends on the third power of the wind speed. The very wind speed dependet on the height above the ground, such as up to 450 m it increases and then decreases. With the development of technology, materials and knowledge of aerodynamic processes, the actual usage is rapidly increasing and approaching the limit. Only in the period 1998 - 2004, it has increased from 22 to 38%. To obtain the generated electric power must be taken into account losses in the gearbox, in the generator, the various conversions and also in the propeller due to the contamination and damage of the surface of the propellers.*

Keywords: *Wind turbine generators, conversion of wind energy into rotational mechanical, generated electric power*

1. Introduction

The necessity for diversification of the energy generation, which arises from safety requirements, unsteady prices of the fuel and climate changes, leads to the development of non-conventional sources (wind, small hydroelectric stations, solar, tide, geothermal resources, etc.) or the so called renewable energy in the entire world. The advanced countries have already accepted renewable energy as a key tool to decrease bad emissions in the environment, as well as to achieve energy independence, to diminish the import of oil, gas and coal.

Wind electrical power is a new class of energy, different from the conventional types. It sets a lot of new problems concerning its generation, as well as its inclusion in the existing networks.

The energetic potential of the wind is indeed remarkable. About 1÷2 % of the solar energy falling on earth is turned into wind energy. For comparison, the energy absorbed by plants through photo synthesis and transformed into bio mass is only 0.02÷0.03 %, almost hundred times smaller. Modern civilization, often considered quite lavish, consumes about 0.005÷0.006 % of this energy [1]. According to the estimation in [2] the actual energy consumption could be satisfied by wind power generation at height up to 80 m on 20 % of the sites, with average annual wind rate above 6.9 m/sec.

The world resources of easily obtained wind power is evaluated at 1 500 GW, with annual production of 3.10^{12} kWh, that makes 500 kWh per an inhabitant of the already over 6 milliard world population [3, 4].

The main technology for wind energy generation is based on the well known old wind wheel. Its improvement during the last decades has moved this technology to its limit capacities – deriving energy up to 50 % from the ground wind layer at height up to 180 m. The generation is limited by Betz law, and the diameter of the wheel (propeller) – by the mechanic strength of the materials used.

2. Conversion of wind energy into rotational mechanical

The kinetic energy carried by the wind through the intersection Q for the 1 sec, is:
or expressed by surface power density (specific power)

$$E_R = \frac{1}{2} mv^2 = \frac{1}{2} PQv^3$$

$$G = \frac{1}{2} mv^2 = \frac{1}{2} PQv^3$$

Here $\rho[kg/m^3]$ is the air density in this area, and $V[m/s]$ - wind speed. Density ρ is a function of temperature ú, atmospheric pressure and is given by the relationship [5]

$$\rho = \frac{\rho_0}{R_d\,(T+\beta.z)}\left(1+\frac{\beta.z}{T}\right)^{1-\frac{9}{R_d{}^{\beta}}}$$

Here $\rho[kg/m^3]$ is the density of dry air under pressure - the level of sea level and temperature 25^0 C, R_d - gas constant, T - local temperature in ^0K, z – altitude, $g = 9{,}81[m/s^2]$ – gravity, $\beta = 6{,}5^0\,C/km$ - vertical temperature gradient in standard atmosphere

Power density G depends on the third power of the wind speed. The very speed dependent on the height above the ground, such as up to 450 m it increases and then decreases. To use wind power interest is the range of 40-150 m, which include wind turbine generators (WTG). In this area, the relationship can be represented by empirically equation [5, 6]

$$v_h = v_{h_0}\left(\frac{h}{h_0}\right)^{\alpha}$$

where v_h is the rate of height h, v_{h_0} is the known speed of height h_0, α is experimentally determined coefficient. The value of α may vary within wide limits depending on the height, the time of day, season, temperature, nature of the terrain. In Table 1 are given typical values of α, dependent on the shape of the terrain (the covering surface) [6].

Table 1

Terrain type	α
Sea, lake, smooth ground surface	0.1
High grass on rough terrain	0.15
Tall crops, shrubs	0.20
Woodland with lots of trees	0.25
Small villages with trees, shrubs	0.30
Cities with tall buildings	0.40

Although the value of α is not large, it has a noticeable impact on the specific power due to strong depending on wind speed. This dependence can be used to select the optimum height of the pylon of WTG. It allows for a more realistic estimate of wind resources of the country on the available data on the rate charged for the needs of meteorology. They relate to height above ground 10 m. Drivers with height of 80 m, and for the smallest value of α = 0.1, specific power increases $\left[v_{10}\left(\frac{80}{10}\right)^{0,1}\right]^3$ fold.

Certain specific power G implies a reduction of wind speed to zero. Taking into account the need to shift the volume of air which is withdrawn from the kinetic energy in order to give way to the new volume of high velocity air, the usable part of G is substantially less than 1. Marginal, theoretical usability, in the absence of losses, known as the limit of Betz is 16/27 = 59.3% [3]. It can be considered achievable technical approach to this boundary 0.8, which often gets assigned the value of utilization rates.

$$c_P = 0{,}59^3.0{,}8 = 47{,}3\%$$

With the development of technology, materials and knowledge of aerodynamic processes, the actual usage is rapidly increasing and approaching the limit. Only the interval 1998 - 2004, it has increased from 22 to 38%. [7]. In Table 2 are given the specific power G and the aerodynamic power P for the most common wind turbine with a diameter of the propeller (rotor) 77 m, capacity 1,5 MW and depending on the wind speed.

$$P = \Pi \frac{D^2}{4} GW^3[W] = 1{,}0268 v^3 [kW]$$

$$G = \frac{1}{2}.1{,}225.0{,}38.v^3 = 0{,}22 v^3 \left[W/m^3\right]$$

Table 2

$v[m/s]$	4	5	8	10	12	15	20
$G[W/m^2]$	14,11	27,56	112,90	202	381	744	1764
$P[kW]$	65,71	128,34	525,7	1027	1774	3465	8214

The nominal power of the WTG is given for a rated wind speed, which in most generators is set in the range of 12-16 m / s.

Data on wind picture in our country, comparisons with other countries and assessments of the prospects for wind energy in our country are given in [8, 7]. For Kaliakra considered the most promising area for wind energy, maximum speed does not exceed 8,3 m / s, which means $\left(\frac{12}{8{,}3}\right)^3$ times less power than the nominal for the majority of existing WTG. From presented data show that the energy density of wind in England is an order of magnitude higher than in Bulgaria.

In Table 3 shows the relationship between the diameter of the propeller, respectively, the surface of which is extracted wind power and power to the shaft for a nominal wind speed 12 m / s and $G = 0{,}22V^3\left[W/m^2\right]$.

Табл. 3

$P[MW]$	1.2	1.8	3	5.4
$G[W/m^2]$	63.4	77.66	100.2	134.5
$P[kW]$	3157	4737	7885	14208

To obtain the generated electric power must be taken into account losses in the gearbox, in the generator, the various conversions and also in the propeller due to the contamination and damage of the surface of the fins.

The coefficient c_p is the most significant aerodynamic characteristics of the wind turbine. It depends on the wind speed, by means of the ratio between the peripheral speed of the propeller v_T and the wind speed v_W

$$\lambda = \frac{v_T}{v_W}$$

A typical form of this dependence on turbine blades 2, the most common for powerful WTG is shown in Figure 3 [10].

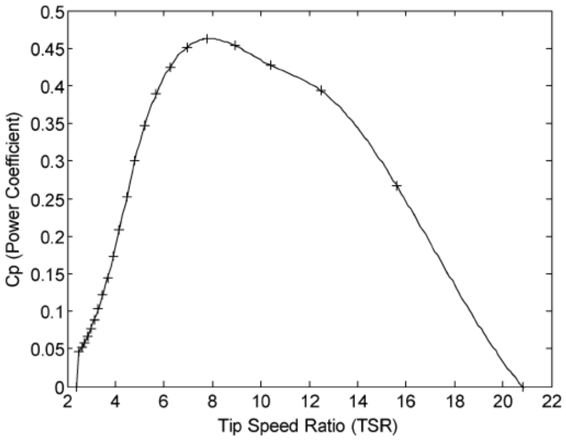

Fig. 3

It has a pronounced maximum and to maximize the extraction of energy the turbine has to work with a variable speed range of variation of wind speed than the minimum V_δ, which began to give energy to nominal V_n with which the rated power of the generator. For speed above nominal c_p decreases to maintain the nominal output power. This is achieved by varying the angle of attack of the vanes β. At wind speeds above the mechanical resistance of the propeller V_m, c_p is changed to zero - the propeller is stopped. The conversion factor is a function of the parameters λ and β

$$c_p = \Gamma(\lambda, \beta)$$

A typical form of this relationship is shown in Figure 4. [11]

WTG at a constant speed work in optimal mode about c_p on only a narrow field of wind speed. About WTG with variable speed, with proper management the conversion factor c_p maintains a maximum in a wide range to rated wind speed. For higher speeds longer limited c_p by the angle of attack of the vanes.

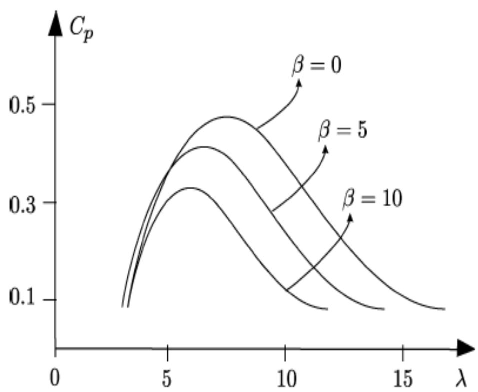

Fig. 4

In Figure 5 [10] is shown the dependence of the power generated by the turbine speed (given in vol. / min.) at various wind speeds. When using the maximum use of wind energy, the control must ensure that the load on the turbine.

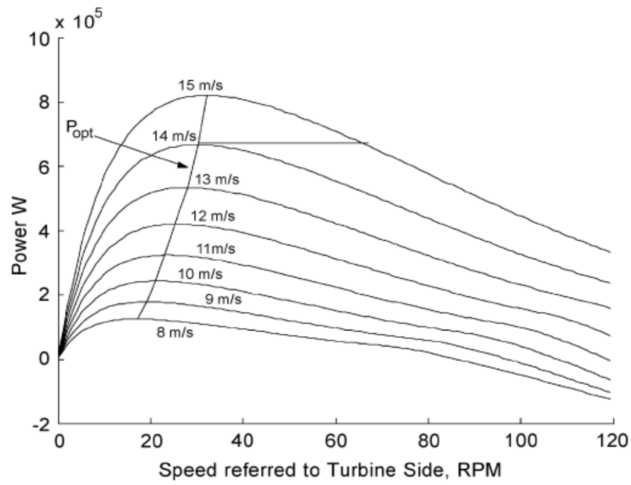

Fig. 5

— a curve P_{opt} below rated speed

— with rated power ranging par-top speed
— off over nominal speed

Due to the low angular velocity of rotation of the propeller, torque

$$M = \frac{P}{W_T}$$

accepts unusually large values. For example, for VTG power 1,5 MW and 24 rev / min of propelle $M = \frac{1{,}5.10^6}{2\Pi} . \frac{24}{60} = 0{,}95.10^6 \left[N.m \right]$

When storms this point can be repeatedly exceeded, which is transmitted as a blow to the shaft and the following gearbox and generator.

4. Conclusion

Presented is the conversion of wind energy into rotational mechanical in the use of wind turbine generators (WTG). Power density G depends on the third power of the wind speed. The very wind speed dependet on the height above the ground, such as up to 450 m it increases and then decreases. With the development of technology, materials and knowledge of aerodynamic processes, the actual usage is rapidly increasing and approaching the limit. Only in the period 1998 - 2004, it has increased from 22 to 38%. To obtain the generated electric power must be taken into account losses in the gearbox, in the generator, the various conversions and also in the propeller due to the contamination and damage of the surface of the propellers.

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Преобразование энергии ветра в ротационно-механическую и ее влияние на ветрогенераторов

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Р е з ю м е

Представлено преобразование энергии ветра в ротационно-механическую при использовании ветровых турбинных генераторов (ВТГ). Плотность мощности G зависит от третьей степени скорости ветра. Сама скорость ветра зависит от высоты над поверхностью земли, например, до 450 м она увеличивается, а затем уменьшается. С развитием технологий, материалов и знаний о аэродинамических процессах, фактическое использование быстро растет и приближается к пределу. Только в периоде 1998 - 2004, оно увеличилось с 22 до 38%. Для получения вырабатываемой электроэнергии должны быть приняты во внимание потери в коробке передач, в генераторе, различные преобразования, а также в пропеллером из-за загрязнения и повреждения поверхности пропеллера.