Wind Generators

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Abstract – **The paper presented discusses the wind generators, which implement the real possibilities for rational wind energy use. The theoretic formulation of wind energy transformation into rotational mechanic energy and the features of the two types – wind turbine generators (WTG) and wind vane generators (WVG) are considered. Comparison is done between 5 different types of WTG and the perspectives of WVG in the production of electrical energy at the lowest price are presented.**

Keywords – **wind turbine generators, wind vane generators, electro-energy**

I. INTRODUCTION

The possibilities for rational use of the wind energy are indeed remarkable. About 1÷2% of the sunny energy, falling on earth is converted into wind. For comparison, the energy, absorbed by plants in photosynthesis, and its conversion into bio mass is only 0.02÷0.03%, or about hundred times smaller. Modern civilization, often regarded as lavish, consumes totally about 0.005÷0.006% of this energy[1].According to the estimates in [2,3,4],the actual energy consumption can be satisfied byobtaining wind energy at a height of80mover 20% of the regions with average annual wind speed 6.9m/sec.

The world stores of easy obtained wind energy are estimated at1 500 GW, with annual production of $3{\cdot}10^{12}$ kWh, that makes 500 kWh per every inhabitant of the world population of 6 milliards[5].

The main technology of wind energy generation is based on the wind wheel, known for centuries. Its improvement in the last decades puts this technology close to its limit capacities -– energy deriving up to 50 % of wind ground level at height up to 180m. The energy generation is limited by Betz law, and the diameter of the wheel (propeller) – by the mechanic strength of the known materials.

There is also another technology [4], realized by a fan (kite). It enables energy obtaining at height of 200÷800m, where the wind speed is higher, less dependent on the covered surface, the fan itself has a simple construction, small weight, but requires more complex control.

II. THEORETIC FORMULATION

2.1. Conversion of the wind energy into rotational mechanic energy

Kinetic energy, carried by the wind through a section *Q*for1 sec, is:

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

or expressed by the surface power density (specific power)

$$G = \frac{1}{2}\rho v^3 [W/m^2], \qquad (1)$$

where $\rho[kg/m^3]$ is air density in the region considered, and$V[m/s]$ – the wind speed. The density ρ is a function of its temperature, the atmosphere pressure and is given by the relation [6]

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

where $\rho_0 = 1{,}225[kg/m^3]$ is the density of the dry air at sea level pressure and temperature 25^0C, R_d - a gas constant, T – local temperature in ^0K, z – height above the sea level, $g = 9{,}81[m/s^2]$ - earth acceleration, $\beta = 6{,}5^0 C/km$ - vertical temperature gradient for standard atmosphere.

The power density *G*depends on the third power of the wind speed. The speed itself depends on the height above the earth, up to 450 mit increases, after that – decreases. In order to use the wind energy, it is of interest to know the interval 40 - 150 m, in which the wind turbine generators (WTG) are located. For this area the relation can be presented by an empirical equation [6,7]

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

where v_h is the speed at height*h*, v_{h_0} is the known speed at height h_0, α is an experimentally determined coefficient. The value of α may vary in a wide range, depending on the height, the day time, the season, the temperature, the site features. Table 1 gives typical values of α, depending on the terrain surface (covering surface) [7].

Regardless of the fact that the value of α is not big, it influences significantly the specific power, due to its strong dependence on the wind speed. This dependence can be used for selection of the optimal height of WTG tower. It enables the obtaining of a more realistic preliminary estimate of the wind energy resources of the country by the available data about the speed, collected by meteorology.

They refer to terrain height above 10 m. For a pile, high 80mand for the smallest value of α = 0,1, the specific power increases $\left[v_{10}\left(\frac{80}{10}\right)^{0.1}\right]^3 = 1.87$ times.

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TABLE 1

Terrain type	α
Sea, lake, smooth earth surface	0.1
High grass on an even terrain	0.15
High crops, bushes	0.20
Forest site with many trees	0.25
Small settlements with trees, bushes	0.30
Towns with high buildings	0.40

When a fluid flow meets a barrier, a dynamic force appears on it, equal to the speed of the fluid and the barrier. This force is used in the wind turbine to extract wind energy. Meeting the turbine fans, the wind forms a force, tangential to the fans and it drives them in a rotating movement, which directly or with the help of a speed box (for increase of the rotating speed), is transferred to the electric generator. In the current constructions the turbine, the speed box and the generator are made as a monolithic block and together with the propeller they form the wind-turbine generator (WTG). The extracting of the complete kinetic wind energy is not possible. The limit theoretic generation at completely smooth fans surfaces and non-viscosity fluid is given by Betz bound and it is $C_p = \frac{16}{27} = 59{,}7\%$ [8]. It is assumed that the value of 0.8 is a technically achievable approximation to this bound, hence the real limit extraction, often quoted, is C_p=0,8.59,3=47,3%. With the development of technologies, materials, and knowledge of the aerodynamic processes, the real extraction is increased and it comes close to the limit one. Only in the last years it has increased from 22% up to 38% [8].

III. GENERATORS

3.1. Wind turbine generators (WTG)

The main type of generators, used until 1990 for power up to 1.5 MW, are the asynchronous ones, with a cage rotor, directly connected to the power line, from which they obtain the excitation - a Danish concept for WTG. They differ by their simplicity, reliability and a century developed technology of mass production. They operate at constant revolutions which does not allow maximal extraction of the wind energy. It is obtained for one single wind speed. The connection to the network is done by controlled valves restricting the big current overloading. After the transition process of switching $(0{,}2 \div 2s)$,the valves are shunted by contactors. In order to compensate for the magnetizing (excitation) current, some adjusted capacitor batteries are joined. The excitation current depends on the degree of loading and for its constant compensation, the battery must be adjustable.

A serious disadvantage of this type of generators is its firm characteristic resistance moment/revolutions. The typical for the wind speed changeability of frequent stormy nature causes stress loading on the propeller shaft and especially on the speed box.

The introduction of a winded rotor is an improved modification of the asynchronous motor. The slippage is controlled by the degree of loading on the rotor windings, and thus on the revolutions, and the characteristic moment/revolutions becomes soft. The wind blow and the impulse loading of the generator are smoothed. The operation revolutions can be co-coordinated with the wind speed for maximal energy extraction. They are available in brush and non-brush variant. The heat mode of the rotor is lightened in the brush variant. Usually the revolutions differ from the synchronous ones by 1-10% [9].

The most widely used type of a generator in WTG is the Doubly Fed Induction asynchronous Generator (Doubly-FedInductionGenerator – DFIG), shown on Fig.1. Regulating the energy, obtained by the rotor windings, the speed of propeller's rotation is controlled.

The double inversion enables efficient control of the slippage power (which reaches up to 30% of the nominal power), as well as its transfer together with this of the stator to the network. The new valves of IGBT type allow inversion with a high yield.

In order to design generators with acceptable dimensions, and hence – weights, their revolutions are most often chosen within the limits 1000-2000 rev./min and the poles number - 4 or 6. To achieve these revolutions, three-degree speed boxes are used. It is considered, that the losses in every transmission unit, if not higher than 6 is about 1% of the transmitted power in case of good support.

Synchronous and asynchronous generators with variable rotational speed and with double conversion of the whole power – both the main one and that of slippage, are used. The entire disconnection between the propeller rotational speed and the network frequency enable the operation in four quadrants – in a mode of a generator, of a motor, of a consumer, and a generator or reactive power (capacitive, induction). This is an important feature, the use of which can improve the reliability of the network, to which it is attached. For small active power due to the wind low speed, such a generator can provide reactive power to the network up to its nominal apparent power.

The present-day WTG are constructed for nominal wind speed within the range 12÷16m/sec.It is selected according to the function of distribution for the site, where WTG is installed. For speeds above the nominal ones, the nominal output power is obtained with the help of the angle of vanes attack.

For the widely spread two vanes propellers, the maximal extraction is achieved at relation peripheral speed/wind speed λ=7÷8. At nominal wind speed of 12 m/sec, the peripheral one for the propeller is 320km/h. The peripheral speed influences to the greatest extent the acoustic interference and the amortization speed of the propeller.

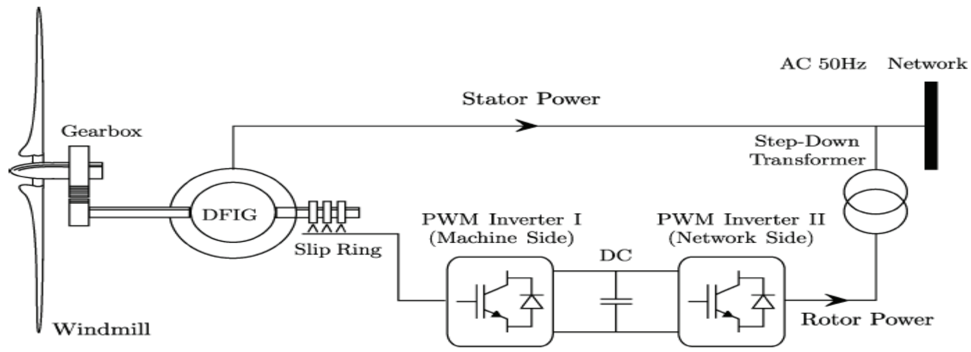

Fig. 1

At nominal speed of the wind 12m/sec, extractionC_p=38%, dry air, at sea level, temperatures of 25°C, the useful power density is 381W/m^2.

For such density, power on the propeller's shaft of 3MW, the propeller diameter must be 100.2m and it will extract energy from 7885m^2. The averaged power density is 87,3W/m^{2}atvery good effectiveness.

When building wind farms, in order to support the aerodynamic interference in acceptable bounds, the distances between the separate WTG must not be smaller than 4-5 multiple of the propeller diameter. With this constraint, the terrain density of a farm, built of WTG with nominal power of 2 MW,at nominal wind speed of 12m/sec (diameter of 90m),is 9MW/km^2 [4].

Both densities –the wind and the terrain are very low. Though the primary energy is free of charge, its extraction requires large investments and big areas. This concentrates the design of wind farms on deserted land only.

The achievements in generators construction, computer technologies and power electronics have enabled the design of new generations of generators with complete conversion and variable speed that allows maximal extraction of the energy for any wind speed. These are mainly the synchronous generators with constant magnets made of rare metals and the asynchronous doubly fed generators. The generators with complete conversion enable operation in a three-quadrant mode – active power, reactive induction and reactive capacitive in arbitrary portions. Their main advantage is that even at weak wind they can generate reactive power equal to the nominal apparent one.

Interesting comparison is presented in[10] between 5 different types of WTG with nominal power of 3MW:

— doubly fed asynchronous generators with complete conversion and a three-degree transmission box (transmission relation 1:80) – DFIG;

—directly connected to the propeller (without a speed box) 80-poles synchronous generators with electric excitation and complete conversion – DDSG;

—directly connected to the propeller 160-poles synchronous generators with constant magnets and complete conversion – DDPMG;

—synchronous 112-poles generators with one-degree transmission box with constant magnets and complete conversion – PMG1G;

—doubly fed asynchronous generators 80-poles generators with one-degree transmission boxes with complete conversion – DFIG1G.

The values of the main parameters are given – geometric dimensions, weights, losses in the separate units, efficiency coefficient,energy produced annually, including the construction and mounting activities for towers building. Despite of the essential differences, the margin in the significant indicators is not big – 10% in the cost of the energy produced and 2.2% - in the annually produced energy.

3.2. Wind vane generators (WVG)

The vane technology is not developed to the extent of its real application, but thanks to its potential possibilities, it must be accounted in the development of wind energetic strategy [4,11].

The extraction of wind energy from the wind vane generator (WVG) is accomplished with the same aerodynamic force, as in WTG. The barrier in them is made as a vane, (kite)of folio, similar to a ship sail, as shown in Fig.2. With the help of two cables the vane is connected to the ground equipment, which transforms the vane movement into electric energy. The cables are winded/unwinded on separate drums, each one connected to an electric machine that can work in a generator and in a motor mode. With the help of the cables the information about the vane and the wind speed is used to regulate the attack angle, so that cyclic movement, normal for the wind speed, is obtained.

The most significant advantages of this technology, are:

— the energy extraction is realized at big height with the help of simple and light equipments;

— the heavy equipment is found on the earth;

— possibility to work in a wide range of the wind speed of 2-50m/sec;

—higher usability in comparison with WTG;

— higher terrain density of the energy extracted.

Many simulation investigations have been carried out. The results from them are illustrated by an example WVG with the following basic parameters:

— vane ofpolyhedron with usable surface of500m^3, weight of300kg;

—cables of a composite material, with length of 900m, diameter - 30mm and linear weight of 68.6gr/m;

—area, swept by the vane axaxΔr=300mX300mX50m.

—losses for vane control - 30% and efficiency coefficient of the ground equipment - 70%.

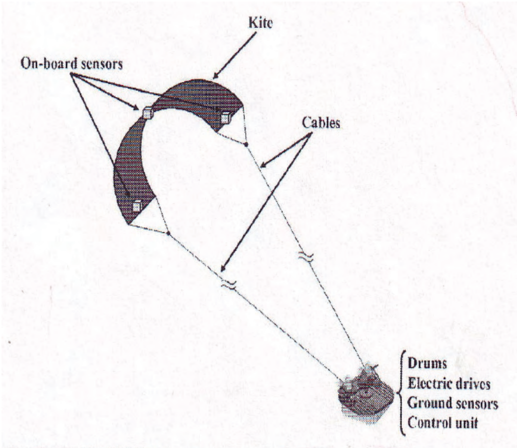

Fig. 2

The power, generated by such a WVG, for wind speed of 9m/sec, is 2MW, and for speed of 12m/sec, the lowest nominal speed for a present-day WVG is already 5kW.

Taking into consideration the aerodynamic interference, the degree of vane regulation, protection against cables intertwining with neighbouring WWG, at nominal speed of the wind 12m/sec, the terrain density of the nominal generated power is 80MW/km^2. This density is one order higher than the density of WTG with nominal 2MW.

IV. Conclusions

The storing of wind electric energy is solved nowadays in a new way. There are constructed powerful electric networks with built in systems for voltage and frequency support, which enables their assuming as infinitely powerful. The connection of WTG to such networks does not practically alter their mode, independently on the changeability of the power injected. The introduction and use of considerable power does not lead to surpassing of the feasible limit values of the network basic parameters. At considerably small share of the wind electric energy, for example, up to 10 %, the built-in system for network stability support may remain without any changes. At larger participation, with the connection of WTG farms in the operative control of the network and the use of the prognostic values for wind speed, the relative value may reach big values, 30% or more. A network is presented in [12], in which the wind energy may cover the whole consumption and may be injected in other networks.

Considerable increase of the energy, generated by the wind, is noted since 1980.This is connected to a great extent with the improvement of the shape of turbine propellers, which leads to raising the share of the energy extracted by wind, improvement of the electric generators, especially those with variable speed, of the electronic converters, that realize partial or complete conversion and improving the technology of connection to the power line.

In[4] a probable cost of the energy, obtained by vane technology in 2030, is given. In Table 2 this cost is compared to IEA prognosis for the same time, by different resources, taken from [13].

TABLE2
ENERGY COST IN 2030

Resource	Maximal c$/kWh	Minimal c$/kWh	Average c$/kWh
Coal	5	2,5	3,4
Gas	6	3,7	4,7
Sun	50	18	32,5
Nuclear	3,1	2,1	2,9
WindWTG	9,5	3,5	5,7
Wind WVG	4,8	1	2

The promises of WVG are very attractive, which requires the technology putting into operation. The main problem is the necessity of a very complex control, which covers the most actively developed areas of human knowledge – aerodynamics, control, microelectronics.

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