The future of the world wind power.

Much is told about necessity of the further development of wind power already. There are no any doubts in its necessity. The basic efforts now consist in efficiency increase of already existing and being developed wind turbines, and also on updating of the statistical information on wind areas with the purpose of an optimum choice of places for wind stations and definition of number of wind turbines and their nomenclature for them. Besides variants of optimization of the coordination of the received wind power dependent on presence of a wind, with a power supply system of region with consumers demand are examined. Basically this optimization consists in creation powerful systems of accumulation of energy; uniting regional networks in one with a possibility of redistribution of energy and application of traditional reserve power stations capable to change size of produced capacity rather quickly. There are a lot of the questions on wind power, however the purpose of given article is, to highlight the most important one-

the increase of efficiency of wind turbines.

What is the essence of concept – efficiency? This reception of the maximal benefit (in our case – reception of a maximum quantity of wind energy, usually per year) at the least expenses (example of calculation of expenses and efficiency as a whole is examined in http://www.nrel.gov/wind/docs/lwst_coe_projection_format_baseline2002.xls).

The increase in efficiency of the wind turbine usually means expenses reduction for manufacturing, maintenance, transportation and installation either the turbine itself, or its components due to application of new technologies, the equipment or optimization of organizational actions. Besides, efficiency is influenced by life span of the turbine, quantity of orders for manufacturing and accommodation of turbines (in case of line production and delivery the cost of each one gets lower).

It is considered that the first component of efficiency is energy production which depends only on the wind characteristic of an installation site of the wind turbine and is considered be the maximum level where wind turbine is not liable to any modernization. One of the ways of increasing of this component is **increase in size** and, as consequence, power capacities of each turbine (which does not concern independent turbines of small and average capacity where the concept of efficiency pursues other purpose, namely minimization of expenses for achievement of sufficient and more stable capacity). So what happens? ***First of all***, the increase in the size of the turbine results in increasing the height of a rotor, and at the greater height the wind is stronger too. As capacity of a wind from its speed has third-degree dependence, and speed of a wind at big height usually increases according to the law $V_h = V_{10} \times (h/10)^{0,143}$ at the big heights capacity of a wind increases essentially. ***Second***, at increase in the size capacity grows in square-law dependence on diameter of a rotor. ***Thirdly***, expenses for manufacturing, maintenance and rent for the ground on which the turbine (is installed. it is cheaper to produce, maintain and pay rent of one powerful turbine, than, say, ten small turbines of the same total capacity) decrease. Experts in the field of wind power of course know everything about it. For this reason wind turbines of nominal capacity of 100 - 500 kW are being replaced by new ones - with capacity of 1; 1,5; 2; 2,5; 3; 4,5 MW and even more. Thus the sizes of greatest of them just impress: diameter of a rotor – up to 120 m, weight of each blade up to 20 t, height of a tower up to 120 m.

So why not increase the size of turbines even more then? It appears, that at the present stage of development of technology rates of growth of cost of wind turbines with the further increase in their sizes start to exceed rates of growth of their capacity so, efficiency goes down and cost of each kilowatt thus grows. What is the reason? Let's see. Let us admit, it is necessary to increase capacity 4 times. In case of the turbine with length of the blade 5 - 10 m it's not a problem to increase diameter of a rotor 2 times, but is a problem to increase 2 times the blade 60 m long, as well as the big problem is to deliver it to an installation site, also lift and fix it at height more than 200 meters. Besides, similar problems will arise while the construction of a tower, manufacturing, transportation and installation of the generator, a reducer and so on.

In order to analyze an opportunity of the further increase of efficiency of wind turbines it is necessary to consider in details the technical problems limiting increase of capacity and resulting in cost of obtaining wind energy power.

The analysis of problems.

The basic problems can be classified by two types - manufacture, delivery, installation and operation, and problems with components – blades, the generator, a reducer, a control system of operating modes of the turbine, a tower and so on.

As a rule such elements of the wind turbine as the generator, the reducer, a control system of modes, the cable equipment and so forth, though are complex enough and expensive themselves, but there are no problems with their manufacture, delivery, installation and operation are well enough adjusted, investigated and, most likely, there will be no problems and rises in price increase.

It is more difficult to solve a problem of increase in cost of a tower. We know and can speak about towers for wind high-power turbines of 2 types: integral ferro-concrete, made by continuous casting, and steel in form of a huge pipe of varying diameter on length. Cost, and disadvantages of these two types of towers experts, certainly, knows. It is known also, that one of problems is delivery of steel towers to the installation site of the unit. One variant of reduction in price of manufacture, delivery and installation of such a tower is manufacturing separate segments and with their further connection by their internal flanges (internal in order not to spoil appearance) on an installation site of the turbine. There can be from 3 up to 10 of such segments of a tower. For strengthening flanges welded edges of rigidity as rectangular triangles can be used. It is necessary to take into account that the more powerful turbine is the more reliable fastening of a tower to a ground it will need as force of pressure of the wind on a rotor and size of the lever in a case of higher tower will increase. In any case the increase in capacity and the sizes of the turbine will lead to rise in price of a tower.

There are also additional expenses for auxiliaries, such as special tractors for transportation of heavy large-sized details of the wind turbines, special barges, in case of installation of turbines in a coastal zone, the huge powerful cranes necessary for installation of turbines and so on. The increase in the sizes of wind turbines will cause the need of creation of new more powerful and more expensive equipment that should affect cost of wind energy.

Another possible problem may be the problem of creation of more effective rotor.

Efficiency of a rotor of the wind turbine.

The basic role of a rotor of the turbine is transformation of wind energy into mechanical rotation of a shaft of the electro generator. As any converter, a rotor has the efficiency. In aerodynamics it has its own name **Cp** which means useful factor of a wind power**.** This factor has its theoretical limit. For a rotor with ideal characteristics Cpi = 4e × (1-e) / (1+e). Cpi has a maximum value of 0,686 (or 68,6 %) at e = 0,414. The aerodynamic parameter "e" is equal to the relation of change of speed of a wind a plane of a rotor towards the speed of a wind before rotor and refers to as factor of slowing down of a stream of air in a plane of a rotor. It depends on speed of movement of blades, their width and their quantity. Real factor Cp always less than the ideal one and depends also on the quality of an aerodynamic structure of the blade expressed in aerodynamic factors Cy, Cx and k = Cy / Cx. This quality defines, first of all, the basic component of losses of a rotor, namely loss from friction of air about the blade which, in turn, grows with increase of speed of an air stream accumulating on the blade.

In practice average Cp is within the limits of 0,35 – 0,45. The matter is that this factor is not constant; it depends on speed of a wind, speed of rotation of a rotor and varies on length of the blade. For example, in a narrow external part of the blade speed of its moving is so great, that losses of friction become comparable with useful capacity which forces to reduce speed of rotation, reducing thus parameter "e" (as well as Cp). It’s possible to increase parameter "e" in this part of the blade, without increasing speed of rotation, only either increasing the width of the blade, or increasing the number of blades. Thus, the wide edge of the blade increases so-called trailer losses. In wider part of the blade located closer to the center of a rotor, speed of an accumulating stream is small, but the big relative thickness of the blade is necessary for mechanical durability, which considerably worsens aerodynamic parameters of this site. The average part of the blade has intermediate values of speed of an air stream and thickness of the blade that also reduces Cp. Special expensive materials are applied for reduction of relative thickness of the blade at preservation of necessary durability. However powerful loadings on the blade of the big rotors do not allow us to achieve good results.

With increase of speed of a wind the factor "e" starts to increase which allows reducing speed of rotation of a rotor, reducing thus losses because of friction and thus increasing Cp. For obtaining of an opportunity to change speed of rotation of a rotor special generators are applied the ones, capable to work in a range of speeds of rotation varying up to 1,5 – 2 times.

There is one more aspect which needs to be taken into account, when speaking about efficiency of the wind turbine. It is a question

about a choice of rated power of the generator.

Manufacturers of wind turbines in the documentation to each model specify 3 speeds of a wind: speed of a wind starting the turbine, speed of a wind for rated power and the maximal speed of a wind. Usually speed of a wind for starting the turbine makes 3 - 4 m/s. At smaller speed of a wind capacity appears insignificant and, as a rule, is not sufficient even to make the turbine rotate. Speed of a wind for a rated power usually equal's 11 - 13 m/s. The choice of this restriction is explained by the fact that at rated power the loading on the blade, a tower, other units of a design corresponding to this speed, reaches maximum values. At the further increase in speed of a wind, system of automatics of the turbine due to change of corners of turns of blades and speeds of rotation of a rotor support rated power on an output of the turbine. At the maximum speed of a wind, which is 22 - 27 m/s, the generator is switched off, the rotor is stopped, blades are established parallel to a wind, and the turbine stays in a waiting regime until the wind abates. Very often speed of a wind when, the turbine is not guaranteed against destruction, which usually is 50 - 60 m/s, is pointed out.

There is a question. Whether change of rating value at these speeds can affect the size of annual harvest of energy and at what cost? To answer this question it is necessary to know the average probable distribution of speeds of a wind for different wind areas and to take into account the power contribution of each of these speeds. An example of such calculation can be http://www.nrel.gov/wind/docs/weibull_betz5_lswt_baseline.xls

Taking into account the fact, that capacity of a wind has third-degree dependence on its speed, it is possible to assume, that at increase in rated power of the turbine annual gathering of energy will increase, as the probability of obtaining speeds higher than nominal ones is still high enough, but capacity is already limited. We shall check up this assumption calculations for the wind turbine with parameters: Diameter of a rotor – 120 m; Height of hub – 120 m; Capacity – 4,5 MW; Speeds of a wind: initial, nominal, maximum – 4, 12, 25 m/s accordingly; Cp – 0,4. Let us increase (without changing the sizes of the turbine) rated power up to 15 MW, speeds of a wind – up to 5, 18, 35 m/s accordingly and make the similar calculation. The comparative analysis we shall make for 4 basic wind classes 4, 5, 6 and 7 (for districts with mid-annual speeds 5,8; 6,2; 6,7 and 8,2 m/s) and parameters Weibull K – 1,5; 2 and 2,5 (the less K is, the more probable the disorder of speeds of a wind is and the more K is, and more probable average speed and less the disorder of speeds is. Usually in the general calculations value of K is K = 2). Calculations are applied on a sheet 2 «**power 120-3**» tables Excel.

Results of calculations are submitted in Tab. 1.

Tab. 1. Gross annual production of wind energy, GWh / year

	K = 1,5, for classes				K = 2,0, for classes				K = 2,5, for classes			
	4	5	6	7	4	5	6	7	4	5	6	7
Prated = 4,5 MW	13,38	14,38	15,42	17,38	13,92	15,45	17,16	20,77	14,04	15,91	18,07	23,00
Prated = 15 MW	23,04	26,39	30,46	41,16	18,83	22,61	27,53	42,14	16,04	19,82	24,99	41,72
Benefit	1,722	1,836	1,975	2,368	1,352	1,464	1,604	2,029	1,143	1,246	1,383	1,814

From the table one can see, that there is a real benefit and it averages 1,5 times and more and is the more the higher the wind class of area and the less parameter Weibull K is. However, it is not as easy as it appears.

The increase in rated power of the wind turbine with 4,5 MW up to 15 MW will show in the following. ***First***, powerful generator, a reducer and control systems of modes will cost much more. Thus due to increase in rated power and reduction of factor of transformation at low powers the basic gathering of wind energy will be carried out at the increased capacities, and it means greater instability of wind energy in loading. ***Second***, loading will increase on a tower which will demand its strengthening. Nevertheless, at a significant benefit in amount of energy gathered, the listed above expenses and lacks are allowable. ***Third***, and the most unpleasant, loading on the blades will increase. Even in case the blades are made from the strongest and the most expensive materials, it will be necessary either to make them very wide (and also thick, heavy and expensive), reducing thus the speed of rotation, or to increase their relative thickness, thus, worsening aerodynamic quality and reducing Cp. Both will considerably reduce or kill the total benefit.

Above mentioned reasoning allow us to draw a conclusion - traditional 2 – 3 bladed wind turbines do not allow to raise essentially gathering of wind energy and, in sense of considerable increase of efficiency, have exhausted the opportunities. Offered (suggested) by many developers and manufacturers roundabout, including orthogonal wind turbines, and also the wind lattices consisting of several turbines of the various form, also do not allow increasing efficiency because of the same small wind loadings and low Cp. They may compete with traditional 2 – 3 bladed ones only as independent wind designs and are of little use for the great powerful wind industry.

New design of wind turbines.

The only way to raise wind loading on the blade in the vertical turbine with a horizontal axis, without causing their destruction and worsening their aerodynamic quality, is increase in quantity of blades and a fastening their ends by a ring in a shape of an airfoil. In such design the wind loading onto blades does not make any bending influence to the blade, but extending (especial small conicity a rotor and its inclination providing) as the external ring will not let the blades to be bent, similarly to the spokes in a rim of a wheel of a bicycle. Besides fixing of the ends of blades stabilizes position of blades, practically, excluding probability of flutter. As it is necessary to change the angle of turn of the blade, connection of the end of the blade with a ring should be mobile and have the bearing. At the reduced rigidity of the blade it is possible to apply the device of forced turn of the end of the blade which will be directed either by own electromotor, or mechanical draft of the device of turn of all blade which are placed in the central sleeve of a rotor to each of them. The most loaded part in such design will not be the blades, but an external ring. Therefore it is necessary to strengthen it, most likely, longerons (spars) and nervures (similarly to a wing of the plane) will be required.

The quantity of blades is taken out of reasons of sufficiency at uniform loading of a ring (with small quantity of blades, it is less than 7 - 8, loading of a ring is different as there are long intervals between places of fastenings of the blades, and number of blades more than 10 – 15 is hardly justified). Optimum quantity of blades will equal 8 – 9. Considering complexity of manufacturing, delivery and installation of an integral ring of the big diameter, it can be broken into identical segments the number of which should be multiple to number of blades for unification. Taking into account reduction of bending loading onto the blade (it will decrease also due to redistribution of all capacity from 2 – 3 onto 8 – 9 blades), each of them (in reasonable limits) can be made less wide, less thick, less heavy and, as consequence, less expensive. Also appears an opportunity of increasing rated power of a rotor, having increased rated speed of wind, and essentially increase its sizes at preservation of strength of a design. Besides the blade also can be made compound, that will facilitate and will reduce the price of their manufacture and delivery.

Aerodynamic quality of a design.

At increase in quantity of blades from 2 – 3 up to 8 – 9 speed of moving of the blade, corresponding to optimum value "e", will decrease, that will lead to reduction of losses because of friction and, as consequence, to increase of Cp. Besides due to presence of an external ring so-called trailer losses will practically disappear that will allow to increase the width of the end of the blade and to choose it from the point of view of an optimality of number "e". Reduction of the blade bending force (even at increase in capacity) will allow to reduce relative thickness of the blade up to the values corresponding to high aerodynamic quality, which also will raise Cp. Additional increase of aerodynamic quality can be achieved by applying so-called laminarized airfoil the use of which in the traditional wind turbine is limited by the big relative thickness and increase of probability of flutter because of displacement of the center of rigidity in such structures.

All these advantages are confirmed by the comparative aerodynamic calculations submitted in the table Excel. In these calculations values are chosen: diameter of a rotor – 120 m; a range of change of speed of rotation of a rotor – 2; one of the most known airfoils – Espero. Calculations were carried out by discrete summation of parameters of 10 separately taken average segments of the blade which usually provides few errors and sufficient accuracy for comparison. On a sheet 1 «**aero 120-3**» aerodynamic calculation of traditional 3 bladed rotor with capacity of 4,5 MW with initial, nominal and maximal speeds of a wind is shown; They will be 4, 12,5 and 25 m/s, accordingly. There is no sense to make estimation of durability of blades in a general view .It is too difficult without taking into account a material of blades, technology of their manufacture and so on. Therefore, the typical approximate sizes of the blade (the error of these sizes concerning real determines the basic error of comparison of results) have been chosen. As a result of calculations average value Cp = 35,6 % is obtained which, in general, is close to a real one. It is possible to increase Cp a little, optimizing the sizes of the blade taking into account calculation of durability and a choice of the different airfoil more suitable for a concrete site of the blade. This growth of average value Cp varies from 36 to 45 % (most likely about 40 %).

On a sheet 3 «**aero 120-8**» aerodynamic calculation of 8 bladed rotor with an external ring as an airfoil is shown. Capacity of 20 MW is chosen; initial, nominal and maximal speeds of a wind 5; 18 and 35 m/s, accordingly; the ring is chosen 1,5 m wide and 0,3 m thick, it has symmetric laminarized airfoil with Cx = 0,01. The chosen speeds are not too great taking into account, that they are calculated for height of 120 m. Speeds of a wind corresponding to them at height of 10 m are 3,5; 12,6 and 24,5 m/s. The estimation of durability also was not carried out, and the choice of the sizes of the blade is based upon optimization of aerodynamic parameters and taking into account the reduction of loading of the blade due to an external ring (of course in case of the real model of the turbine the estimation of durability is obligatory). Results of calculations confirm above mentioned reasoning about increase of aerodynamic quality. So average received Cp = 56,9 %, and with the use of laminarized airfoil and more careful optimization of the sizes of blade Cp will exceed 60 %. The external ring will not worsen aerodynamic quality, and force of pressure of a wind because of the ring onto rotor will increase insignificantly even at very strong wind. As energy of losses of a rotor is spend basically for noise, and in a new design losses are considerably reduced, also the noise level of the turbine will strongly decrease.

Let's estimate now

the general benefit in annual gathering wind energy

with application of the wind turbine of new type instead of the traditional turbine.

The comparative analysis also we shall carry out for 4 basic wind classes 4, 5, 6 and 7 (for districts with mid-annual speeds 5,8; 6,2; 6,7 and 8,2 m/s) and parameters Weibull K – 1,5; 2 and 2,5. Calculations are shown in a sheet 4 «**power 120-8**» tables Excel, and results – in Tab. 2.

Tab. 2. Gross annual production of wind energy, GWh / year

	K = 1,5, for classes				K = 2,0, for classes				K = 2,5, for classes			
	4	5	6	7	4	5	6	7	4	5	6	7
3 blades, P = 4,5 MW	13,38	14,38	15,42	17,38	13,92	15,45	17,16	20,77	14,04	15,91	18,07	23,00
8 blades, P = 20 MW	33,37	38,00	43,59	58,07	28,01	33,38	40,26	60,25	24,26	29,79	37,21	60,45
Benefit	2,494	2,644	2,826	3,340	2,012	2,160	2,346	2,900	1,728	1,872	2,060	2,628

Results of calculations show, that annual gathering with application of the wind turbine of new type is 2 – 3 times greater, then that of traditional turbine, depending on a wind class and factor Weibull K of district of installation of the turbine. In other words, one new turbine replaces 2 – 3 traditional turbines of the same size, and it is already essential benefit and it the greater, the higher the wind class and the less parameter Weibull K of district of installation of the turbine is. From schedules «**power 120-8**» one can see how the choice of rated power of the turbine influences annual gathering of energy. At its increase annual gathering of energy grows due to the best use of more powerful winds, and in case of weaker winds because of reduction of factor of transformation of energy of the powerful generator (when the load is not sufficient). Therefore speed of a wind of starting the turbine (initial) increases. Speed of a wind of switching off (maximum) is desirable for increasing too. Besides the increase in a range of speeds of a wind from initial up to nominal demands increase in a range of adjustment of speed of rotation of a rotor. These factors limit increase in rated power of the turbine.

So perspective development and manufacturing could be seen for new turbines of two types of wind areas. For areas with a powerful wind it is possible to apply turbines with higher rated power, and for areas with a moderate wind – with less one. Besides in case of underloaded generator it is possible to apply the double generator to increase in factor of transformation with the shaft for both ones, capacity of one of them should make 10 – 20 % of capacity of another. At a weak wind the powerful generator switches off and only less powerful one goes on working. At strengthening of a wind automatics will switch on windings of the powerful generator and switch off windings of less powerful. Losses of transformation thus will decrease. Additional argument for the benefit of the double generator can be increase of the range of adjustment of speed of rotation of a rotor because each of these generators is meant for different working revolutions. Their range is being blocked at the moment of switching over their windings. Application of the double generator will lower speed of a wind of starting the turbine and will increase the annual benefit shown in Tab. 2 even more.

Taking into account increase of annual gathering of wind energy, we shall define

the general increase in efficiency of turbines of new type.

Let's try to estimate increase in expenses of new turbines in comparison with traditional.

Firs of all, as it was already stated, with increase in capacity the generator, a reducer, and a cable facility will rise in price. Because of increase in number of blades, expenses for the control and adjustment of their angles of turns will increase. ***Second***, wind loading on a tower will increase approximately 2,5 - 3 times (see results of calculations «**aero 120-3**» and «**aero 120-8**»). It's strengthening, and also strengthening of a platform under a tower will also lead to increase in expenses. ***Third***, manufacturing and installation of 8 – 9 blades instead of 2 – 3 (even less expensive) will be costly. ***Fourth,*** manufacturing and installation of a ring also will increase expenses. Installation of a ring can be carried out from the long platform lifted by the crane, attaching to the ends of blades and fastening among themselves segments of a ring, periodically turning a shaft of a rotor.

Connection of segments includes connection of longerons (if they are), for example, longitudinal - releasable clutch and connection by screws of mantles of segments strong internal overlays or wide nervures. Anti-lightning protection of rotors of new type will differ presence of a metallized strip only from the external side of an external ring and its connection with the wires which are taking place inside blades. Change of the sizes because of temperature factor of expansion of materials of a rotor will lead only to insignificant (seasonal) change of conicity of a rotor.

Detailed estimation of expenses for all types of turbines is difficult to carry out. It is usually made by each manufacturer of wind turbines individually, taking into account their own conditions and opportunities. However, approximately it is possible to assume, that the increase of expenses will make not more than 20 – 50 % in comparison with traditional turbines of the same size.

Thus, summing up estimations of efficiency, it is possible to draw a conclusion, that application of turbines of new type will raise general efficiency (while reducing the cost of wind energy) approximately 1,5 – 2,5 times. Besides there is an additional reserve in increase in the sizes of wind turbines up to diameters of a rotor of 250 – 300 meters at increase of rated power of each turbine up to 100 – 200 MW. The increase in the sizes of turbines will raise their efficiency in complement, at least in 1,5 - 2 times, and finally will allow to lower cost of wind energy in 3 – 5 times.

Such essential expected growth of efficiency in use of the wind turbines of new type allows considering, that the future of the big wind power will be based on application of that kind of turbines.

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