VETROTURBINE SNAGE PREKO 20 MW – TEHNOLOŠKA PERSPEKTIVA

WIND TURBINE BEYOND 20 MW – TECHNOLOGY PERSPECTIVE

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Trend razvoja vetroturbina ima poseban značaj u eksploataciji obnovljivih izvora energije. Vetroturbine velikog prečnika rotora i visokih tornjeva sve se više razmatraju u istraživačkim i razvojnim centrima širom sveta. Upotrebom vetroturbina na većim visinama gde je brzina vetra znatno veća ostvaruje se mogućnost boljeg iskorišćenja ovog obnovljivog izvora energije. Razvoj novih tehnologija otvara mogućnost za novu generaciju vetroturbina snage preko 20 MW. U poslednjih nekoliko godina razne studije izvodljivosti su pokazale da koncept vetroturbine velikog prečnika rotora koji se nalazi na visokim tornju daje pozitivne rezultate sa aspekta analize strukturalnih i aerodinamičkih parametara. Posebna pažnja posvećena je smanjenju ukupne mase i prigušenju vibracija korišćenjem novih materijala. U ovom radu prezentovan je razvoj vetroturbina velike snage, dat je pregled tehnoloških mogućnosti u proizvodnji osnovnih komponenti kao i perspektiva za realizaciju vetroturbina snage preko 20 MW.

Ključne reči: *vetroturbine; elementi vetroturbine; nove tehnologije; materijali; perspektiva*

The trend of wind turbine development has a special significance in the exploitation of renewable energy sources. At higher altitudes, we have better wind energy utilization higher speed and their conversion are achieved in the best possible use of wind turbines. The development of new technologies opens space for a new generation of wind turbines with a 20MW rated power. In recent years, various feasibility studies have shown that wind turbines with large rotor diameter and high towers give positive shifts in the analysis of structural and aerodynamic parameters, with a focus on reducing overall mass and damping vibrations due to the use of new materials. In this paper, the evolution of high power wind turbines and an overview of the technological development of the basic components of the turbine will be presented. Perspectives in the further development of wind turbines with rated power above 20MW will be also considered.

Key words: *wind turbine, turbine elements, new technologies, materials, perspective;*

1 Introduction

There are many different ways in which devices can convert the energy of wind into mechanical work. Today there are a lot of divisions of wind turbines (WT). According to the location WT can be onshore, offshore and airborne. According to Jacobson et al. [1], onshore WT in 139 countries cover the area of 1105000 km^2, while offshore WT occupy 653200 km^2 of global water area. The realization of wind turbines from idea to final product implies a multidisciplinary approach. The development of a WT follows the increase in dimensions and weight. Therefore, designers tend to use different tools and techniques, to project, optimize, realize the construction, and extend the exploitation life of WT. The policies of an increasing number of countries are to produce the most percent of electrical energy from wind power. Improvements in the production of wind generators involve a larger and heavier construction to get lower energy costs from renewable energy sources. It's where big problems arise.

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Global annual and cumulative installed wind capacity from 2001 to 2017 is shown in Figure 1 following Global Wind Report - Annual market update [2].

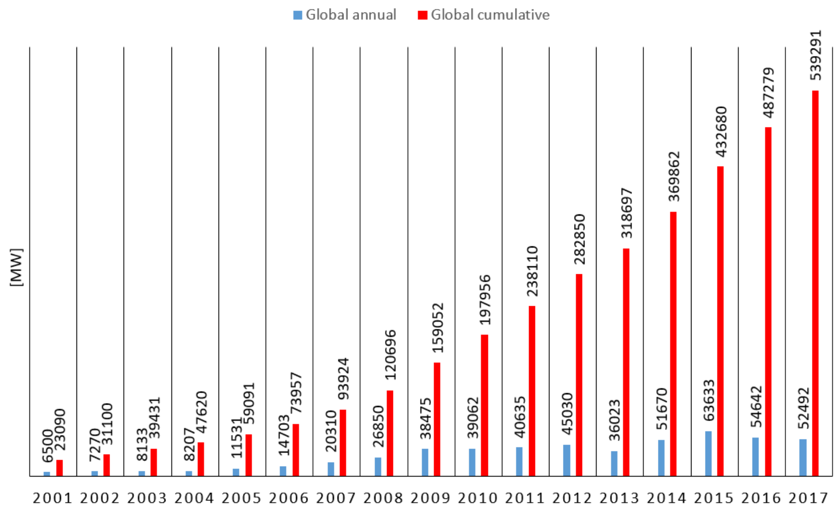

Figure 1 - Global annual and cumulative installed wind capacity

According to [2], overview of total installed WT power for 2017 in developed and developing countries is shown in Table 1.

Table 1 - Global installed wind power capacity

Regional distribution	Country	Total installed capacity to 2017 [MW]	Wind power capacity added in 2017 [MW]	Number of turbines	Share of wind generated in electricity consumption
Asia	PR China India	188392 28700	19666 4184	104934 32136	4.8 4.35
North America	USA	89077	7017	54430	6.3
Europe	Germany France	56132 13759	6581 1964	150000 6000	16.1 4.8
Latin America	Brasil	12763	2022	6491	7.44
Mid. East and Africa	South Africa	1467	618	961	2.15

PR China planned to produce 30 GW of electric energy by WT to 2020. Although, because of huge technological progress, this plan is achieved in [3]. According to that plan, China took over the leadership from the USA in the field of producing electric energy by WT. British petroleum gives a comparison between using oil and all other energy sources. In 2017 consumption of energy produced by all other sources increased 2.2% relative to oil energy consumption. The development and supply chain of electricity from renewable sources of energy is projected for the period 2015-2050. Forecast of increasing is given respectively: 2015 (5.6 %), 2020 (20%), 2025 (56%),2030 (80%), 2040 (95%), 2050 (100%) [1]. Today, the realization of wind turbines with large powers exceeding 20MW has become imperative. In general, there is little data on the research of these WT. Starting from the structure, the realization of the tower and rotor wind generators becomes more and more complex. A multidisciplinary approach is increasingly used in optimizing the design of WT. This involves obtaining a new aero-elastic tower and rotor design including problems that can occur through: removal of ice from the leading edge of the blade, load distribution, modal frequency appearance, velocity at the tip of the blade, and the appearance of fatigue damage [4].

Table 2 - A chronological overview of companies who developing WT [12, 47]

Company	Name	Country	Year	Power [MW]	Diameter [m]	Hub height [m]
Poul La Cour	-	Denmark	1891	0.035	20	-
FL Smidth	-	Denmark	1941	0.05	17	24
Smith Company	Smith Puntam	USA	1941	1.25	53	36
Tvind	Tvindkraft	Denmark	1978	2	54	53
Aeolus	WTS-75	Sweden	1983	2	75	77
NASA	MOD 5B	Hawaii, USA	1987	3.2	97.5	61
Adwen	Adwen AD 5-135	Germany	2004	5	135	95
Ming Yang	Ming Yang SCD 6.0	China	2014	6	140	100
Siemens	Siemens Gamesa Sg 8.0-167	Unitet Kingdom	2017	8	167	155
Vestas	MHI Ves-tas V164 - 9.5	Unitet Kingdom	2018	9.5	164	140

The starting point of this paper is to investigate the feasibility of WT outputs larger than 20 MW and to provide an appropriate model for reducing energy costs. In the period from 1999 to 2012, the use of wind energy to a total of 283 GW increased sharply, while for 2020 it is expected that this number will reach 760 GW [5]. Table 2 shows the trend of increasing of hub height, the diameter of the rotor, and the power of WT from 1941 to 2018. Chronologically, the major steps were made in 2005 with the implementation of a 5 MW wind generator [6]. Then there were transient solutions for expansion of power from 7-8 MW, so in 2012 there was a wind turbine power of 8 MW with a rotor diameter of 164 m. A step further, Bak et al. [7] presented the WT power of 10 MW. It is a rotor with three blades for a speed range from 5 m/s to 25 m/s. As for research for this WT, CFD analysis was performed to obtain detailed aerodynamic characteristics of the rotor [8].

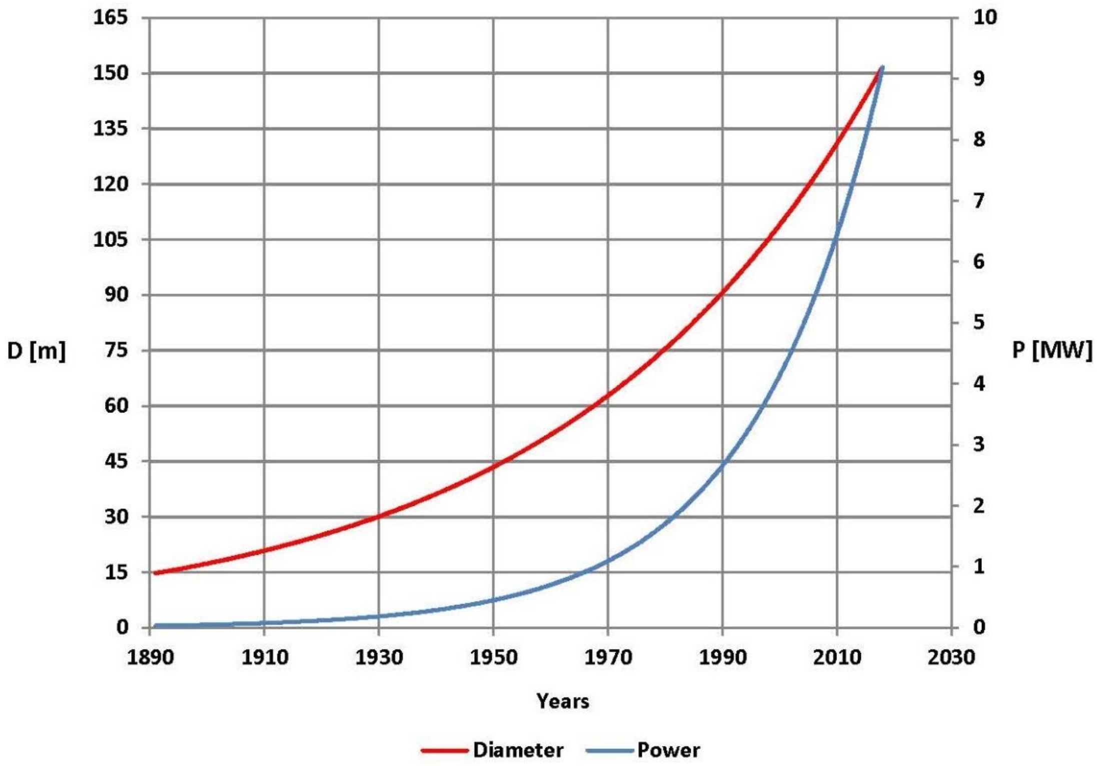

Figure 2 - The trend of increasing rotor diameter and power of WT

Peeringa et al. [9] presented the preliminary WT design of 20 MW and controller design. In this context, the WT of 5 MW is being upgraded as a starting point for the analysis of the reference WT of 20 MW. The concept of wind turbines with multiple rotors on one tower is being considered [10]. The conclusion is that the price of a 20 MW multirotor type wind turbine is less 80% compared to four 5 MW single-rotor type WT. These researches depend on many assumptions, but they indicate that the concept of multirotor deserves more intense research. In this paper, we will talk about WT with a horizontal axis of rotation (HAWT). HAWT has much higher efficiency for the same wind conditions relative to the vertical axis wind turbine (VAWT). Also, their blades are connected to the hub [11]. The biggest disadvantages are reflected in the noise production, large space they occupy, and price. Generator and gearbox are on the tower, which is also a problem in case of failure.

2 Rotor

The WT blade is one of the most important components of WT. In this sense, the manufacturing of a WT blade requires innovative design approaches, material selection, and manufacturing processes. The current and future development blades are related to the construction, selection, development of materials, and production. The design of the blade must fulfill two basic conditions: an analysis of structural requirements and achieving aerodynamic efficiency. For large diameter rotors, the airfoil selection is important. The aerodynamic efficiency of the blade increases with the choice of the thinner airfoil. In the blade construction, the four objectives are set: optimization of aerodynamic design, blade length, blade design and, production requirements, and reliability of blades testing. The multidisciplinary optimization is becoming more and more common for the complex calculation of WT components [13]. Composite materials are increasingly used today for the production of WT blades. Blades that are made of these materials are light in weight but at the same time have good structural characteristics as strength, stiffness, and fatigue resistance [14]. Very easy shaping is one of the most important characteristics of composite materials. This characteristic is very important in the case of complex body geometry. Also, new materials contribute to reducing the costs of producing blades [15]. On the other hand, WT manufacturers are not able to provide proper quality control related to the elimination of defects in manufacturing such as waves and wrinkles [16] and porosity [17]. The development of the rotor and usage of new materials, the weight of the blades increases nonlinearly with their length [18]. The comparison rotor diameter of WT with a wingspan of big planes is presented by the Figure 3. Here appear large structural loads due to blades suppleness. Therefore, these loads and the phenomenon of natural bladder frequency must be reduced.

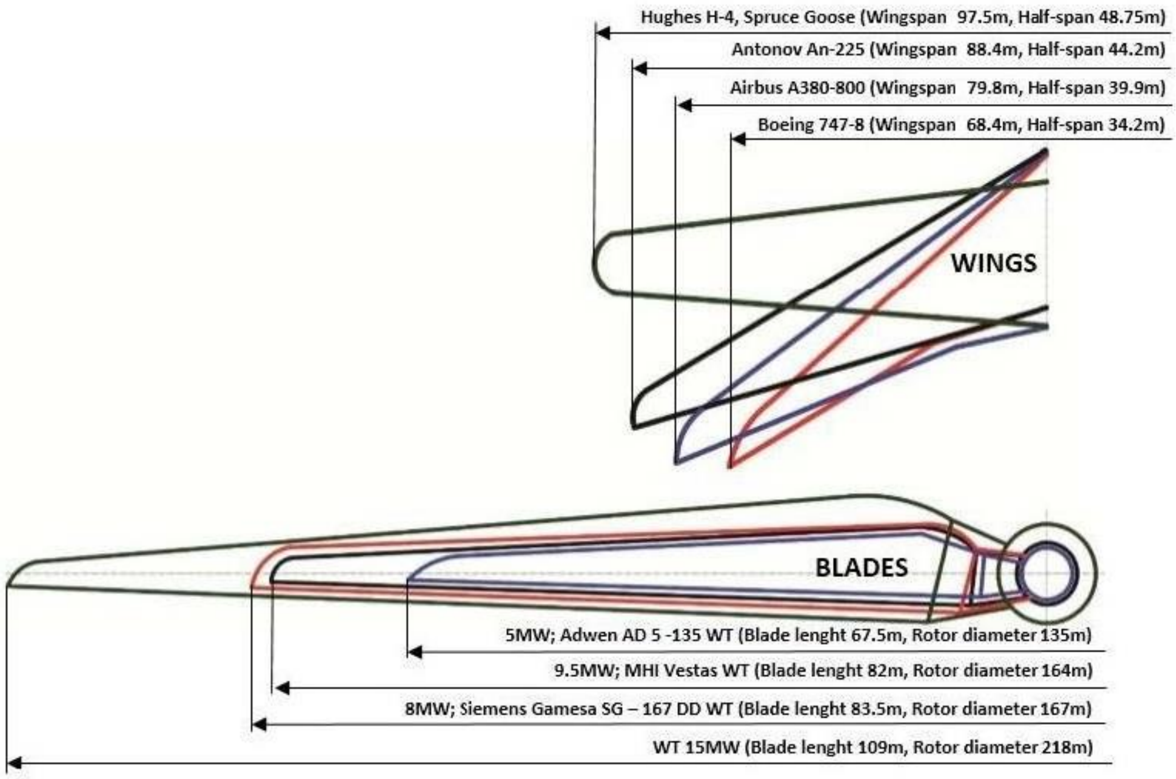

Figure 3 - Comparison rotor diameter of WT with wingspan of big planes

The future research and directions of the rotor development are: increasing the diameter of the wind turbine rotor whose goal is to exploit wind energy at higher altitudes, efficient optimization of all data, considering the potential costs of innovative materials, and improving quality control to reduce defects in rotor production.

3 Transmission

One of the classifications of WT is the concept of transmission. In accordance with this classification, WT can be geared type and gearless type [19]. Both type have their own advantages and disadvantages which will be more explained in further text.

3.1 Wind turbines with gearbox

The WT gearbox has the function of increasing the shaft angular speed that is connected with a generator of electrical energy. Block scheme [20] of the conversion of mechanical energy to electrical energy in wind turbines is given in Figure 4. Most commonly used is a three-stage WT gearbox [21]. The first stage is a planetary gear train, which has three planet gears, one sun gear, and one ring gear. The second and the third stages are parallel gear trains that each have a pair of gears. This gearbox uses eight pairs of helical gears, nine in total, to perform its operation. The dimensions of drive gears are much larger than the driven gear [22,23]. The speed of the input shaft is around 25 rpm while the output shaft speed is about 1500 rpm [24]. Parallel gears transmission with parallel axis units is used for speeds with medium and higher transmission ratio, while gearboxes with planetary transmission are used for speeds with a lower transmission ratio.

Gearboxes for high-power WT (MW type) are usually used with three-speed transmission [25]. All vibrations from the rotor and the wind are transmitted to the gearbox. There are various failures: from damage and breakage of all gears to damage to the input shaft, due to poor lubrication and damage to the housing [26]. Because of all mentioned, the gearbox is the source of the failure of many wind turbines, which prevents them from reaching a projected lifetime [27].

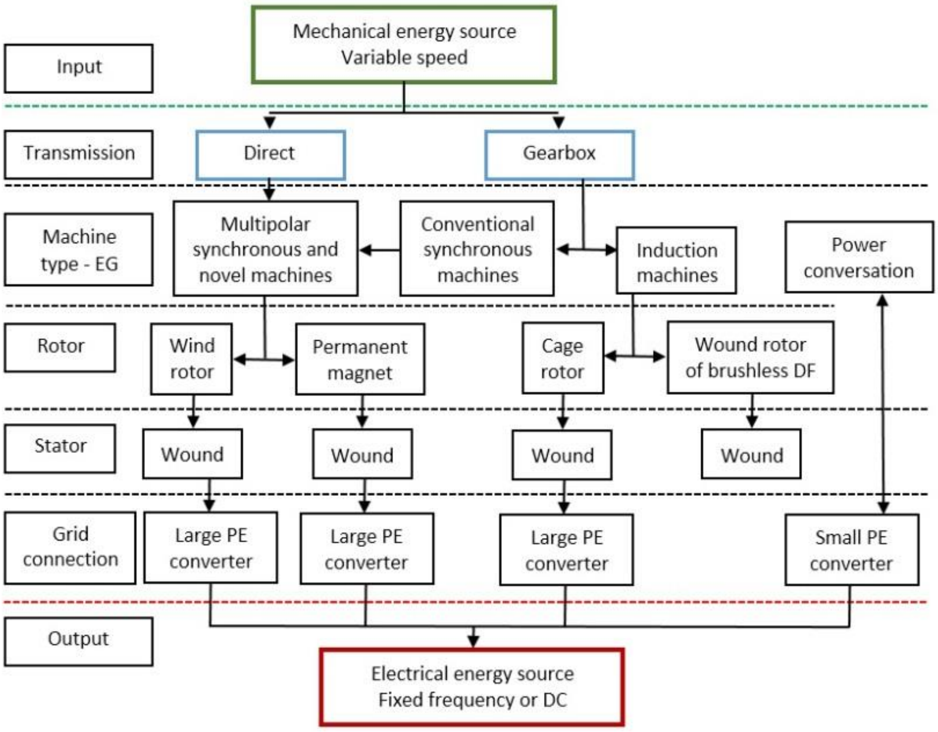

Figure 4 - Block diagram of conversion mechanical energy to electrical energy using wind turbine

3.2 Gearless wind turbines

The idea of a direct connection of the rotor with the electric generator is now more and more in use. This solution is slowly applied to avoid the use of the gearbox to reduce the weight of the WT. The advantages and disadvantages of geared and gearless WT are presented in Table 3.

Table 3 - Advantages and disadvantages of geared and gearless WT

Type of wind turbine	Advantages	Disadvantages
Gearless wind turbines	- Simplified drive train - Increased energy yield - Higher reliability - Reducing total weight	- Heavy electric generator - Large rotor shaft diameter - Large torque
Magnetic	- Cheaper - Low weight of electric generator - Low torque on high speed shaft	- Failure fatigue - Problems with maintenance - A lot of parts

4 Electric generator

In order to maximize and use gained power and reduce costs, WT with different engineering solutions have been developing simultaneously. The classification of electro generators is being done by power level and the working principle. Synchronous generators featuring new engineering solutions are the most common generators existing in market. They can also be classified as inductive generators [28]. More and more WT are being included in electrical network. Frequency is still being controlled by conventional thermal power stations. The question is how to maintain frequency in a predefined domain. Nowadays, conventional generators are equipped with primary and secondary control. More and more WT are being included in the electrical network. Frequency is still being controlled by conventional thermal power stations. The question is how to maintain frequency in a predefined domain. Nowadays, conventional generators are equipped with primary and secondary control. The direct wind energy method is part of primary frequency control [29]. In normal conditions, WT are not supplying available energy to the electrical network, so the limits stay defined by power control. A considerable amount of kinetic energy is accumulated in the rotating mass of blades of wind generators. This energy is contributing to network inertia in case of constant speed WT, but in case of varying speed, rotation is isolated from network frequency by the electric power converter. Considering this, additional control by means of "hidden inertia" can be acquired by inertia imitating and limited time primary frequency control [28]. As important representatives in the realization of electro generators in this paper, the most common technologies will be presented: generator with planetary magnets and HTS (High Temperature Superconductor) technology. The principal of superconductor generator technology is shown in Figure 5.

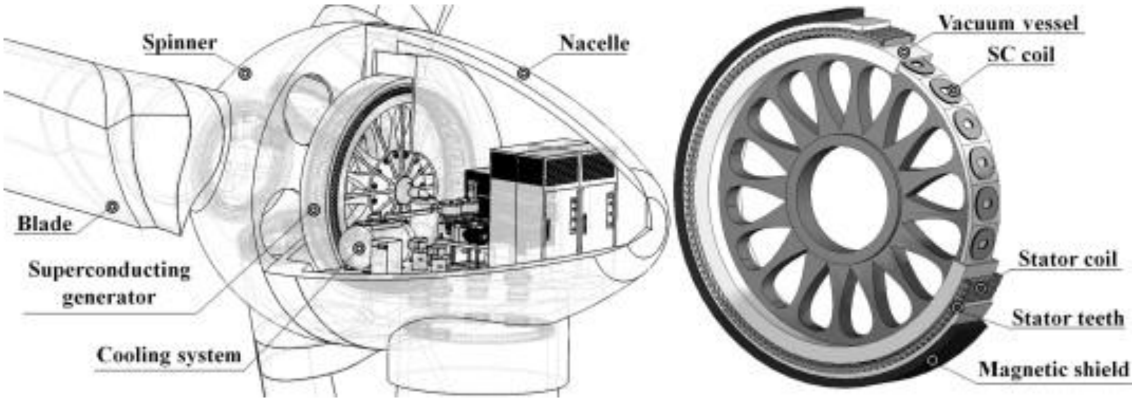

Figure 5 - Basic elements of superconductor generator technology [19]

The generator with permanent magnets is connected to the main rotor assembly through the main rotor bearing clutch and separated generator bearings [30]. In general, switching generators with permanent magnets has three concepts: PM radial flux (RFPM machines), PM with the axial flow (AFPM machines), and PM transverse flow (TFPM machines) [31]. RFPM machines produce magnetic flux in a radial direction with radial orientated PM [32]. These machines are a better economical solution for big WT with direct drive. AFPM machines produce magnetic flux in an axial direction with PM. These toroidal-stator machines have some advantages: compact design, reduced length in an axial direction, appropriate connection with motor [33]. They are designed for small power machines [31]. TFPM machines point that the direction of magnetic flux is perpendicular to the direction of motor rotation. These machines provide more space for coil, but at the same time reduce available space for main flux [34]. They also feature big specific torque and a large number of parts, which represents discussing a matter of maintenance and elements optimization [35]. High temperature superconductor (HTS) technology is present nowadays which allows generators to operate with a third of mass and half of the loss compared to conventional machines [36-38]. HTS coil operates at extremely high and low temperatures [32]. Size and weight reduction of 10MW wind generators are accomplished by this technology, with a consequence regarding reducing pure energy costs compared to copper generators and permanent magnet generators. Also, this technology is practical and allows an economical approach to maintenance. HTS technology eliminates separated gearbox generator assembly, i.e. flexible structure is mounted in that part. Integrated multipolar permanent magnet generators enable the creation of a technically simple and at the same time innovative design of WT with high efficiency. This type of generator achieves a nominal power even at an angular speed of 12 rpm. In addition to reducing the weight of the WT, this concept also ensures low noise during its operation.

5 Tower

The WT tower transmits the load of the gondola and the WT rotor to the ground. The most common are made from steel, concrete, or composite materials. Also, there are hybrid solutions that represent a combination of concrete and steel. Depending on the height, different solutions to the construction of the columns are applied. According to the de la Fuente [39], an overview of the realization of the rotor with its basic characteristics is given in Table 4.

Table 4 - Wind turbine towers: Applications, strengths and weaknesses

Type of tower	Height [m]	Diameter of base [m]	Weight/Height [t/m]	Strengths	Weaknesses
Steel (Tubular)	60-120	3-4.5	2-5	Less material and optimal transport for h < 80 m	High transport and assembly costs for h > 80 m
Concrete (On-site)	60-115	3-8.5	8-19	Monolithic, durability and stiffness	Weather conditions vulnerability
Steel + Concrete	60-146	3-5	3-15	Expected to slove weaknesses of previous alternatives	In experimental stage
Active Composite	80-146	3-5	-	Possibility of damping wind vibration	The inability to dampen the vibrations

5.1 Steel tower

The steel tower consists of steel profiles interconnected by wire links or welded together at the position of the WT. Such constructions allow for realization at altitudes from 60m to 160m. For height greater than 80m, conical cast iron poles are most often used, with the main advantage of the transport and material optimization [40]. The main goal is how to achieve a small mass of the tower for different conditions as well as obtaining a lower load [41]. Enercon has developed a new method for assembling sections of tubular steel towers using a grout joint [42]. The new Enercon design is based on the separation of the tower pillars into the longitudinal sections. These sections are much easier to transport from place to place.

5.2 Concrete tower

Towers of WT are generally made of ferroconcrete. Following Grünberg and Göhlmann [43] company Enercon made a WT E126/6 MW with characteristics (hub height 135 m and rotor diameter 126 m). WT tower is divided in both horizontal and vertical direction, and design improvement of the ferroconcrete tower is made. On the other side, minimal costs of manufacturing ferroconcrete towers are provided by Ma and Meng [44]. High quality of tower construction is obtained by using FEM analysis, and they made optimization to obtain the minimum concrete cost. Lofty [45] designed a new kind of tower in which the cross section is a triangle shape. The ferroconcrete towers are cheaper in comparison with steel towers.

5.3 Hybrid tower

Dutch company Mecal has set up a hybrid tower for WT of 2.3 MW for a hub height of 133m. The concrete tower has five rings, and each ring is divided into four quarter-circle and four flat elements for easy transportation. One of the advantages of a hybrid tower is the possibility of replacing the steel part after 20 years because the lifetime of the concrete is 40 years. However, for the latest generation of hybrid towers, the data is not available and is still in the development phase.

5.4 Composite tower

The construction of a WT tower of materials such as steel profiles or sheet metal is heavy, expensive to manufacturing, and require special conditions for transporting materials. Besides this lacks of steel, concrete, and hybrid constructions, the main disadvantage is the inability to dampen the vibrations. In this respect, composite materials have a significant advantage in comparison with other designs due to the possibility of damping wind vibration, which reduces vibration loads, which is very important for high construction. Another significant advantage is that tower production can be done on-site. This way of production allows reducing the cost of production facilities, where the mold manufacturing equipment fits into the existing standards [46].

6 Conclusion

Wind energy has been gaining more and more important as the element of renewable energy resources. Hence, the chronological development of wind turbines points to a rapid increase in active power. The analysis of achieved technical solutions has been done throughout the basic elements of the wind turbine in this paper. Using composite materials in designing rotor blades, reducing the size of the gearbox, new technological achievements in improvements of generator performances, and acquiring more usable power are all the factors that will be researched in future development. Knowing this, aerodynamic characteristics and structural components must be designed in terms of mass reduction and maximizing wind potential at nominal and extreme work conditions. New technologies and materials are in expansion. It means a multidisciplinary approach in designing and manufacturing wind turbines. The usage of new materials gives many advantages and limitations at the same time. At high altitudes, the speed of the wind is greater and that provides more wind exploitation.

Knowing this, aerodynamic characteristics and structural components must be designed in terms of mass reduction and maximizing wind potential at nominal and extreme work conditions. WT with power beyond 20 MW have a significant role in increasing tower height, rotor diameter, and dimensions of other elements. All of this increases the total mass of the WT possibility of damping wind vibration. The tendency is to reduce the total mass of the WT as well as the simplification of the structure with the usage of new composite materials and technical solutions. Using composite materials in designing rotor blades, reducing the size of a gearbox, new technological achievements in improvements of generator performances, and acquiring more usable power are all the factors that will be researched in future development.

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