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TRENDS OF PATENTS ON WIND POWER ELECTRIC GENERATOR

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ABSTRACT

This article discusses the patents related to wind energy to identify technologies, their degree of development as well as their applications and trends. The research was carried out with Google Patents, which delivered more than 700 results from worldwide intellectual property offices. The terms Wind & Power & Electric & Generator were reviewed, analyzed, and classified. Patents were identified with a significant focus on Machines, Structure, Applications in Vehicles, Methods, and Control, that apply the concept of a horizontal axis wind turbine – HAWT (93.8%), followed by a vertical axis wind turbine - VAWT (5.6%) and incipient development in non-rotational systems (static) - WS (0.6%). Finally, a summary of the functional components of a wind energy system is included as a conceptual model for the development of a vertical axis wind source (VAWS).

Keywords: wind, power, electric, generator, patents.

INTRODUCTION

Electricity is a symbol of the level of modernization of a country, having the purpose of solidifying economic growth and it provides security, comfort, and social transformation [1].

The environmental impact of carbon emissions and other contaminants has led to a change in how electric energy is generated by choosing to implement renewable energies in a massive manner. Hence, it is expected that by the year 2030, the European Union can generate 45% of said energies and the United States 27% [2].

During the last two decades, the transition to renewable energies was increased by 19.3% in terms of worldwide consumption and it is estimated that by 2035 said consumption reaches 30% of worldwide demand [3]. Among renewable energies, wind energy has a high penetration compared to other renewable energies [4].

Wind energy dates back to the end of the 12th century, beginning with systems that used air thrust to move rudimentary vanes that translated into a rotational or vertical movement to push water, windmills, or even lift loads [5]. This technology evolved into current wind systems for the generation of electric energy [6] which implies further developments in the sea and the continent. Over time, they were standardized into turbine systems shown in Figure-1, with structures whose costs regarding installation and maintenance surpass 7.00 dollars per installed kW [7]. These generation systems tend to be developed under the concept of smart grids and microgrids given their advantages in terms of control, scalability, flexibility, reliability, fault tolerance, and reduction of operation costs of the distributed systems [8].

PATENTS BASED ON WIND ENERGY FOR POWER GENERATION

Power generation based on wind-based sources will have an important role in the worldwide supply of electricity that is sustainable and friendly to the environment. Therefore, it is paramount to review the inventions and utility models developed within the scope of interest and particularly over the last three decades in order to characterize the technologies, models, and conversion techniques of wind energy into electrical energy and identify the needs, gaps and voids related with said technology.

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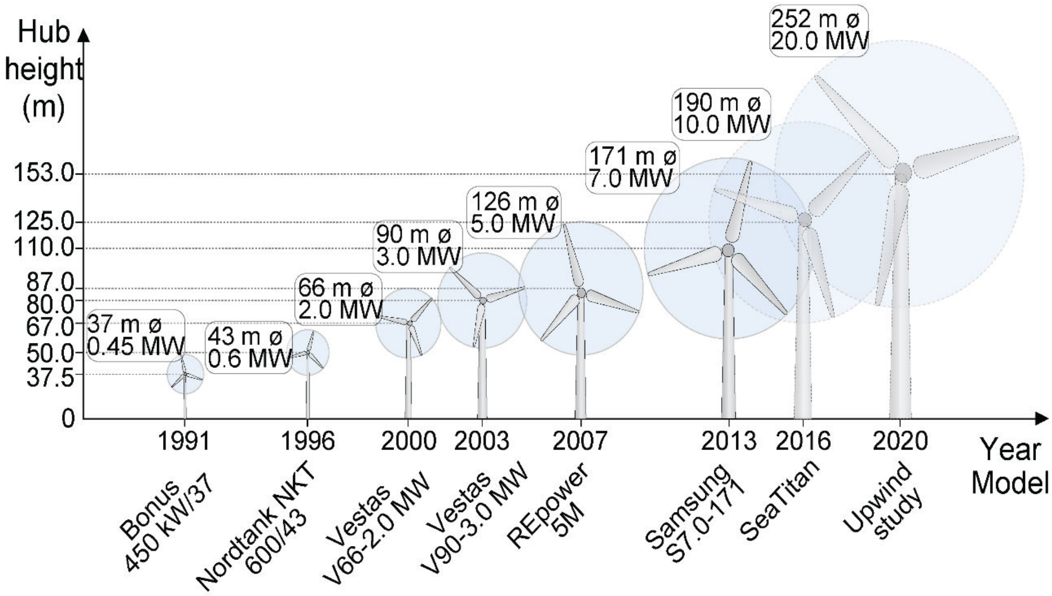

Figure-1. Evolution of wind turbine generators. Source [9].

742 patents were reviewed from 1922 to 2019, which were handed by intellectual property offices all over the world. They were classified into two categories: turbines and static technologies as well as by country and year. The term turbine refers to wind energy systems that move helixes, vertical or horizontal sails based on mechanic reduction mechanisms that move a rotational electric generator. Static systems harness the wind to move parts (axes, sails, posts) without generating rotational movement. Figure-2 illustrates the previously described systems.

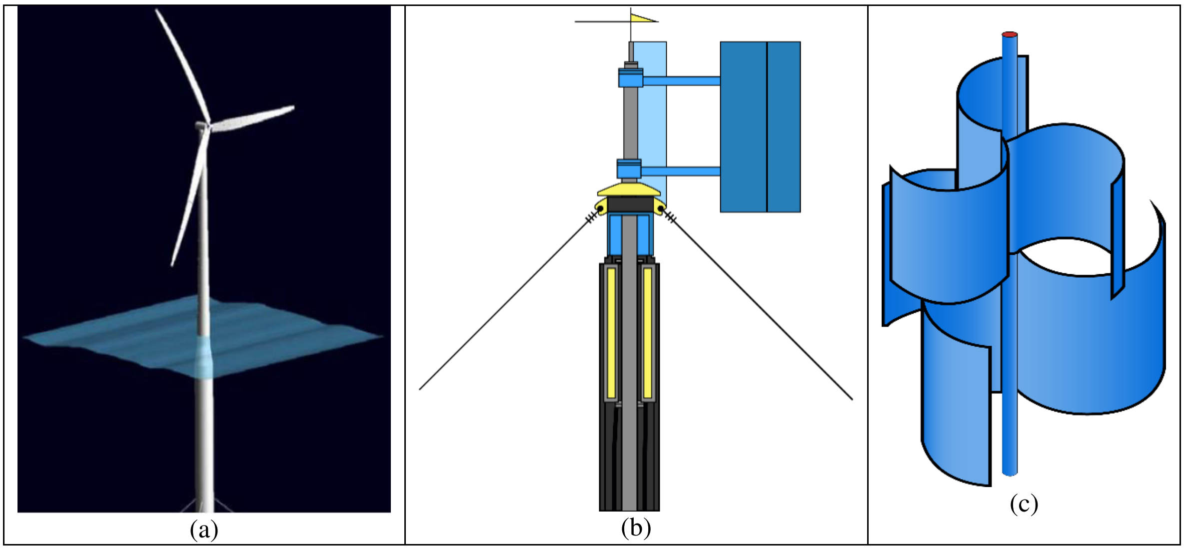

Figure-2. Systems with: a) Vertical axis turbine [10] b) Horizontal axis turbine[7], c) Static configuration [11], adapted by the authors

Figure-3 shows the summary of patents from WPEG having three patents in 1934, which rise to 57 patents in 2010, adding to 416 in total. Over the last 9 years, more than 44% of the patents corresponding to 327 have been published within the observation window.

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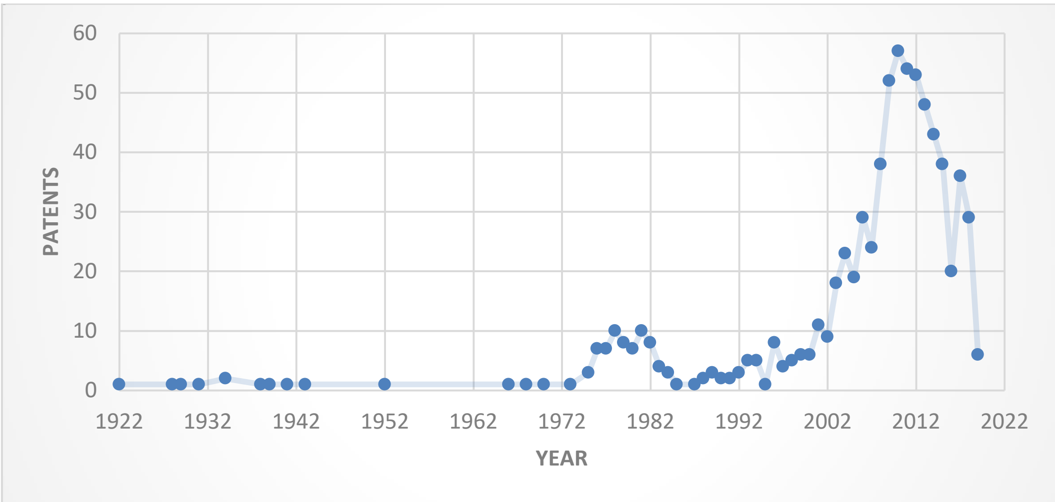

Figure-3. WPEG patents per year. Source: Authors

The timeframe between 1990 and 2019 (partially) represents a period with significant activity where almost 90% of the patents were filed regarding wind-based power systems (Figure-4).

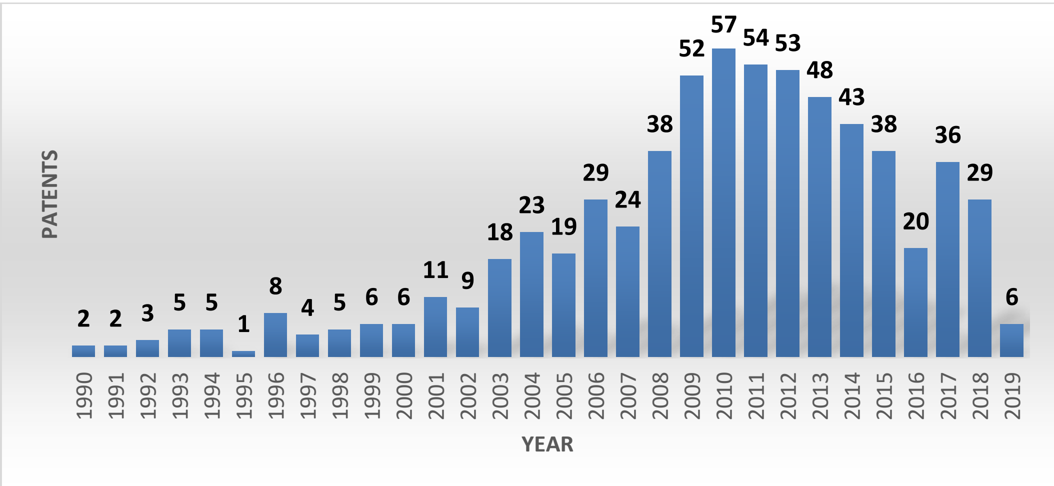

Figure-4. Period with most inventions registered on the WPEG. Source: Authors.

Figure-5 shows the ranking of countries that generated patents in the WPEG, led by China with 27.3%, Germany with 23%, France (9%), Korea (7%), Japan (5.5%), United States (5.2%) and Greece (4%). They are followed by Taiwan (2.7%), Europe (2.7%) and other International Patents (3.5%). These countries represent 90% of the total, which means that the remaining 10% share is distributed among 23 countries (Figure-6), including Brazil (1.5%), Russia (1.1%), Spain (0.9%), Italy (0.9%), Belgium (0.8%), Switzerland (0.7%), Chile (0,7%), Netherlands (0.5%), Argentina (0.3%), Austria (0.3%), Australia (0.3%), Canada (0.3%), Finland (0.3%) and Ukraine (0.3%). 1.2% of the filed patents are supported by Czech Republic, India, Mexico, New Zealand, Rumania, former USSR and Yugoslavia.

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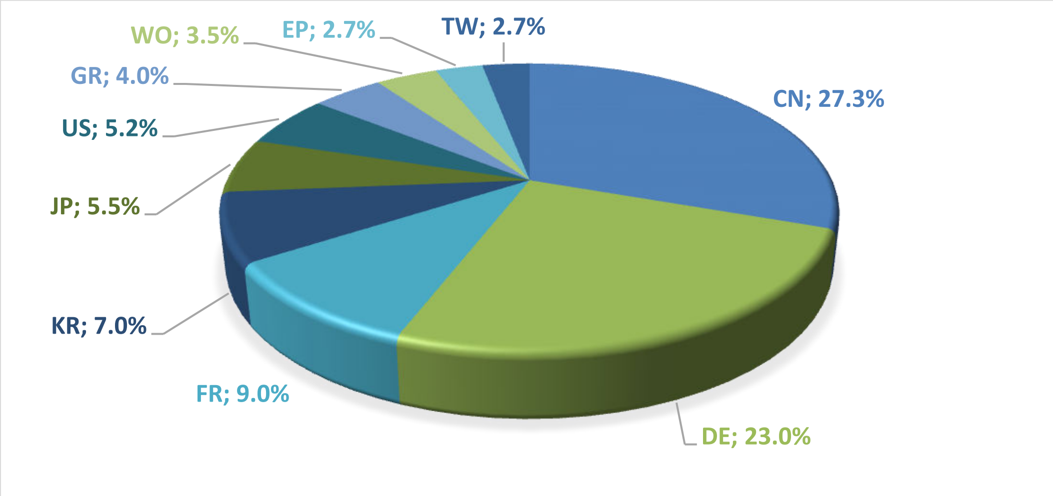

Figure-5. Ranking of the countries with most patents in WPEG (90%). Source: Authors

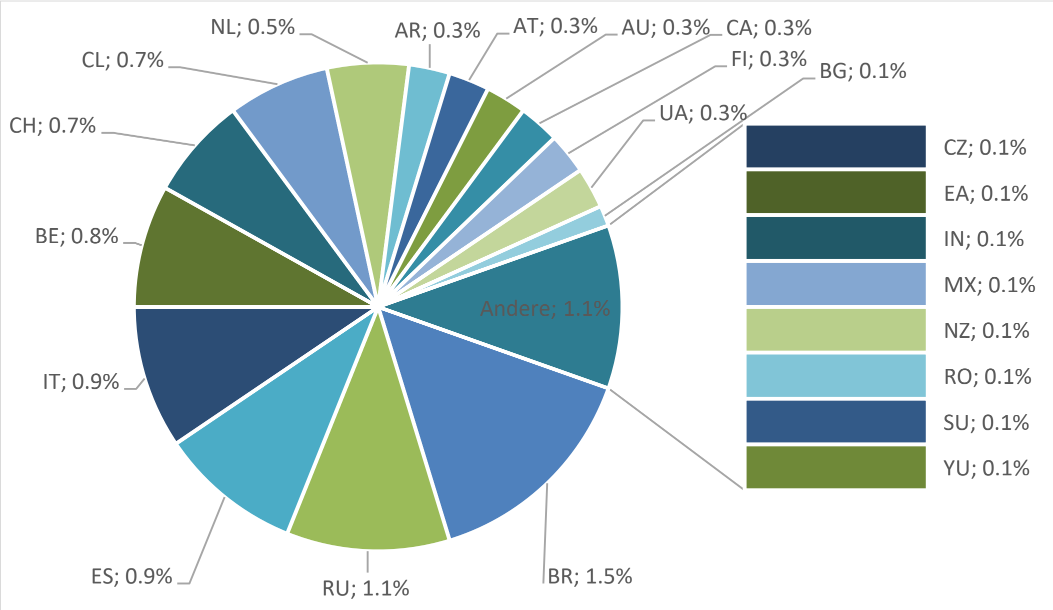

Figure-6. Other countries with patents registered in WPEG (10%). Source: Authors

Based on the patents consulted, it was evidenced that around 30% were granted to companies such as: Mitsubishi Heavy Industries, Enercon, Siemens, Vestas, General Electric, Hitachi, Nordex Energy, Repower System, Gamesa Innovaction and the University de Xi'an Jiaotong (Table-1).

Table-1. Main beneficiaries of patents. Source: Authors

Assignees	Participation
Mitsubishi Heavy Industries, Ltd.	8,3%
Aloys Wobben (Enercon)	6,1%
Siemens Ag	4,4%
Vestas Wind Systems A/S	2,5%
General Electric Co.	2,5%
Hitachi Ltd	2,2%
Nordex Energy Gmbh	1,8%
Repower Systems Ag	1,1%
Gamesa Innovation & Technology, S.L.	0,7%
University of Xi'an Jiaotong	0,7%

TRENDS IN WPEG PATENTS

As a first conclusion, the patent review process reveals that there are two tendencies in WPEG: turbine-based systems and static systems. The information summarized in Figure-7 shows that 99.34% of the patents are oriented to turbine systems, which in turn are divided into horizontal axis wind turbine (HAWT) with a development share of 93.77% and vertical axis wind turbine (VAWT) with 5.57% of the development share. Meanwhile, only 0.66% is oriented to static systems (SWS).

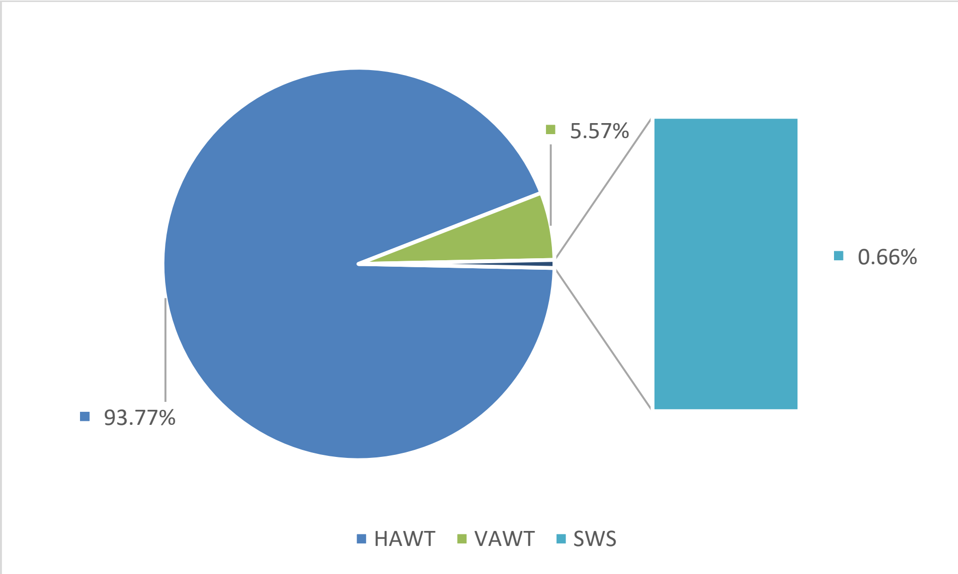

Figure-7. Trends in WPEG patents. Source: Authors

The in-depth analysis of the orientation given to patents states that there are several areas of focus: Machines (38.6%) refers to developments related to electric machines or rotational generators; Structure (31%) dwells on the structures needed to house the generators; Vehicles (12%) explicitly concerns power generation in electric vehicles; Method (4.29%) pertains to the development of machines, structures or systems for regulation; Control (3.96%) assembles the developments aimed at the regulation of physical variables regarding wind power and electric energies; Buildings (3.14%) harnesses these structures to place rotational generators; Studies regarding Propellers (0.99%), Compressor (0.66%), Piezoelectric elements (0.66%) such as a transducer for the generation in static systems, Mechanism for rotational systems (0.66%) and other developments with low development share (3.96%).

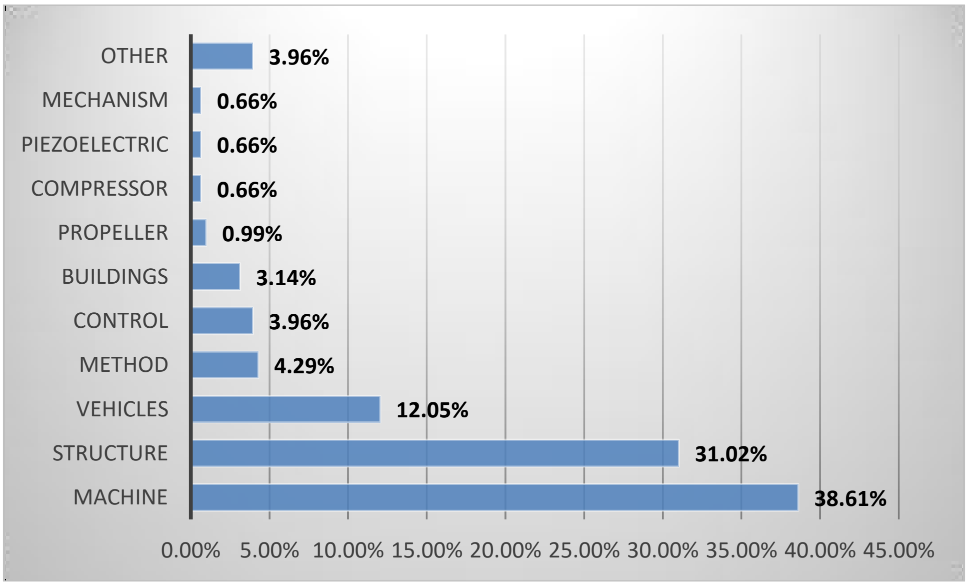

Figure-8. Focus areas of patents in WPEG. Source: Authors

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90% of the reviewed patents can be classified into the five areas shown in Figure-9, with a significant development in machines and structures and a marked trend in wind energy vehicle systems.

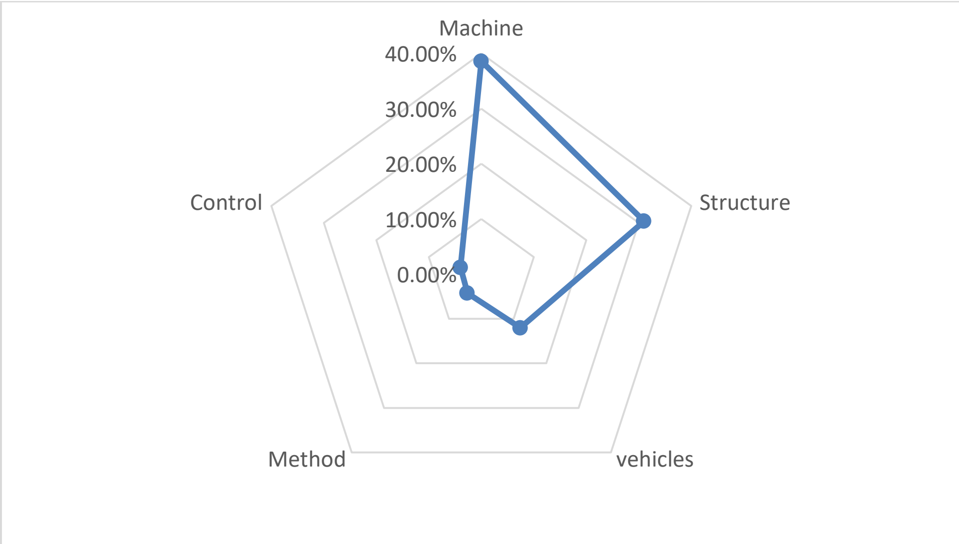

Figure-9. Five focus areas in WPEG. Source: Authors

EMPHASIS ON MACHINES

In this emphasis, an important number of patents are developments that have turned wind generators from simple windmills into sophisticated systems found in the sea in wind farms as seen in the Netherlands and Norway. The path of discussion followed by designers and inventors is now detailed.

Over the first decades of the last century, inventors began to explore how to connect an electric generator to the helixes of windmills in order to use this resource and obtain electricity, by incorporating passive electric systems and speed regulation mechanical systems to stabilize power generation [12]-[14].

For the optimization of wind turbine systems, inventors developed various devices, which include: Electric generator [15] which is the most common model used by designers; Air-harnessing systems (helixes) [16]; Mechanical systems to increase speed [17]-[19]; Horizontal rotation systems to align according to the direction of the wind [20], [21]; Regulation and braking systems[22], [23]; Stator-cooling systems [24], among others.

Regarding the electric generator, the approaches are quite different, with improvements made on electromechanical designs, as seen in [25] where an armor is implemented with coils under shifted angles which cancels out the longitudinal attraction of the poles when facing each other in resting periods. There is a system that sets the winding of stator and rotor as an electric transformer that can be supplied with alternative current [26], similarly to [27] where an electromotor winding is set within the armor to help the generator to compensate inertia under low wind currents. There are systems based on synchronous generators with variations in magnetic poles in terms of position and number [28], with coils winded between the poles to create an additional rotating magnetic field [29]or with asynchronous magnet systems that allow to commute the number of poles in terms of the generator speed [30], [31] as well as neodymium-ferroboron rotors [32], and systems which use power electronics to control the generated voltage [33], thus eliminating the mechanical system of gears to stabilize the generated voltage [34].

Other developments use new magnetic materials in rotational settings such as the axial flow generator [35] that is shown in Figure-10. A voltage is induced over the coil due to the field generated by the permanent magnets facing each other on the sides of the coil, leading to an array seen with more detail in Figure-11.

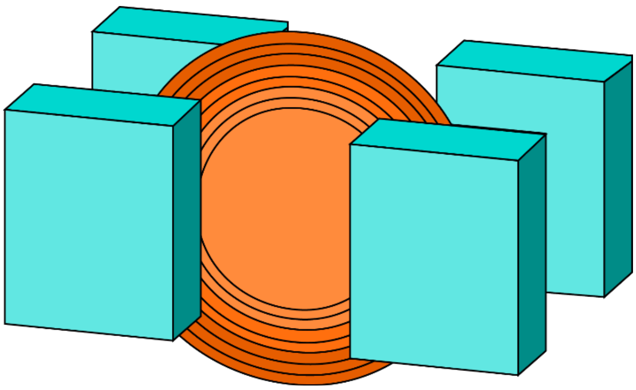

Figure-10. Generator of axial flow. Source [35], adapted by the authors

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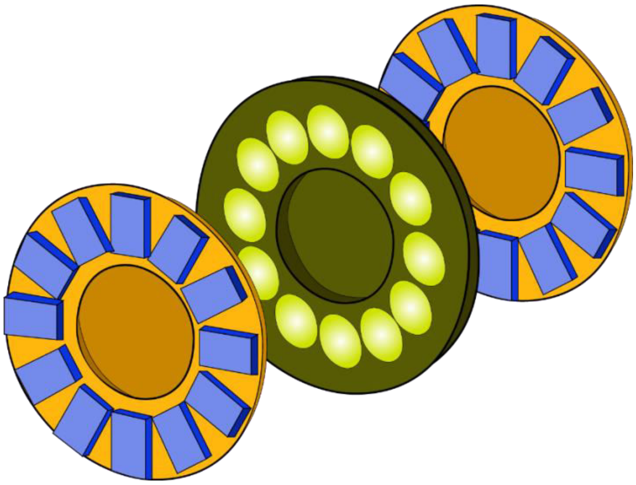

Figure-11. Generator of rotational axial flow. Source [35], adapted by the authors

Following the line of developing new materials, [36] presents a system that uses self-induction properties from FeGa crystals to build an array of generators coupled to a rotational system that turns rotational movement into oscillations over the FeGa cells. This leads to voltage induction as shown in Figure-12.

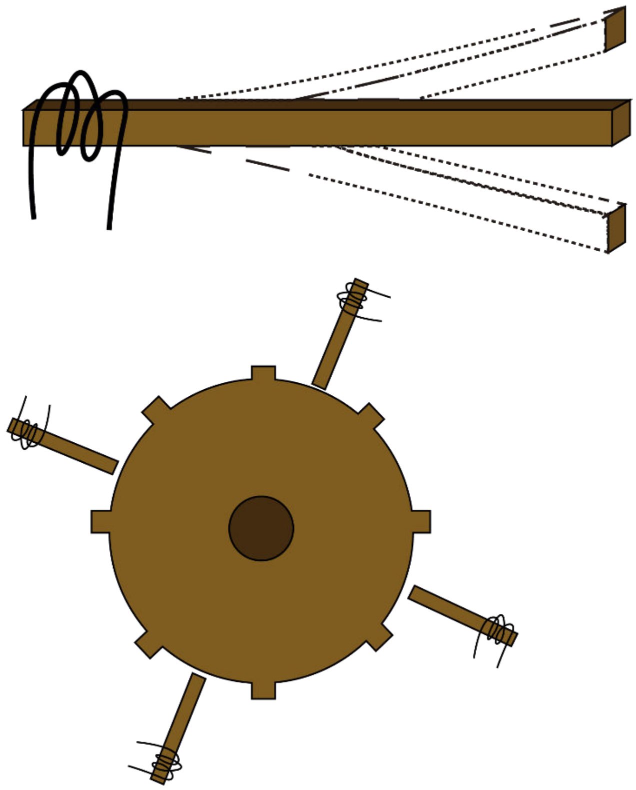

Figure-12. Rotational FeGa generator. Source[36], adapted by the authors

The design model adopted by inventors corresponds to vertical wind power generators, which use adirectly coupled electric generator [37] or through a box of gears to a special helix [38] that differs from one design to the other, incorporating vanes or sails [39]as shown in Figure-13.

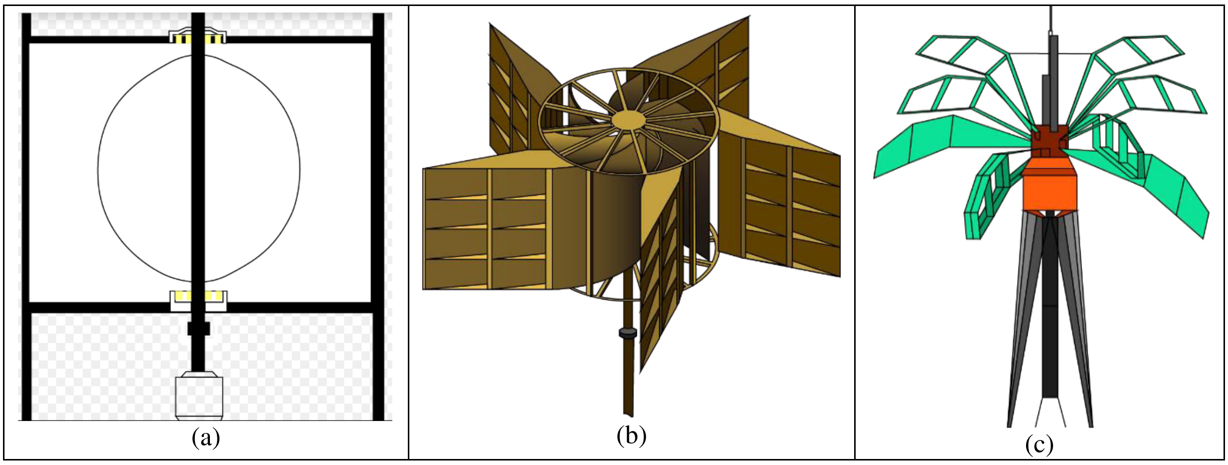

Figure-13. Vertical generator. Source a) [40] b) [41] c)[42], adapted by the authors

Finally, it is common to find in patented designs the use of systems with permanent magnets to form magnetic bearings to reduce friction and optimize the wind thrust. These type of developments is evidenced in [40], [43], [44].

EMPHASIS ON STRUCTURE

In this classification, the patents developed the physical structures for wind-based power generation including platforms, helixes for horizontal and vertical systems, systems that house the generator body and protection systems.

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As previously mentioned, the most used systems are based on horizontal turbines, for which the classic model of assembly consists of a tower as presented in Figure-14, where the first section is for the earth anchor or sea anchor [45]. The section is followed by a rigid tubular structure [46] ending in a gyratory base [47] that houses the generator body. This is similar to the one proposed by the Mitsubishi Company [48], energy transformation systems and Device housing patented by Samsung [49] and [50].

Adjustment systems are presented for pitch control [51], aerodynamic design to maximize the Magnus effect through the geometry of the helix [52], reducing the generated noise [53], and including accessories similar to flaps [54].

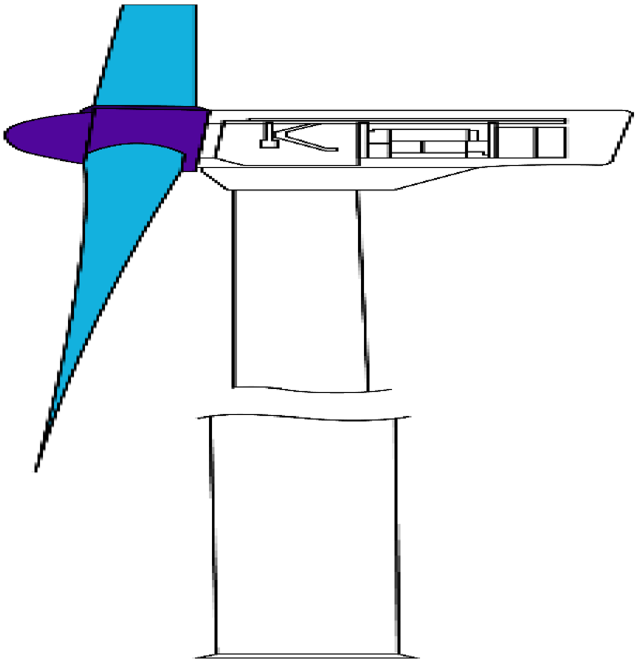

Figure-14. Model of wind-based horizontal generator. Source [55], adapted by the authors

Some examples of vertical generators are shown in Table-1, those vary parameters such as the distribution, number and shape of the vanes, disposed in a rotating drum coupled directly or indirectly to the electric generator.

Table-2. Patents of vertical generators. Source: Authors.

TITL	REFERENCE
A device for converting wind energy or energy from water waves in order to operate a generator or alternator to produce electricity	[56]
Windmill, wind power generator and electrical apparatus using this	[57]
Assembly and disassembly device for utilizing wind energy for wind electricity generator	[58]
Modular Wind-Driven Electrical Power Generator and Method of Manufacture	[59]
Wind-powered generator for generating electric energy	[60]
S-shaped spiral type wind energy electric generator	[61]
Fluid flow power system e.g. wind power system for use in vehicle for generating electricity from water, has generator coupled with rotor for converting rotational movement of rotor into electric current	[62]
Device e.g. vertical axis wind turbine, for deploying blades according to thrust of wind and folding blades during upwind, for transmitting power to electric generator, has gear rims whose simultaneous revolution create variable distance	[63]
Drag-type wind turbine for wind-driven electricity generators and wind-driven electricity generators using drag-type wind turbine	[64]
Vane for vertical shaft wind turbine, wind turbine and electric power generator	[65]
Drag-type vaned fly with (blade) wheel vertical axis wind turbine generators (as shown in figure 2, hereinafter referred to as the vertical axis wind turbine generators) means for improving the conversion ratio of electrical energy of the wind energy	[66]
Wind energy electricity generator for low wind velocity	[67]
Electric energy parallel output type vertical axis wind power generation system with axial power generators	[68]
Rocking blade type wind generator with vertical shaft and electricity generating method thereof	[69]

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EMPHASIS ON VEHICLES

The systems proposed in general apply to the same operational principles of wind turbine generators but vary the way in which aerogenerators are incorporated into the physical structure of the vehicle. One example is to house the system on the roof [70] from Citroen Automobiles and KR-101211409-B1, 2012; CH-702904-A2, 2011) or inside the vehicle [71], [72]. In most cases, these systems generate electric power as a complement to increase the autonomy of the vehicle [73]-[75].

EMPHASIS ON METHODS

A high percentage is focused in the development of detection and control methods of harmonic components in permanent magnet generators and doubly fed induction generators (DFIG) as well as harmonic component detection in groups of generators connected to the network. [76] uses Jacobian matrices as a mathematical foundation to perform calculations and correction, [77] analyzes the parameters of the system, calculates thresholds and performs commutation between the direct generation [78] or through AC-CA converters [79] and injects voltage to the network [80].

Other methods propose to operate a WPEG when it enters into spinning mode, meaning that the low speed of the wind cannot generate the energy needed for self-support [81]–[83] and determine failures in generator systems such as in output filters [84] and WPEG permanent magnet design [85].

EMPHASIS ON CONTROL

In this emphasis, most patents in WPEG are oriented to the development and application of electronic control methods based on power electronics (regulation of generated voltage, regulation of voltage while the network operates, quality control of the generated power, applying classic and smart control strategies).

As an example [86], a reactive power is proposed oriented to work in idle speed in a group of generators patented by State Grid Nanjing Automation Research Institute. [87], [88] presents control Solutions when the electric grid has a failure caused by a short-circuit [89], [90] and patents from Enercon Gmbh to control power generation in wind farms operating in the network.

In general, the proposed systems use the control strategy known as Proportional Integral - PI method [91], Nanjing Aerospace University [77], [92]-[95] property of Vestas Wind Systems AS, Northeast Electric Power University, State Grid Liaoning Electric Power Co. Ltd., State Grind, among others. Another strategy is optimal control which can be applied for cooperative control of WPEG [96] or the quality control of the generated power [97] and finally smart control [98] to mention a few cases.

STATIC SYSTEMS

These systems use their own structure to harness the oscillatory thrust of the wind and turn it into electricity. In most cases, piezoelectric transducers can be located in the body of the structure in order to take advantage of the torsion movement as the one presented in [11], in the base of the structure [99], or turn movement into thrust for a hydraulic or pneumatic system that presses the piezoelectric cell EP-3275074-A1, 2019). Finally, the system presented by the University of Zhejiang [100] is a relevant example of harnessing wind to generate movement and, in turn, generate electrostatic loads due to friction. Figure-15 presents the pillars 1, 2 and 3 that experience friction among its surfaces due to the airflow W, thus generating electrostatic loads.

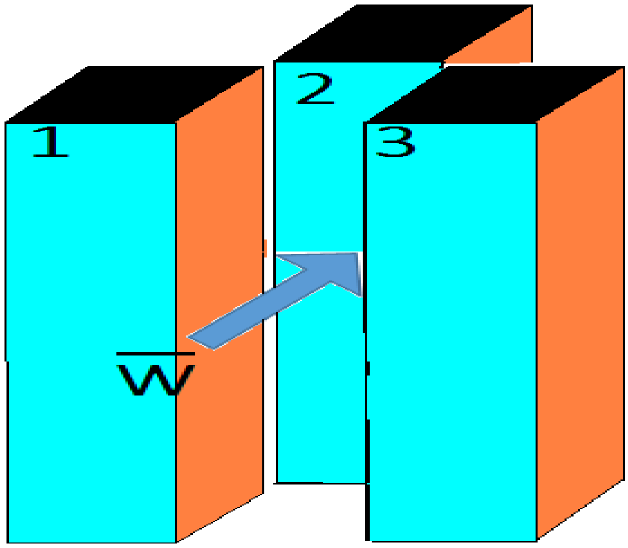

Figure-15. Static generator model for electrostatic loads.
Source: Authors

ANALYSIS AND DISCUSSIONS

The research carried out highlights the evolution and sophistication of wind power generators that can identify the components and subsystems within this type of generation (Figure-16). These subsystems and components include structures, helixes, gearbox, electric generator, subsystem of power electronics useful for the regulation of voltage and power, control subsystem and strategies applied to regulation, protection subsystem, data acquisition (DAQ) subsystem and network subsystem in charge of managing the ignition, interconnection and uncoupling of the electric grid.

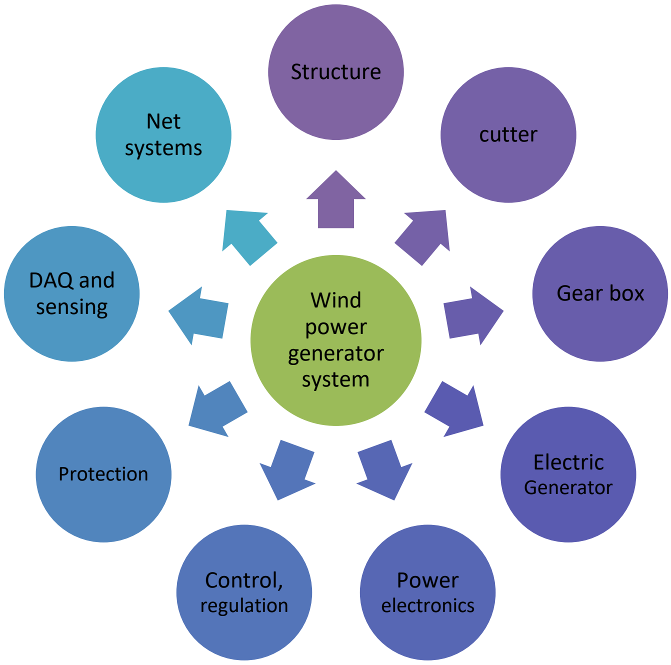

Figure-16. Subsystems and components of a wind power generator. Source: Authors

Structure: In this component, the physical structures enable the anchorage of generators in earth and sea. In the case of HAWT and VAWT, structures represent 30% of the implementation costs and their evolution. Dimensions are only manageable offshore as the systems proposed by Mitsubishi, Enercon, Vestas and Samsung, which tend to include 250 meter-high structures with 20 MW generated power installed in the wind farms. For countries with geographic mountain conditions and deficient access roads, the assembly of such large systems is difficult thus isolating even more the areas that are not interconnected.

Cuter: In the case of HAWT, power generation systems of 2 MW have helixes with a diameter of 40 meters in structures of 60 meters. This causes problems such as noise, bird endangerment and reduction of aerial and maritime navigation in the implementation areas.

Gearbox: The gearbox system elevates the revolutions that are transmitted to the electric generator. However, these systems are not dynamic and generate a braking effect. They need to be lubricated which implies maintenance and special oils under low temperatures and systems to be incorporated to defeat inertia at low revolution speeds.

Electric Generator: For HAWT systems, the most common generator is the doubly fed generator while VAWT involves synchronous and permanent magnet generators that need a minimum speed to generate significant loads.

Power Electronics: This component takes the energy from the generator, turns it into DC and then into AC with AC-DC and DC-AC converters based on power electronics devices such as IGBTs, MOSFETs and TRIACs, among others. These devices have some restrictions for high power levels and suffer from losses due to commutation and dissipation, which require cooling systems.

Control and regulation: This is an essential component in any type of generator to guarantee proper operation and deliver energy to the load within adequate ranges.

Protection: Protection mechanisms are necessary in any system. In the case of low-power HAWT, various states are defined to limit the operation as in the case of low RPMs in the generator, high currents, high or low load conditions and input or output conditions of the network.

Data acquisition system: Measuring parameters is important, especially in wind power generators given their interdependence on stochastic weather conditions, which causes uncertainties in the system.

Network systems: Given the decentralized nature of alternative power sources, wind energy systems require network settings to accumulate the energy generated by each device. This means that the system must be coordinated as in the case of wind farms.

Static wind power generation systems (SWPEG) are a barely unexplored field that has become an interesting research niche due to the development of new self-inductive materials, piezoelectric cells and inductive effect generators such as permanent magnets.

The authors propose a generic model of static wind power generator (Figure-17) which opens the possibility of establishing and developing a new line of research in this area.

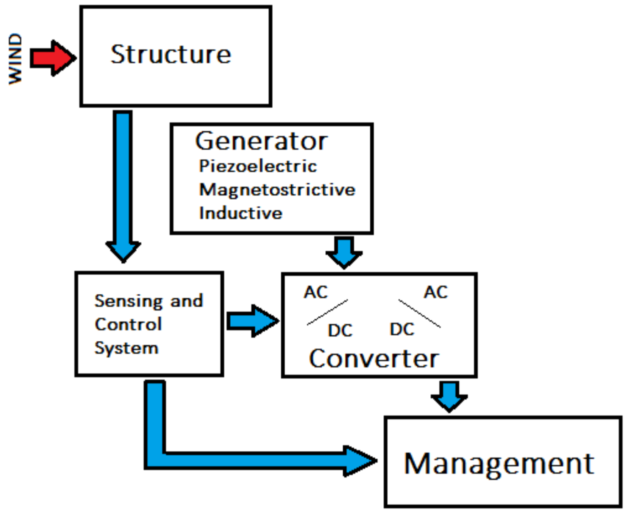

Figure-17. Static wind power generator model.
Source: Authors

Structure: A helix-shaped structure is developed whose area and geometry enable the oscillation with the thrust generated by the wind currents that land on the structure. For this component, it is possible to propose various settings such as mono-helix and accessories that improve its sensitivity.

Generator: To turn oscillatory movement into electric power, it is necessary to have a transducer. Various technologies were identified such as piezoelectric cells, magnetostrictive arrays and permanent magnet inductive generators, just to name a few.

Converter: This component is needed to take the electric power and process it for subsequent distribution, where AC-DC and DC-AC converters are impending to regulate energy regarding the parameters demanded by the load.

Management: This component has two functions: the first one is to compile the energy from SWPEG that comprises the wind farm and the second one is to deliver the energy to the load (for non-interconnected areas) or the electric network (interconnected areas), thus allowing the application of control algorithms and strategies for such purpose.

Sensing and control: This item is in charge of acquiring data such as speed and wind direction to optimize generation, regulate the voltage generated over the converter and control the input / output of the generators to the network.

CONCLUSIONS

Although WPEG dominating the market and the development of patents are the systems based on horizontal turbines, there is an emerging field in vertical models, including different adjustments and improvements that can be made.

Horizontal WPEG involves assemblies and structures that are more robust than in vertical systems, so they are not easy to implement in non-interconnected areas, which are hard-to-reach in terms of geographical settings.

The documentary review leads to concluding that the application of WPEG in vehicles is oriented to increasing the autonomy of vehicles instead of satisfying its energy-related needs.

Regarding the model, there are two marked trends: the first one is that there is a predominance of patents from China and the second one is that these patents are mostly developed and patented by universities or universities working alongside companies. It is rare to see patents issued by individuals in this area.

A research and development niche lies in new materials applied to power generation, as in the case of self-inductive and magnetostrictive effects.

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