“The historic development of the modern wind turbine”

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SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

NOVEMBER 2018

THESSALONIKI – GREECE

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Abstract

This dissertation was written as a part of the MSc in Energy Systems at the International Hellenic University.

In this thesis, we will see the evolution of the energy, and more specifically the wind energy, from the antiquity till today. Additionally, we will acquire knowledge in the operation of the wind power technology. Finally, there will be a presentation of various innovations that exist currently in the wind energy domain.

The realization of the dissertation would not have been possible, without the support and the tolerance of some people.

Firstly, I would like to thank the supervisor Dr. Dimitrios Kanellopoulos, professor of the course 'Wind Power Systems' , for the scientific and moral support, that he provided to me throughout the whole duration of the thesis, by responding to all my questions so promptly. Additionally, I consider it essential to mention the interesting tuition that he provided during his course, in a way that it inspired me to follow the wind energy domain and get acquaintance with its knowledge and its perspectives that it can provide.

I would also like to thank my companion of life, Konstantina Sideris , that was by my side throughout the whole academic journey, from the undergraduate level till the postgraduate level, by supporting me throughout the whole process of studies and during the difficult times. Additionally, I would like to express my high gratitude to my parents and my brother, that supported me throughout the entire academic process , living all the bumps and the ups in the road of my dual-phase graduation .

Finally, I would like to thank the School of Science & Technology of IHU , that has given me the opportunity to enter into the world of energy by the Msc in Energy Systems.

Kontogeorgos Panagiotis

12 December, 2018

Contents

1. Introduction

The specific dissertation refers to the analysis of the phenomenon of the rapid in- crease of the wind technology. The main aim of this thesis is the introduction of the public to the world of the wind energy and its various perspectives, being one of the leaders of the new energy technologies in a new and sustainable era.

The results of the research that are used in this dissertation have educative role and can be used for providing necessary knowledge for the people who are interested in the wind energy domain.

Firstly, we will make a journey in the history of energy, and more thoroughly the wind energy, from the ancient times till the recent period. We will discuss about the recent conference of COP21 and its impacts on the development of energy projects. Additionally, we will talk about the necessity for making the alternative sources of energy crucial part of our reality and replacing the conventional forms of energy with the new and renewable ones .

Moreover, there is going to be an analysis in two axis (physics and technology), regarding the function of the wind technology. We will take answers in questions, such as the why we choose specific localization for the installation of the wind platform, the reason for usage of the suitable wind blades, that can lead to the maximizing of the required power output.

Finally, there is going to be a discussion, in the worldwide and in the domestic level, regarding any recent innovative developments that are in process and others that are in the way of their application.

2. Evolution of Energy generation

This chapter beginning with the history of energy and specializing at the history of wind energy summarizes the developments on the domain. Key technologies are referred, as well as, the evolving background in policies and governmental strategies through the period of time.

2.1 History of Energy

Since the beginning of History, humankind was trying to find various ways to create energy for different applications. People’s efforts towards heating, transportation, agriculture work, and other basic needs were based on natural sources, such as solar energy, wind and water. A great example of that era is the Aeolipile (100 AD) or else known as Hero’s engine made in ancient Alexandria and it could spin around as the water was heated and formed into steam. (see **Figure 1**) [1]

Figure 1 Steam Engine (100 AD) invented by Ancient Greek mathematician, Heron of Alexandria.[1]

In the continuity of time, T.Newcomen and J.Watt (1712) upgraded the concept of the simple steam engine and added the use of coal. (see **Figure 2** and **Figure 3**) As the steam engine was continuously evolving, the industrial level engines started to appear. [6]

Figure 2 Upgraded steam engine by T.Newcomen (1712)[2]

[1] Why did it take so long to invent the steam engine? [Online]. Matt Riggsby – Quora. Published date: Jan 4, 2017

[2] James Watt and Steam Power. [online]. John Simkin – Spartacus Educational. Published date (updated): Dec 2016

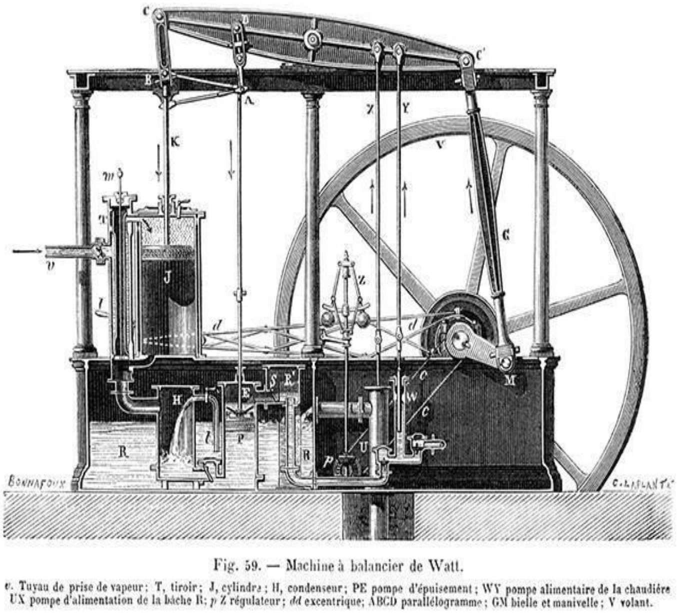

Figure 3 Upgraded steam engine by J.Watt (1712)[3]

At the next evolutionary step in history of energy, the creation of the first energy plant based on hydroelectricity appears, located in Wisconsin of USA. (see **Figure 4**, *left*) At the 18th century, humankind started to exploit the petroleum. After series of different experiments and advancements, its full energy potential was finally discovered and it was used to ignite ICE (*) machines. At the following step, human managed the insertion of petroleum gas in the automobile industry. (see **Figure 4**, *right*) [1]

[3] Watt's Steam Engine. [Online]. Old Book Illustrations. Retrieved date: Nov 2, 2018

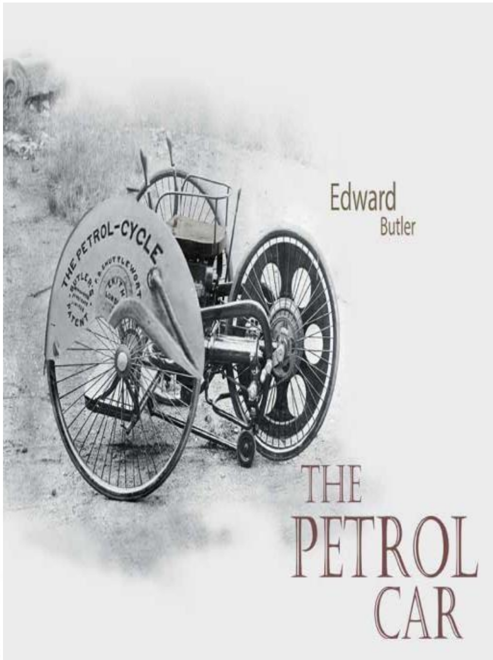

Figure 4 *(left)* The first hydroelectric power plant in Appleton, Wisconsin USA (1882).[4] *(right)* E.Butler created the first petrol internal combustion engine (1884)[5]

The electricity demands increase through various domains of the human society, and as a result electricity became prerequisite for any domestic and professional property. During the WW2 and after numerous radical technological advancements, humankind started to make misuse of his knowledge and technological achievements. One of the most obvious examples is the use of nuclear energy not for the benefit of the better good, but towards the creation of the atomic bomb (**Figure 5**, *right*), abusing in that way the discovery of nuclear fusion made by the physicists Einstein and Oppenheimer (**Figure 5**, *left*). [6]

[4] Sep 30, 1882: First Hydroelectric Plant Opens. [Online] National Geographic. Published date (updated): Dec 16, 2013.

[5] Engine. [Online]. Simply Knowledge. Retrieved date: Nov 2, 2018

Figure 5 *(left)* Creation of the first atomic bomb[6] *(right)* Consequences of the invention[7]

Therefore, governments took severe measures in order to ensure that this destruction will never be repeated, and they created appropriate legislation on the matter. However, the use of the nuclear energy as a source of cheap energy was achieved with the mass construction of nuclear power plants, and under all the necessary precautions taken for safety insurance. At the same calendar time, we have a constant increase in the use of gasoline in the automobile industry. [6]

During the 1970s, there is an extreme demand of oil production, which in fact, after the economic and political turbulence that occurred, made the oil the most dominant energy source, and lead to the 1970s'energy(oil) crisis. [6]

After many years of oil exploitation, we have reached the oil peak, which was said by specialists to be the year of 2008. Additionally, the environmental issues, that have been arisen by the high increase of $C0_2$ emissions and the global average temperature, have turned the interest in finding nature resources that have not a limited time period of life. These sources of energy are called Renewable Energy Sources (RES) (see example **Figure 6**) and they have started to gain ground and claim a percentage from the dominant energy production from the 1990s. [4]

[6] Nuclear Weapon Dismantlement [Online Presentation] Zachary Budda – SlideShare. Published date: Jul 10, 2013

[7] Who invented first Nuclear Weapon. [Online]. Neo – Who invented first. Published date: Feb 1, 2017

The RES include the solar, wind, and hydroelectric energies, biomass, hydrogen and fuel cells, geothermal power, tidal, and wave energy. (Env.Science, 2018)

Figure 6 Alternative Energy Sources (RES)[8]

Despite numerous discussions over the matter have been made through the years, the public and the industries did not seem to realize the importance of the issue. Making the consequences of the extensive oil burn to become more crucial through the passage of years. Moreover, the swift development of technology, results to an increase of enor- mous scale in the power demand by fuel. That was the turning point which has led the governments to begin several discussions over the resolution of the problem, but only at the conference of Paris Climate Summit, in 2015, these discussions were seriously taken and measures were shaped, known as the COP21. (see **Figure 7**) [4]

The point of the conference agreement was to ensure the reduction of environmental consequences, but at the same time the safety of the future generations. The environmentalists and different scientists, that cooperated over the matter, agreed that we should rely on *sustainability* in order to succeed in this initiative. This approach has also the advantage of providing the countries with limited access to oil repositories, the capability to be fully energy-independent supplied by alternative sources. Analysts pre-

[8] Renewable energy sources. [Online] Catherine Vigneron – European Committee for Standardization. Retrieved date: Nov 2, 2018

dicted that the demand on our energy consumption will be tripled in the time frame between 2012 and 2040. [4]

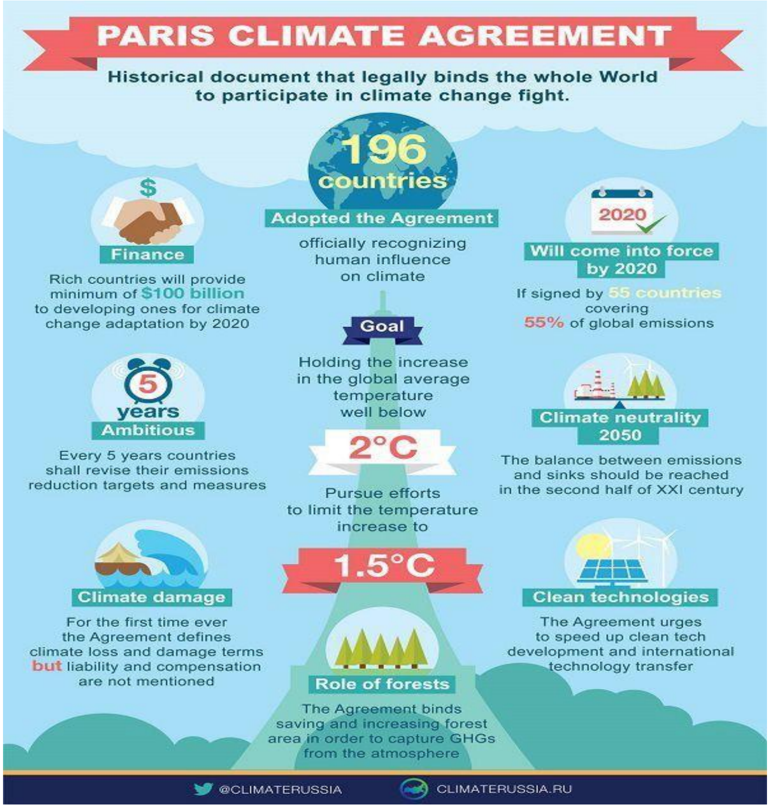

Figure 7 COP21-Paris Agreement[9]

To sum up, the oil reserves will still last for many years ahead, but this does not mean that we should not search for alternative forms of energy that can be combined with the current one and also restore the environmental balance of the planet. [4]

[9] PARIS CLIMATE AGREEMENT – KEY POINTS EXPLAINED [Online] GreatInfographics. Retrieved date: Nov 2, 2018

2.2 History of Wind energy

1st century AD to 12th century: We have the creation of wheel, called windwheel, by a great Greek engineer, pioneer, Heron of Alexandria. This wheel was moving with the aid of wind and was utilized to pump air or water for a musical instrument. (see **Figure 8**) The windmills, in the area near Afghanistan, were used for agricultural activities. Windmills were also used in China and Sicily. At the end of 12th century, horizontal axis windmills appeared in NW Europe for agriculture. (see **Figure 9**) [5]

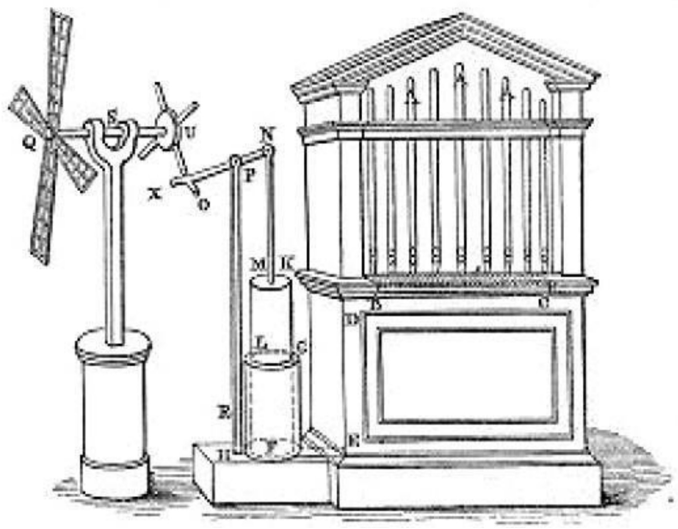

Figure 8 Heron's windwheel[10]

[10] Heron of Alexandria [Online] Michael Lahanas – Hellenica World. Retrieved date: Nov 2, 2018

Figure 9 Persian windwheels at Nishtafun, vertical axis windmill[11]

1880s: The first wind turbine, for electricity generation, was constructed in Scotland. It was created by Professor Blyth from the University of Glasgow and it sourced the charge of the accumulators and the illumination of his property. (see **Figure 10**, *left)* The first US wind turbine was created by the inventor C. Brush for private electricity production. (see **Figure 10**, *right)* [5]

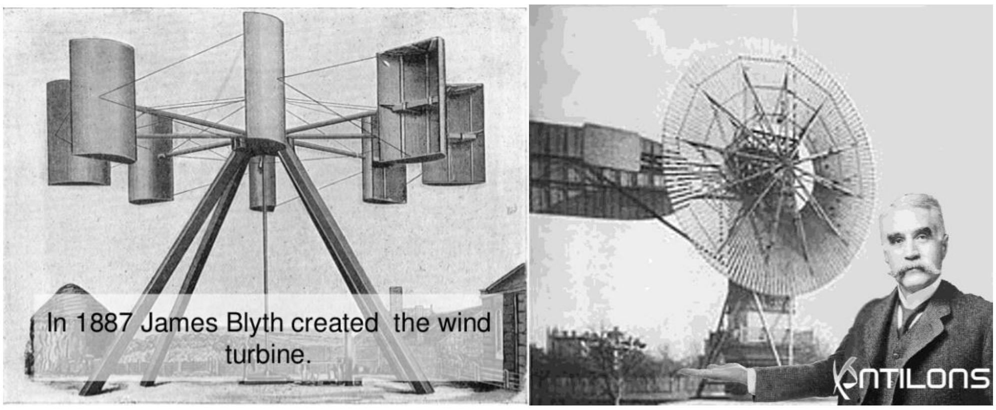

Figure 10 *(left)* Blyth's wind turbine, first ever created.[12] *(right)* Brush' s wind turbine, first US-made[13]

[11] A historical approach to the Wind Energy. [Online] Almudena Ballester – Solute. Published date: Jul 30, 2014.

1890s: The Danish scientist Poul la Cour develops an electricity-generating wind tur- bine and later figured out how to supply a steady stream of power from the wind turbine using a regulator, the Kratostate. Furthermore, he converts his windmill into a prototype electrical power plant providing electricity for lighting for the whole village of Askov. (see **Figure 11**) Moreover, approximately 2,500 windmills with a combined peak power capacity of 30 megawatts were being used across Denmark for mechanical purposes, such as grinding grains and pumping water. [5]

Figure 11 P.la Cour's electricity generating WT that is utilized to cover the lighting of Askov[14]

1900s: The Wind Electricians Society is established. (see **Figure 12**) Research of that time discovered that wind turbines (WTs) with fewer blades have higher efficiency, than WTs with numerous blades. Additionally, there is massive production of wind

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[12] Vertical helical wind turbines [Online] Antonio V – Narkive Newsgroup Archive. Published date: Mar 29, 2016

[13] Wind in the service of electricity with the birth of Charles F. Brush's wind turbines. [Online] Avent Grade – Ventilons. Published date: Oct 2, 2017

[14] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

power systems across Denmark and with energy output ranging from 5 kW to 25 kW. [5]

Figure 12 Society of Wind Electricians[15]

1920s: "Jacobs Wind" industry in Minnesota started to operate aiming at the creation of wind turbines for farms. However, since they got excluded from the grid, the WTs were utilized for other purposes. (see **Figure 13**) [5]

[15] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

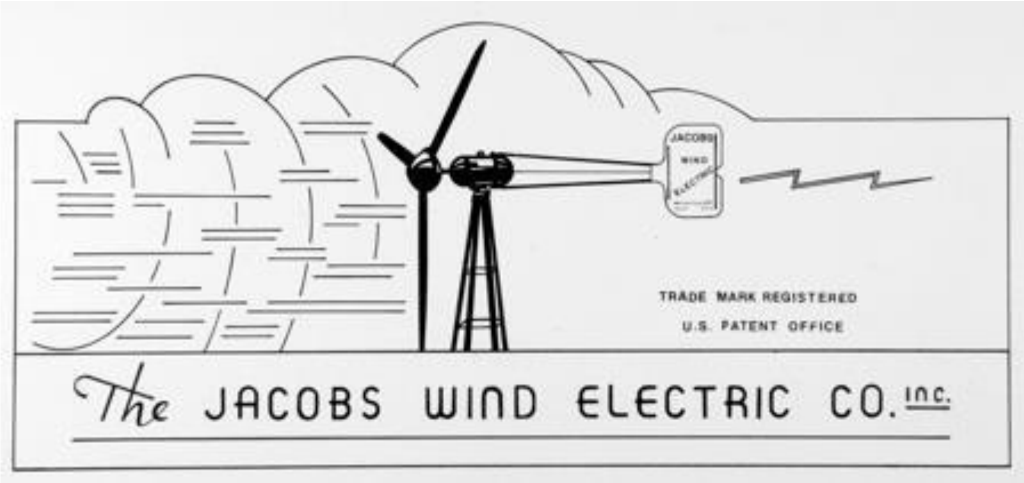

Figure 13 "Jacobs Wind" industry[16]

1930s: The creation of the Darrius WT, which has vertical-axis design, and its concept was conceived by French engineer Darrieus. (see **Figure 14**) During the same year, horizontal-axis WT also got created. [5]

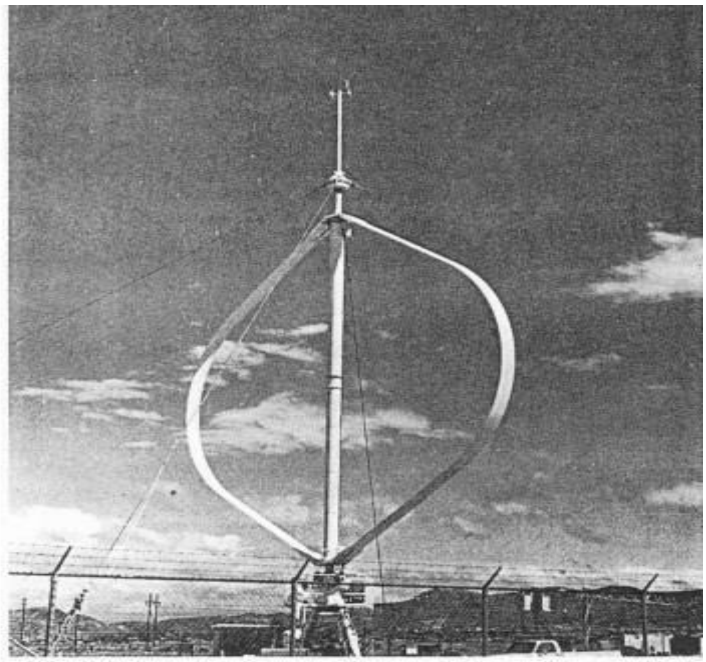

Figure 14 Darrieus Wind Turbine[17]

[16] The Jacobs Wind Electric Company. [Online] Wind Charger. Retrieved date: Nov 2, 2018.

[17] Darrieus Wind Turbines. [Online]. Turbines info. Published date: Jul 20, 2011

1940s: The first MW-size WT was created and connected to the local electrical grid. The first application was in Castletown, Vermont. (see **Figure 15**) During World War II, small WTs were used to reload the batteries and store fuel to the small German U-boats. [5]

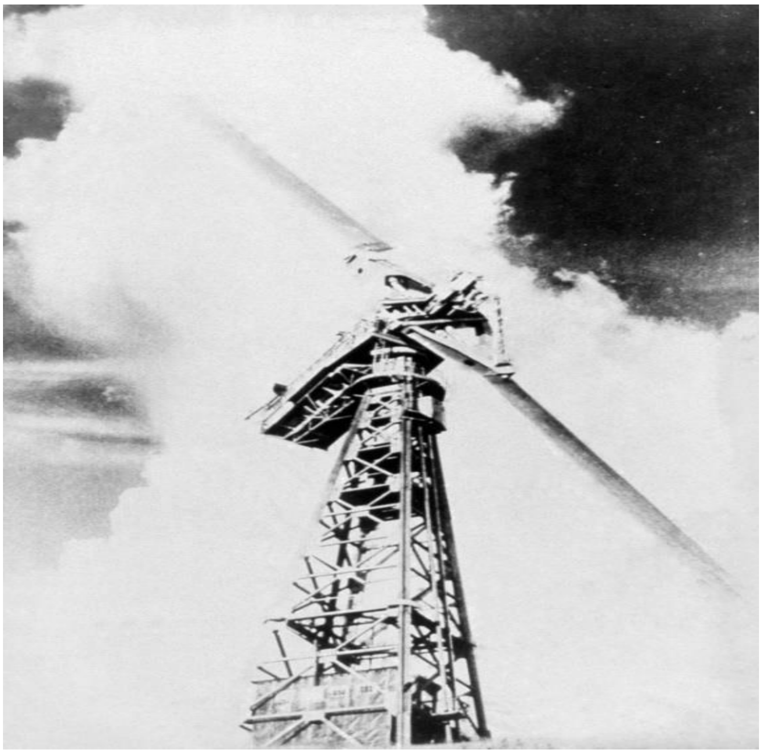

Figure 15 First wind turbine in Vermont (Smith-Putnam)[18]

1950s: Huge increase in sales of wind turbines in energy market, including the one in Africa and Antarctica. In addition to that ,we have the construction of wind turbine with prototype horizontal-axis system by J. Juul similar to the current type. (see **Figure 16**) [5]

[18] Diagram 2018 [Online] Doni Adhika. Published date: Oct 29, 2018

Figure 16 First AC wind turbine by J.Juul[19]

1970s: NASA develops software that could assist the development of WTs in high scale production of MWs output. It must be noted that we have the completion of the first U.S. wind farm which provided electricity to more than 4 thousand households. Additionally, the first WT with capacity of more than 1MW is produced by Tvind at the same period. (see **Figure 17**) [5]

Vestas company, Siemens, and other major companies begin to enter the wind energy sector. Taking advantage of the previous innovations, and the numerous investment opportunities, the wind energy industry moves to the next level. GE Wind Energy company is created, which firstly appeared as Zond and then it evolved. The Regulatory Authority of American Energy (PURPA P.L.) starts to impose legislation in order to settle any alternative energy investments to the central grid of the state. [5]

Figure 17 First TVIND Wind Turbine[20]

[19] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

[20] Tvind Prototype. [Online]. Wind turbine models. Retrieved date: Nov 2, 2018

1980s: Creation of Siemens Wind Power, which was firstly named as Danregn Vindkraft. WTs' evolution continued to occur, and their size was kept growing. Wind farms (WF) in U.S. were continuously evolving and expanding. As a result, the wind energy sector started to cover significant part of the households electricity needs. At the same period, the Enercon company was initiated, which later become Germany's big- gest company in the wind energy sector. [5]

1990s: First U.S. legislation is made concerning the domain of alternative energy, and it is made with the purpose to bend the PURPA's limitations in the magnitude of the relative producing stations. For the first time, the offshore sector in Denmark's industry was taking off. (see **Figure 18**) [5]

During this period, there is a huge upgrade at the structure of WTs. Deficits due to equipment's maintenance are minimized by introducing the tubular steel and strengthening the cemented masts. U.K. enters the wind energy sector with the creation of its first wind farm. U.S. government applied various law modifications in order to give perspectives to different energy companies. However, very soon after, this optimism disappeared, and boundaries re-introduced for the total output. [5]

Figure 18 First Offshore Wind Farm (Vindeby), 4.95MW, built in the Danish Baltic Sea, near the island of Lolland, in 1991.[21]

Vestas' company begun upgrading in order to establish continuous connection and supply, while ,it also entered the offshore domain and gott specialization at the regions with winds of low magnitude. In addition to the previous evolutions, Gamesa, enters also the wind energy sector, creating a supplementary company, named as Gamesa Eólica. The State of India initiated investments on the wind sector by the foundation of Suzlon Energy. Wind energy capacity continued to increase reaching over 10 thousand MW. China is added to the list of countries that invested in wind energy sector, with the creation of Goldwind. [5]

2000s: The total investment in U.S. grew and provided wind powered electricity close to 10 million households. Moreover, the GE and Enron Wind were merged. Similarly, Vester and NEG Micon became one company achieving high involvement in the wind domain. U.K. invested for the first time in its history on wind energy generation at sea, while soon after, the government went public with a big investment plan in offshore domain. The latter was an attempt to cover the electricity to as many households as possible until the 2020. There is an increase of the electricity supply deriving from wind sector, which now is available to 1.5 million U.K. households. Moreover, at the same period, the construction of high-scale capacity WT in Norway sea was achieved. The biggest worldwide investment was made in Texas (Roscoe WF). (see **Figure 19**)

Tax legislation was made for the potential producers in wind sector with 30% bonus for American Investors. [5]

[21] WORLD'S FIRST OFFSHORE WIND FARM RETIRES: A POST-MORTEM [Online] M J Kelly – The GWPF. Published date: Oct 18, 2017

Figure 19 Roscoe Wind Farm, Texas, USA[22]

2010's: The charges in electricity consumption by wind energy, are getting seriously minimized compared to 20-30 years ago. In 2012, U.S. invested highly on the offshore domain and the competition rose between China and the U.S., as the first became the major adversary of the latter, and, eventually, overtook it in installed MW. (see **Figure 20**) Siemens entered the wind energy sector. The radius of the WT and the power output are rapidly increasing over the years overcoming extremely the previous WT models. In 2017, U.S. made the wind domain its primary source of alternative energy.

(see **Figure 21**) [5]

[22] Roscoe Wind Farm in International News [Online] Edwin Duncan – Roscoe Hard times. Published date: Jun 15, 2011

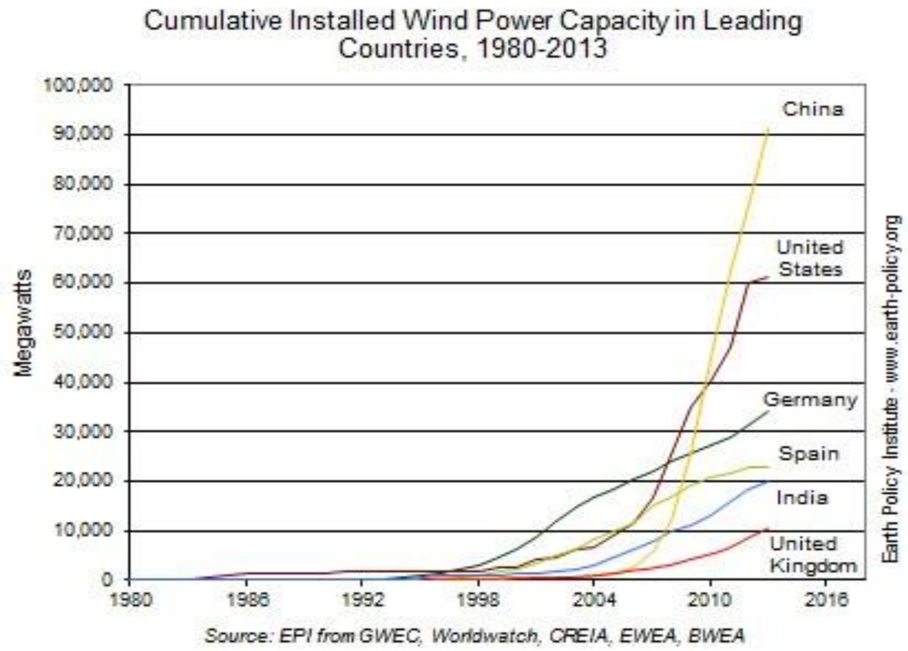

Figure 20 Total Installed Wind Power Capacity in Leading Countries, 1980-2013[23]

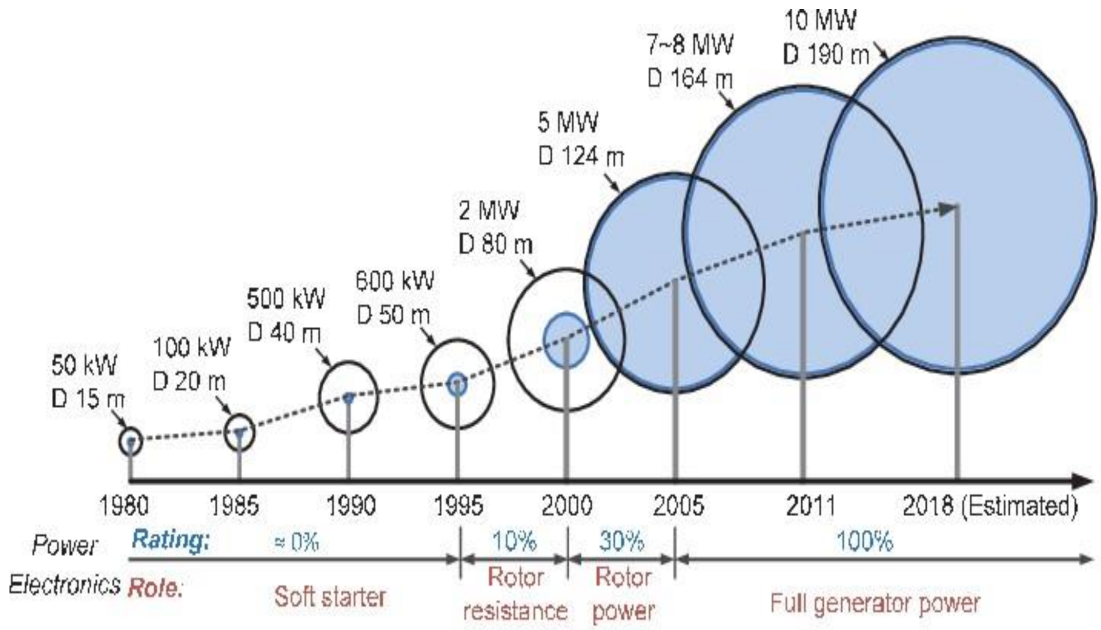

Figure 21 Evolution of wind turbine through timeline (based on its nominal power)[24]

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[23] World Wind Power Poised to Bounce Back after Slowing in 2013 [Online] J. Matthew Roney – Earth Policy. Published date: Apr 10, 2014.

Moreover, in Japan enormous wind energy project at sea is in progress aiming to be completed by 2020. Japan's innovation includes the prototype installation of hybrid wind farm. (see **Figure 22**) The creation of London Array WF leads to the coverage of about 500.000 households, covering their energy needs. (see **Figure 23**) GE company innovates with the addition of energy storage in new WFs production sites. Spain is added to the list of countries that makes big investments in the wind domain, and more than 50 % of its electric power derives from RES. China becomes the leading country in high-scale investments, overcoming U.S. At the same period, U.S. entered the offshore domain. Moreover, wind sector became fourth at the electricity generation ranking. The progress is evolving and more and more conventional power plants are replaced by RES power plants. [5]

Figure 22 Japan's hybrid wind-current power generating system (Wind Farm), prototype by company Mitsui[25]

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[24] Blaabjerg, F., Ma, K., & Yang, Y. (2014, February). Power electronics for renewable energy systems-status and trends. In Integrated Power Systems (CIPS), 2014 8th International Conference on (pp. 1-11). VDE.

[25] World's First Floating Wind-Current Turbine to be Installed Off Japanese Coast. [Online] Mark Boyer – inhabitat. Published date: May 14, 2013

Figure 23 London Array WF. 175 turbines of 630 MW Round 2 offshore wind farm is located 20 km off the Kent coast in the outer Thames Estuary in the United Kingdom[26]

More specifically, wind sector is increasing at high-scale and at enormous speeds, with its percentage at the energy market continuously risen. (see **Figure 24**) Indicatively, we have the leadership of Denmark at the domain with a percentage approaching close to 41 %, and other countries as Spain, and Portugal continue to evolve in order to follow the stream of evolution of the wind domain. The remarkable development in the Asian continent will lead the way, with China on the leadership and India to follow. Big boost of the wind power domain in Latin America is also happening, with Argentina to lead all the way to the top. Moreover, the evolution of the African continent on the sector must me noted, since more and more investments on related projects are initiated. Australia entered also in the global map of investing countries on wind energy domain. Despite the various investment boosts and the significant evolution of the wind domain worldwide, China remains the conqueror. [3]

[26] World's Largest Offshore Wind Farm Opens in Thames Estuary. [Online] Morgana Matus – inhabitat. Published date: May 7, 2013

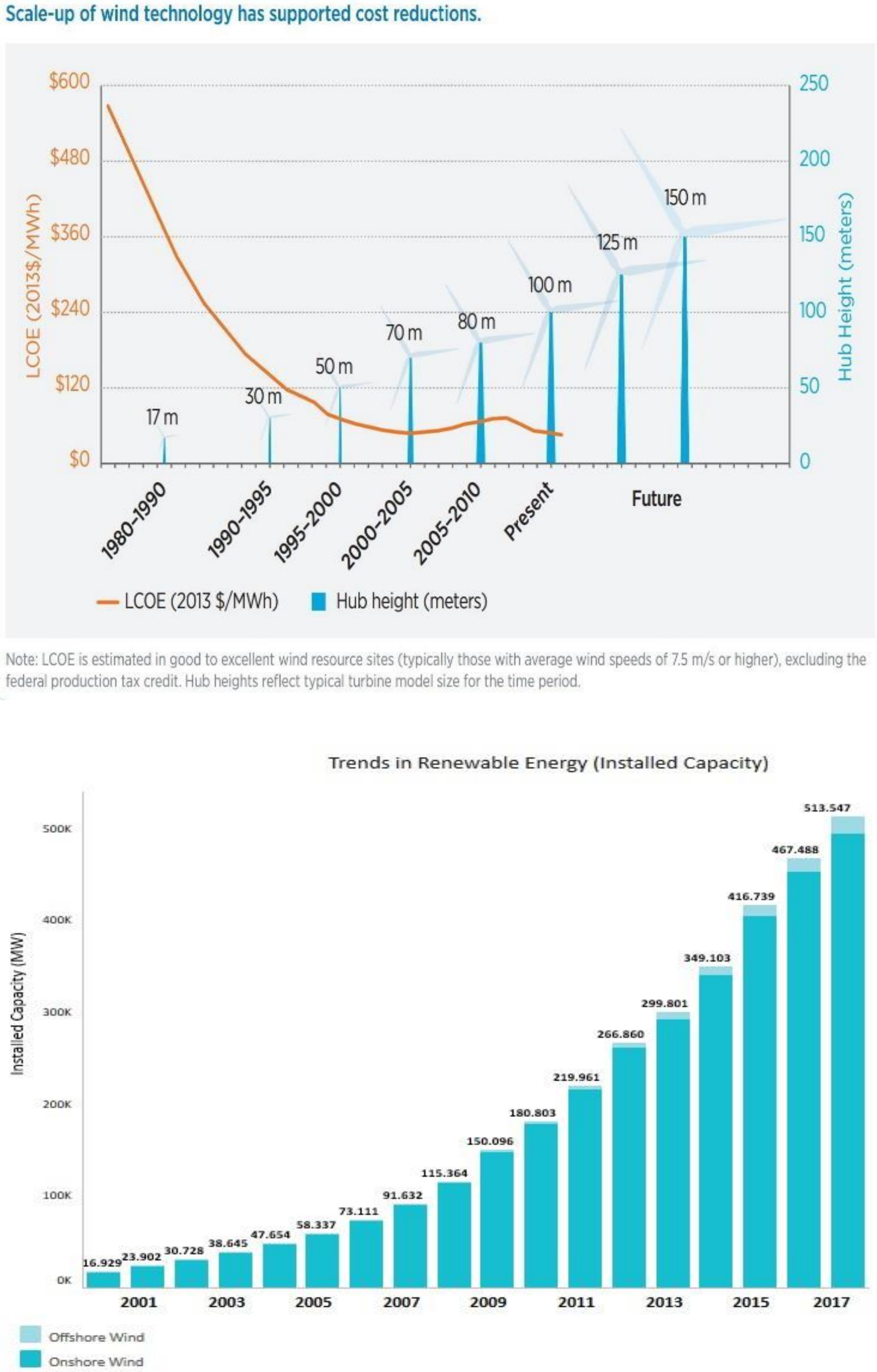

Figure 24 Evolution of wind energy through timeline concerning the cost & installed capacity[27]

[27] Scale-up of wind technology has supported cost reductions [Online] Rameznaam. Published date: Aug 2015

2.3 Wind energy perspective

In this dissertation, we will focus on the evolution of the technological aspects of the wind energy exploitation, which is a high-scale renewable energy domain and a low- price energy source over many years since the evolution of wind power. (IRENA, 2018)

The wind energy is one of the most promising domains of energy and is rapidly developed. The evolution of wind energy and in general the RES has as consequence the withdrawal of power plants that have been working with conventional methods. This choice has been made due to the magnitude of the wind power , as it exists in plenitude in nature in contrary to the old and conventional basic forms of fuels (coal, petroleum). Moreover, it is a high-scale solution to the matters that occur from the extensive demand of electricity generation. [2]

The need for exploitation of wind power derives back in the Ancient Times, as from example in the Ancient Greece, where we have the existence of ancient Greek god, Aeolus, that was responsible for the management of the winds. Reference on the Aeolus can be found from great ancient Greek poet, Homer, who mentions the capture of wind in the “bag of Aeolus”. For a longtime, we have the utilization of wind as driving force for ships, alongside with the use of windmill as driving force for cultivation and other applications. The power output was well increased before the 80s and since it got upgraded in order to produce to electricity as the final product, it fit perfectly under the new context of the scheme RES. Nowadays, in order to deploy the potential that derives from wind energy to the maximum, we make use of the wind turbines, which is an engine constructed firstly in 1887 and its outcome is the conversion of kinetic energy of the wind into electrical. [2]

3. Analysis of wind energy in the axes of science and technology

3.1 Physical approach for the production of electricity from wind

In this section, we will discuss about the way the electricity is generated by wind energy. The whole variation of alternative sources of energy is derived from the sun's radiation. As it is widely known the sun is considered to be the largest black body in the universe. It has enough radiation, which means it is an incredible source of energy. In our case, approximately 2% of the sun's radiation is considered to be the 'fuel' for the supply of wind energy. (see **Figure 25**) [7]

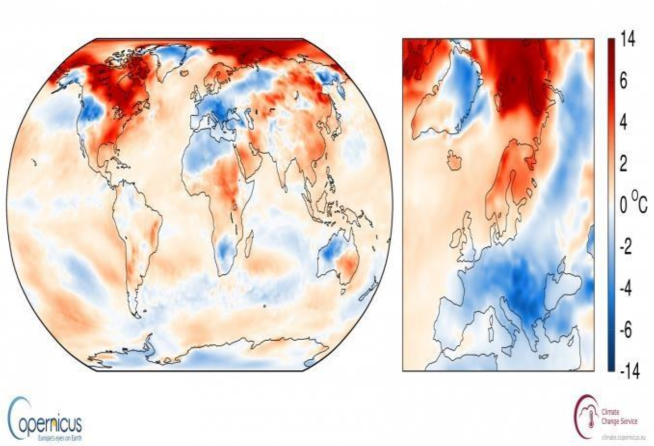

Figure 25 Surface air temperature anomaly for January 2017 relative to the January average for the period 1981-2010.[28]

[28] Average surface air temperatures for January 2017 [Online] Climate Copernicus. Retrieved date: Nov 2, 2018

Let’s mention some mathematical data, concerning the previous process we have mentioned. Firstly, the power that is emitted by the sun is calculated to be $1.74 \cdot 10^{17}$ W on earth. Additionally, the earth's surface area is $5.09 \cdot 10^{14}$ m^2 and the accumulated power output concentrated by plants is measured and considered to be $1.91 \cdot 10^{13}$ W, or 0.011% of the total power emitted to globe. [7]

In order to follow the technological developments of the wind turbines, firstly, it is important to understand the wind at all of its parts.

3.1.1 Coriolis force

Since Earth rotates, wind flows do not move directly from high to low pressure areas. The Coriolis force acts at right angles to the direction of motion, so as to cause deflec- tion to the right in the northern hemisphere and to the left in the southern hemisphere. Numerous factors such as topography, differential heating of the surface etc., alter the wind patterns further. (see **Figure 26**) [51]

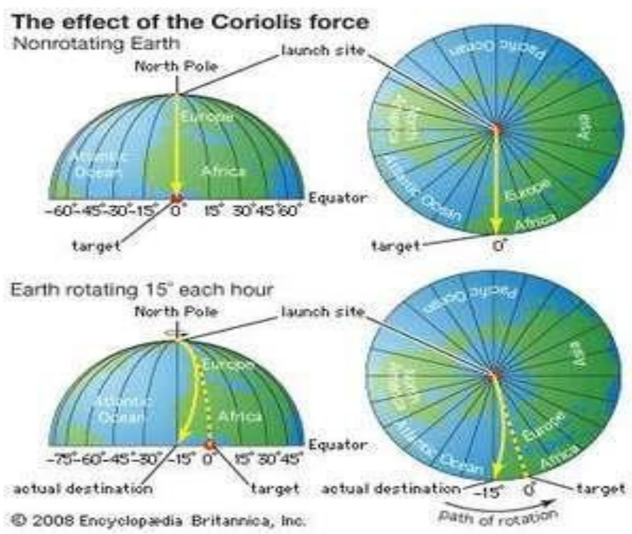

Figure 26 Coriolis force influence[29]

[29] Coriolis effect [Online] Britannica Encyclopedia. Retrieved date: Nov 2, 2018

Concerning the north part of the earth, the wind pattern will demonstrate a clockwise direction, while in the south part of globe, we observe counterclockwise course of the wind. [51]

3.1.2 Wind directions

In this section, we will describe the wind's route. Firstly, at the Equator, we have the rise of the wind, which will continue its motion to the north and south, at the highest level of atmosphere.

Secondly, at 30 degrees, the Coriolis force will block any further movement of the wind. Finally, at this area, we notice a region with very increased pressure, because of the beginning of the wind to renter the earth's surface. Adding to that, around the Equa- tor region, after the wind's rise, we will notice that we have limited pressure, which will result to additional wind flows coming from the northern and southern hemisphere. Meanwhile, at the poles, as the temperature of wind will decrease, we will observe in- creased pressure. (see **Figure 27**) [8]

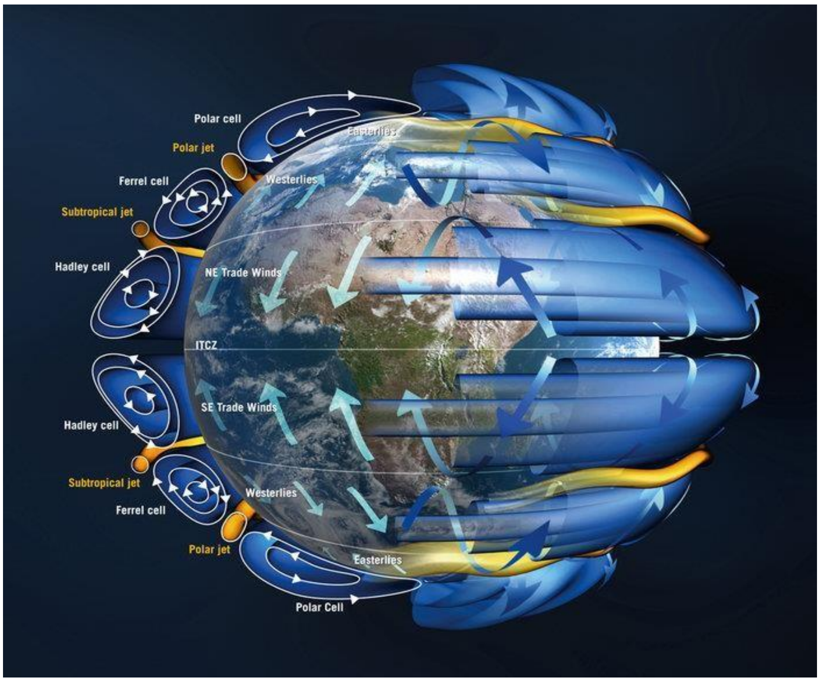

Figure 27 Earth's wind flows[30]

[30] EARTH'S WIND PATTERNS. [Online] ESA/AOES Medialab Published date: Mar 9, 2017

At this point, the predominant wind directions are classified, as you see at the **Table 1**, which are the result of Coriolis force's influence:

Latitude	Predominate wind direction
60-90 N	NE
30 - 60N	SW
0 -30 N	NE
0-30 S	SE
30-60 S	NW
60-90 S	SE

Table 1 Predominant wind directions[31]

3.1.3 Troposphere

At this paragraph, we should point out that any meteorological condition happens at the layer of atmosphere that is placed at its bottom, with extents that cover the earth's surface to the lowest part of stratosphere. This layer is called troposphere and includes the majority of the atmosphere's mass. [9]

3.1.4 Wind Types

Different types of wind must be exploited with different technology. At this subchapter, the different types are explained and visualized with the use of related figures.

[31] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

Geostrophic wind

The type of wind that we have been discussing so far, is named as geostrophic wind and is created by Temperature difference and is independent of global surface. This kind of air is located at heights over 1000 m. The calculation of this type's wind velocity is done by the use of weather balloons. (see **Figure 28**)

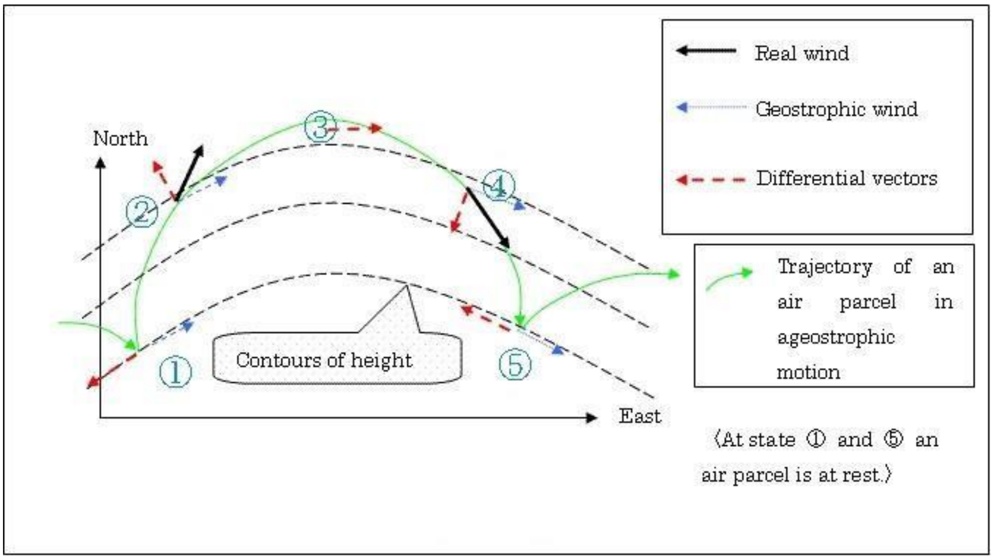

Figure 28 Geostrophic Wind[32]

Surface wind

In general, winds are highly affected by the land, over heights of 100m. The directions close to the surface are not exactly same with the one of geostrophic wind. It is considered essential at the time of wind energy estimation to take into account the surface winds and to have the knowledge for the estimation of usable energy content of wind.
(see **Figure 29**) [55]

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[32] Pressure and Winds in Atmosphere – Geography Study Material & Notes [Online] Exam Pariksha. Retrieved date: Nov 2, 2018

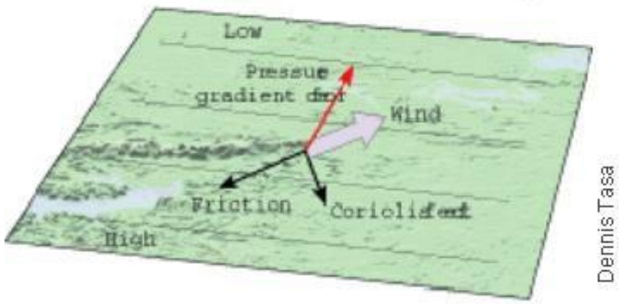

Figure 29 Friction causes surface winds to cross isobars and move toward lower pressure areas.[33]

Topical wind

As it has already mentioned, various parameters play role in the estimation of predominant winds at any region. More specifically, an important parameter is the topical climatic conditions. We observe two patterns in the behavior of topical winds: First situation, there is the dominance of high scale wind systems over topical winds. Second situation, when light high scale winds are remarked, we have dominance of winds of the area. (see **Figure 30**) [10]

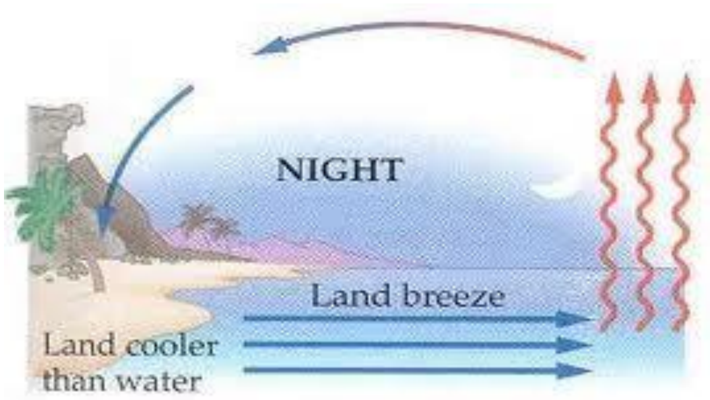

Figure 30 Land breeze[34]

[33] Air Pressure. [Online] Debra Krohn – Cosscience. Published date: Jul 20, 2004

[34] LOCAL AND GLOBAL WIND PATTERNS. [Online]. Mr. Mulroy's Earth Science. Retrieved date: Nov 2, 2018

Sea breezes

It is scientifically proven that diurnal solar heat that is received by land is done in a much faster way than the the one received by sea. In order to explain the definition of Sea Breezes, we proceed as following: Firstly, we observe the movement of air to the sea, which leads to the moderate pressure at surface, and by its turn causes the rise of the cold air of the sea, which is the requested type of wind. (see **Figure 31**)

Before the beginning of a day, a time frame of tranquility is observed, in which we have equality in surface and sea temperature. During nocturnal period, the wind direction is the opposite from the rest of the day. In addition to that, we have to point out the generation of moderate wind velocities from the surface breeze, as a consequence of the low Temperature difference between earth's surface and sea in a nocturnal period.

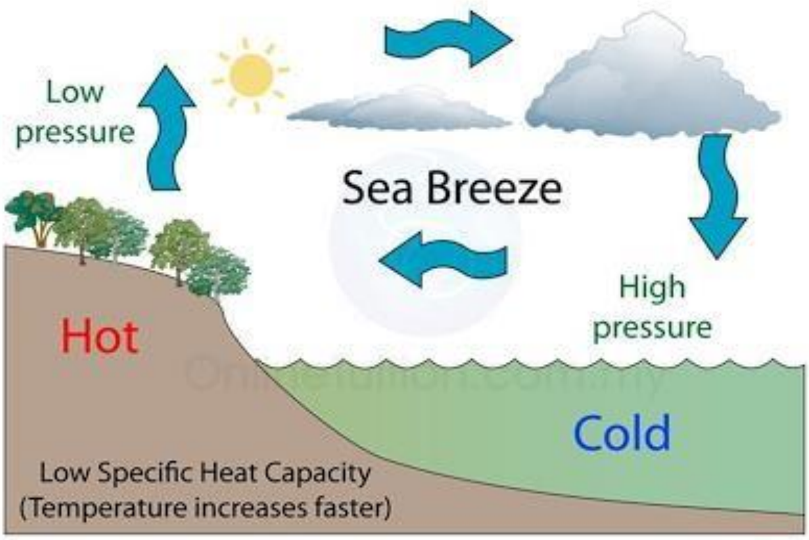

Figure 31 Sea breeze[35]

[35] Phenomena Related To Specific Heat Capacity - Sea Breeze. [Online]. SPM Physics. Retrieved date: Nov 2, 2018

Mountain wind

There is a high variety in weather conditions at the areas all over the hills. By the increase of temperature on the hills and the local wind, we have as result the diminution of air density, and at the same time we have the rise of wind to the top of the hill through hill's land. During nocturnal period, we observe the inverted process with direction of air to the bottom of the hill. At the case of inclination of valley ground, the wind behaves as canyon wind by up and down moving through valley. An example of this category of winds is the Foehn in the Alps of Europe, which represents hot, powerful and parched winds over declination. (see **Figure 32**) [11]

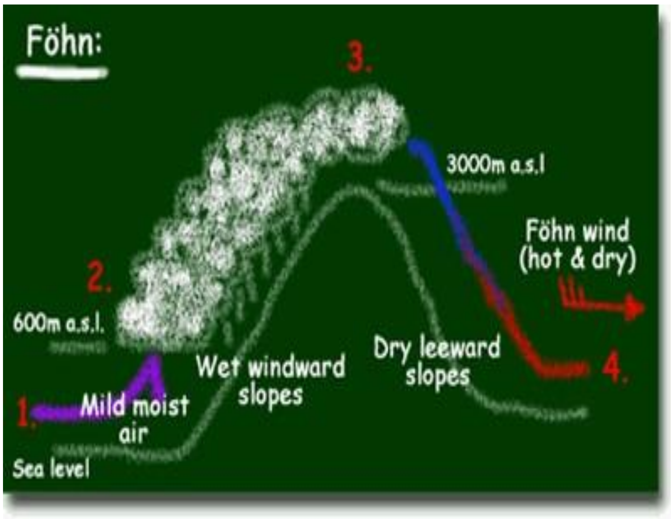

Figure 32 Foehn Effect[36]

3.1.5 WT working principles

The source of wind turbine's power ,it is created by the conversion of the wind's force into the actual force that is responsible for the motion of rotor blades and it is named as torque. The wind velocity, the surface of rotor and the wind density are the parameters that are affecting significantly, how much of the energy deriving of the wind, will be transferred to the rotor.

[36] Foehn Effect. [Online]. Weather Online. Retrieved date: Nov 2, 2018

Swept Area

This parameter defines the potential in the wind energy harvesting by wind turbine. More specifically, the relation in mathematical formula indicates $S=\pi \cdot r^2$, where r is the rotor radius and by this formula we understand that any increase in diameter will result in the square of the increase. (see **Figure 33**)

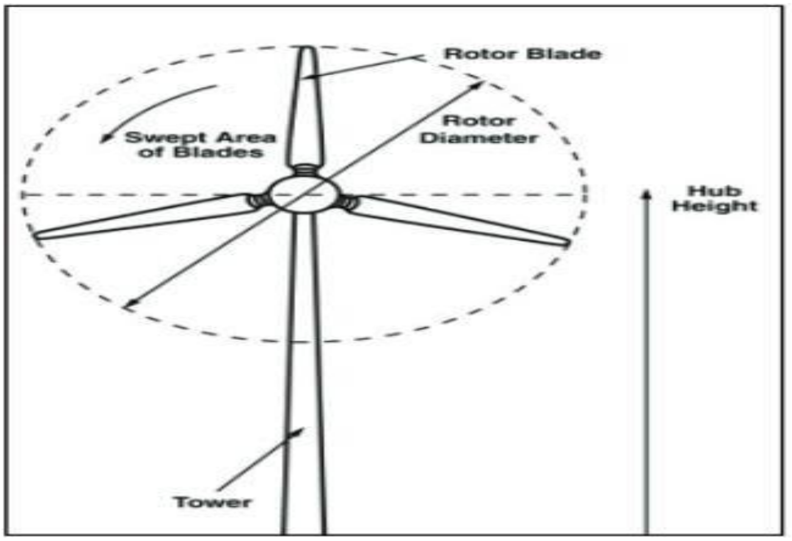

Figure 33 Wind turbine[37]

WT behavior

We observe the wind is diverted on any wind turbine, which will have as consequence part of wind energy will not be harvested. The rotor ‘s role is to reduce the wind’s velocity during the process of the conversion of energy.

The higher reduction of velocity will proceed with the movement of air to the left side of the rotor. Taking as stated fact that either the wind is at the entrance or the exit of the swept area, the total quantity of wind should be exactly equal for both circumstances, the wind shall cover bigger diameter at the back of rotor plane. This is depicted by a virtual tube, known as stream tube. (see **Figure 34**)

[37] Wind Energy Math Calculations [pdf] Minnesota Municipal Power Agency. Published date: Sep 2015

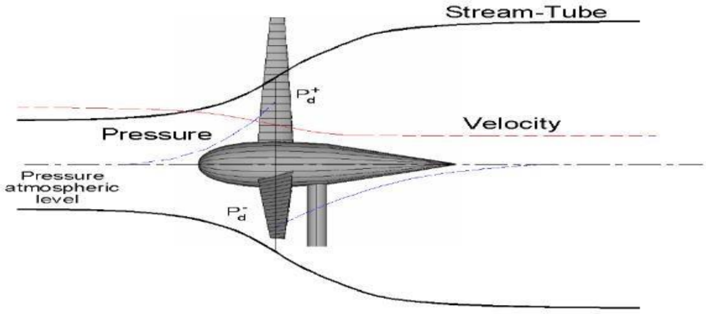

Figure 34 Stream-Tube[38]

We will not observe an immediate decrease of wind's velocity, till it reaches its final velocity at the black of the rotor. Thus, we will have a gradual decrease, till the velocity gets specific value. From the right side of the rotor at the approach of wind, we will notice a gradual increase in air pressure, because the rotor will behave as a hurdle in front of the wind. On the other hand, we observe the opposite phenomenon at the left side of the rotor, during wind's approach.

Wind power

In this section, we will approach the power that can be generated by wind, more specifically the wind speed velocity plays crucial role in the estimation of the energy generated that can later be utilized in the wind turbine for the production of electricity. The mathematic formula of wind power can be written as:

$P_W = (½)\cdot\rho\cdot V^3\cdot A\cdot C_p$,

where $C_p= 4\alpha(1-\alpha)^2$ and by replacing the value of a: $C_p=(4/3)*(2/3)^2=0.59$

Where ρ symbolizes the density of air (kg/m^3), A symbolizes the surface of swept area and often it is equal to $\pi\cdot r^2$, V symbolizes the wind's velocity and Cp is the WT power coefficient. [53]

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[38] Maia, I. A., da Silva Junior, F. I., Rocha, P. A., & Carneiro, F. O. M. (2011). Coupling aerodynamic loading to structural analysis of wind turbines through numerical simulation.

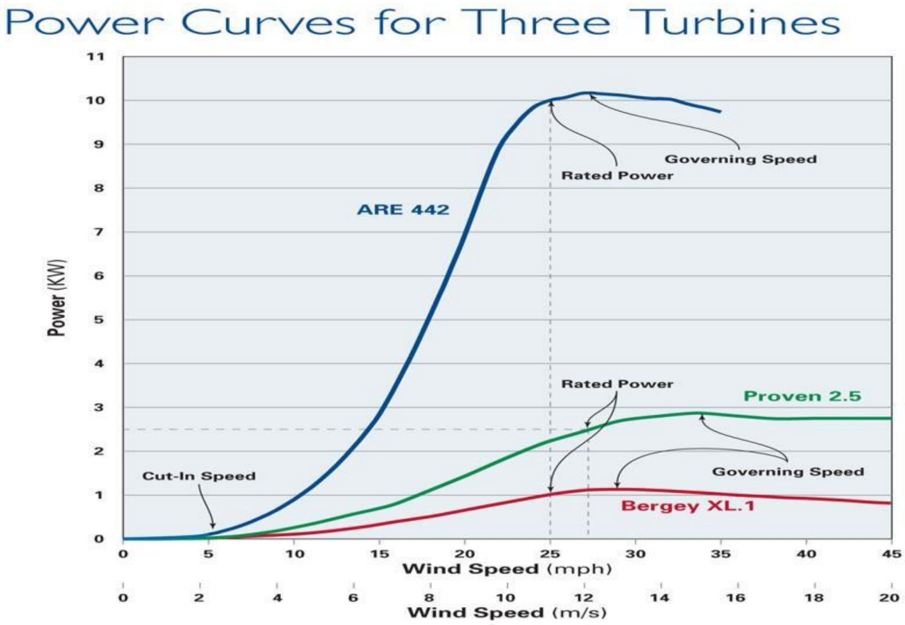

Figure 35 Wind power curves for 3 different turbines[39]

Wind rose

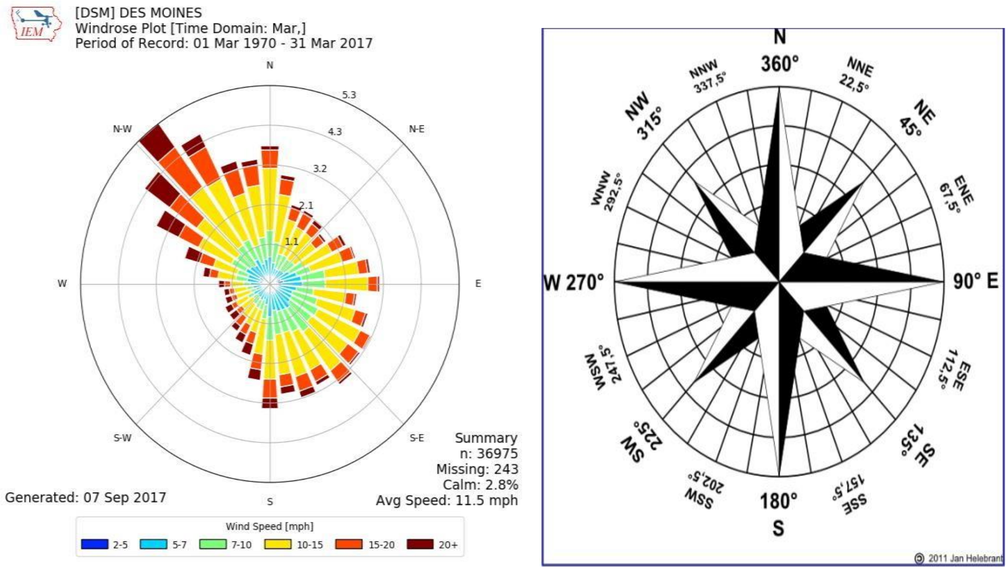

Figure 36 *(left)* Wind Rose[40] *(right)* Wind Directions[41]

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[39] Wind Power Curves. [Online] Ian Woofenden – Home Power. Published date: Oct/Nov 2008

[40] Wind Roses [Online] Jowa State University. Published date: Aug 4, 2018.

This diagram is used for the representation of any records have been collected of wind behavior, and the measurements are based on a weather station, at the area of invest- ment. Let’s proceed to the interpretation of it. We have a kind of compass that is sepa- rated in 16 parts, each part is created for every 22.5 degrees, etc. Furthermore, the wedges can inform us with the average wind speed for any the 16 wind directions and can give us hints about where we can exploit the maximum possible power for achiev- ing maximum wind energy, by finding the predominant wind directions. We can see the classification of average wind speed in the previous figure, ex.2-5 mph, etc. Each loca- tion has its own wind rose. (see **Figure 36**) [53]

Turbine installation

At heights, close to 1km., the wind is not affected by the ground conditions. Closer to the ground, the wind becomes dependent of the morphology. At wind domain , we have 3 categories of influence, or more specifically 3 parameters that affect wind’s general behavior :

1. the ground ‘s roughness
2. the obstacles
3. the region’s orography, which is defined as the effect done by terrain contours.

It is considered of high significance the fact of taking into our consideration the exist- ence of obstacles that can alter the wind’s behavior near any wt, and that’s why we should include them for the higher precision in our estimations concerning the wind en- ergy output. [53]

Ground roughness

The velocity of wind decreases with the increase in the roughness, with classical exam- ple the regions with large number of trees (like forests) or tall buildings, where the wind is highly affected due to the friction with them. Whereas, we observe reverse behavior

[41] Compass [Translated from Greek: Πυξίδα]. [Online] Pixabay. Published on. Apr 26, 2008

at parts of the land, where there is little contact with the wind, like the water. The roughness length is measured in meters, for example roughness lengths of 5-6 show high roughness regions. (see **Figure 37**) [53]

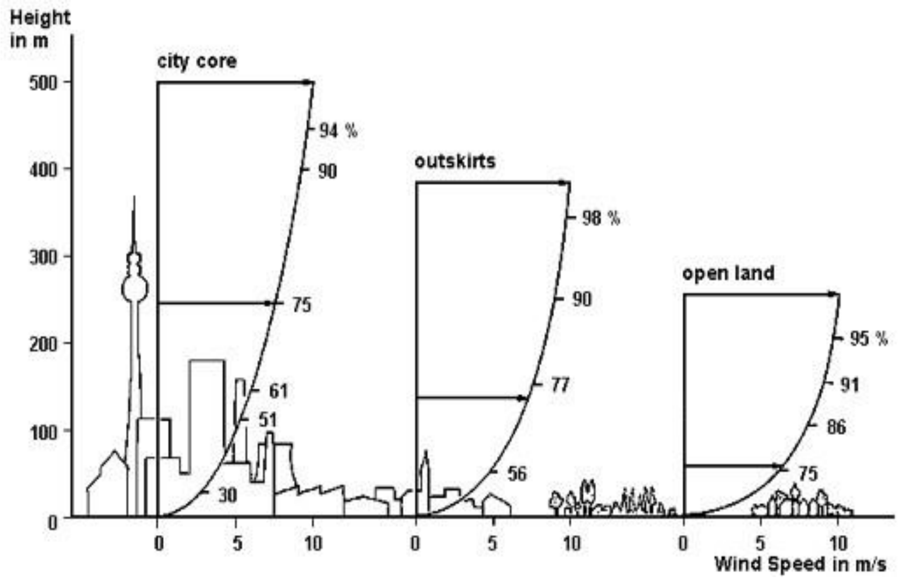

Figure 37 Behavior of wind depending on the land's surface[42]

Wind shear

It is defined as any change in wind's velocity or direction with height. It is considered as matter of high significance at WT installation at the land, more specifically at any hub's blade, when the blade is at its highest level, it receives more pressure by rein-forced wind force. (see **Figure 38**) [12]

[42] Near Ground Wind Speeds [Online] Senate Dept. for Urban Development and Housing. Published on: Mar 4, 2001

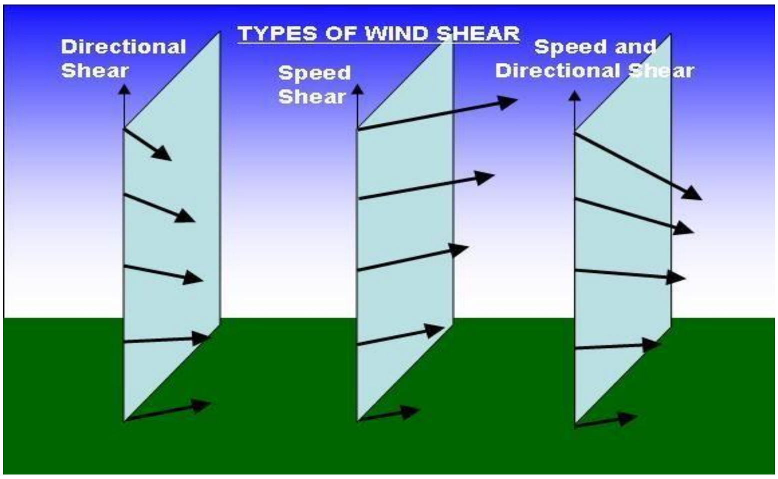

Figure 38 Types of wind[43]

The wind shear formula, which defines wind speed at a certain height (AGL):

$V = V_{ref} \cdot [\ln(Z/Z_0)/\ln(Z_{ref} /Z_0)]$

V = wind speed at height z above ground level.

V_{ref} = reference speed, i.e. a wind speed we already know at height z ref . ln(...) is the natural logarithm function.

Z= height AGL for the required velocity, v.

Z_0 = roughness length in the current wind direction.

Z_{ref} = reference height, which is defined as the height at a particular wind speed V_{ref} .

[43] What is wind shear? [Online] Weather Questions. Retrieved date: Nov 2, 2018

Roughness rose

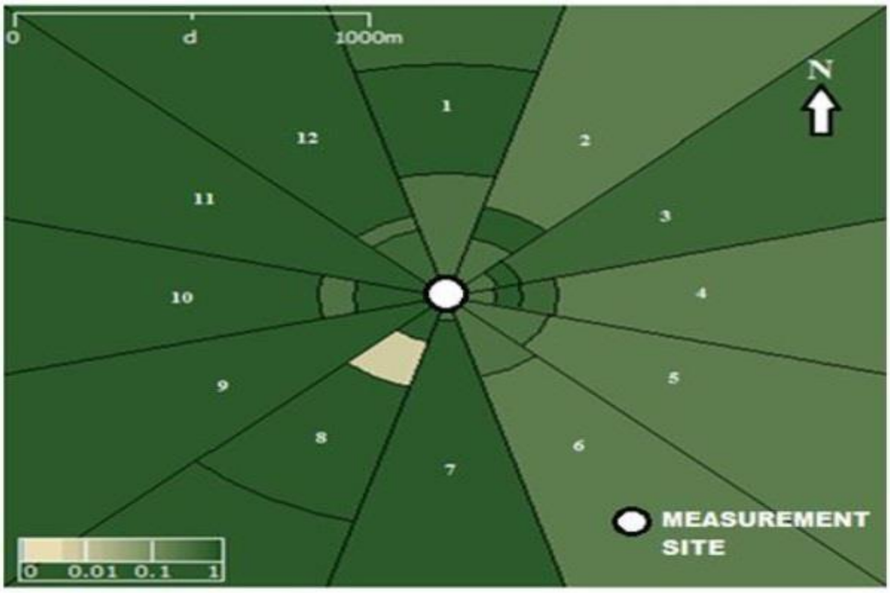

Figure 39 Roughness Rose[44]

It is similar to the wind rose, with the difference that this one shows information concerning the roughness of ground at all possible ways the wind can travel around a potential wind farm. As it is shown on the figure, it is separated into 12 (or 16) sections, with each of them is measured at 30^{o}. Because of the fact that the calculation of roughness will not be so suitable, in order to include it into the roughness classes, we prefer to make an average of roughness calculations. (see **Figure 39**) [53]

Wind speed variability

As it is understood, the wind velocity is not stable, based on meteo conditions, topical ground conditions and the existence of any obstacles. This will have as effect a variation also at the wind energy output. (see **Figure 40**) [13]

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[44] Chandel, S. S., & Anjum, L. (2013). Wind Energy Resource Potential Assessment in a Hilly Terrain of

India using WAsP. International Journal of Energy for a Clean Environment, 14(4).

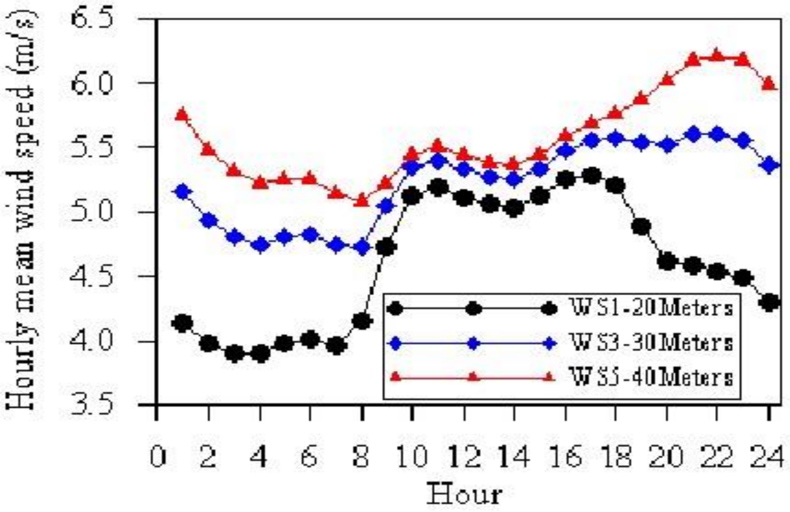


Figure 40 Diurnal wind speed variation at different heights[45]

At this point, we have to introduce the parameter of time that can have effect at the wind variation. Adding to that, we should state that the reduction of wind power is mostly noticed during the nocturnal period of the day, which makes the diurnal part of the day ideal for maximizing the wind power. This occurs due to the temperature differ- ences, more specifically between sea and land, the temperature difference is increasing more during the diurnal period. We should also point out the alteration in wind direction that is considered highly more often during diurnal period, which is because of the high turbulence of wind at that period. The parameter of turbulence, as was previously stated, should not be taken softly into consideration, because can cause serious decrease in wind power. [13]

[45] ECONOMICS OF WIND TURBINES: A REVIEW OF LITERATURE. [Online] Shodganga. Re-trieved date: Nov 2, 2018

Wind obstacles

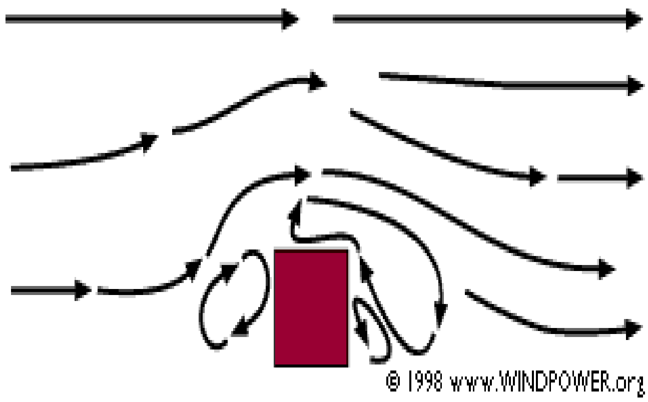


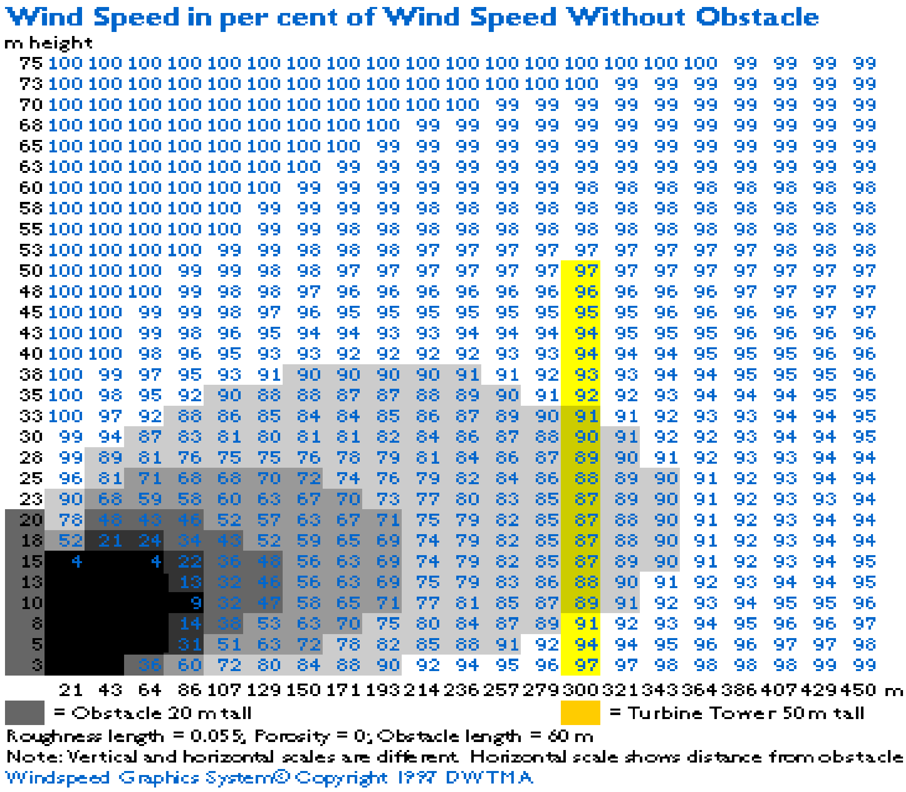
Figure 41 Wind’s movement around an obstacle[46]

As stated previously, the objects can alter in serious manner the course of wind and its output. Here, we can observe the turbulence created mostly at the back of the object at the figure ,that demonstrates the extent of turbulence, which overcomes by much the size of the obstacle, more specifically it can reach up to 3 times the height of the obstacle. (see **Figure 41**) [7]

The parameter of porosity plays essential role on whether we will have decrease of the wind speed and up to what degree, or not. This parameter show how solid is the obsta- cle we want to study, more specifically, the more solid is an object, the more effect it has on wind velocity (building is solid, while a tree, with no leaves, is not). The part of the extent of turbulence, that is closer to the obstacle and to the ground, is where the most effect occurs. [7]

[46] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

Wind shade



Wind Speed in per cent of Wind Speed Without Obstacle

m height

75	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99
73	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99
70	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99
68	100	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99	99	99
65	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99	99	99	99
63	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99	99	99	99	99
60	100	100	100	100	100	100	99	99	99	99	99	99	99	98	98	98	98	98	98	98	98
58	100	100	100	100	100	99	99	99	99	98	98	98	98	98	98	98	98	98	98	98	98
55	100	100	100	100	100	99	99	98	98	98	98	98	98	98	98	98	98	98	98	98	98
53	100	100	100	100	99	99	98	98	98	97	97	97	97	97	97	97	97	97	98	98	98
50	100	100	100	99	99	98	98	97	97	97	97	97	97	97	97	97	97	97	97	97	97
48	100	100	100	99	98	98	97	96	96	96	96	96	96	96	96	96	96	97	97	97	97
45	100	100	99	99	98	97	96	95	95	95	95	95	95	95	95	96	96	96	96	97	97
43	100	100	99	98	96	95	94	94	93	93	94	94	94	94	95	95	95	96	96	96	96
40	100	100	98	96	95	93	93	92	92	92	92	93	93	94	94	94	95	95	95	96	96
38	100	99	97	95	93	91	90	90	90	90	91	91	92	93	93	94	94	95	95	95	96
35	100	98	95	92	90	88	88	87	87	88	89	90	91	92	92	93	94	94	94	95	95
33	100	97	92	88	86	85	84	84	85	86	87	89	90	91	91	92	93	93	94	94	95
30	99	94	87	83	81	80	81	81	82	84	86	87	88	90	91	92	92	93	94	94	95
28	99	89	81	76	75	75	76	78	79	81	84	86	87	89	90	91	92	93	93	94	94
25	96	81	71	68	68	70	72	74	76	79	82	84	86	88	89	90	91	92	93	94	94
23	90	68	59	58	60	63	67	70	73	77	80	83	85	87	89	90	91	92	93	93	94
20	78	48	43	46	52	57	63	67	71	75	79	82	85	87	88	90	91	92	93	94	94
18	52	21	24	34	43	52	59	65	69	74	79	82	85	87	88	90	91	92	93	94	94
15	4		4	22	36	48	56	63	69	74	79	82	85	87	89	90	91	92	93	94	95
13				13	32	46	56	63	69	75	79	83	86	88	90	91	92	93	94	94	95
10				9	32	47	58	65	71	77	81	85	87	89	91	92	93	94	95	95	96
8				14	38	53	63	70	75	80	84	87	89	91	92	93	94	95	96	96	97
5				31	51	63	72	78	82	85	88	91	92	94	94	95	96	96	97	97	98
3			36	60	72	80	84	88	90	92	94	95	96	97	97	98	98	98	98	99	99
	21	43	64	86	107	129	150	171	193	214	236	257	279	300	321	343	364	386	407	429	450 m

= Obstacle 20 m tall   = Turbine Tower 50 m tall

Roughness length = 0.055; Porosity = 0; Obstacle length = 60 m

Note: Vertical and horizontal scales are different. Horizontal scale shows distance from obstacle

Figure 42 Estimate of how wind speeds decrease behind a blunt obstacle[47]

We can observe at the **Figure 42** the consequences created by the obstacles 'shade. Moreover, we can see in yellow the wt hub that is utilized, and the variation of grey that indicates the levels of shade. The numeration in blue represents the percentage of wind speed,at the case of obstacle's absence. We can see at the highest level of the hub(yellow) a decrease of wind speed of 3%. The significance of this effect, which is also called shelter effect, is high, and must be taken into consideration at the estimation of any potential wind farm. [7]

[47] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

Wake effect

Given the fact of the electricity generation of a WT by the energy existing inside the wind, the amount of energy of the wind that approaching the WT should be higher amount compared to the wind that exits the wt. This is due to the physical law of energy preservation. At the back of any WT, there will always be a wake, which is defined as a wind's long pathway, with increased turbulence and tends to its fading as it arrives in front of the wt. Adding to this information, the WTs, that are used in the WFs, should have an appropriate spacing between them. This spacing is estimated to be leastwise 3 rotor diameters, for preventing the potential increased turbulence that can be created close to the WTs. (see **Figure 43**) [7]

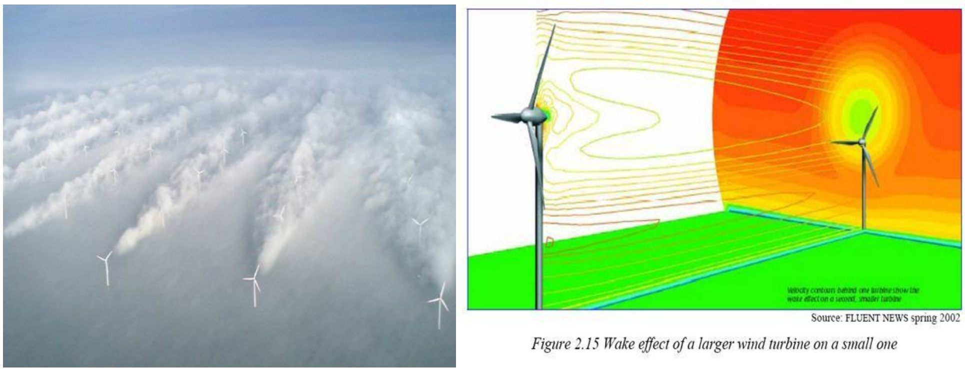


Figure 43 Wake Effect[48]

Park effect

We know that for any WT, the wind velocity will be reduced due to wind energy conversion by wt. Additionally, we would like to separate the WTs in the predominant wind direction. We have as general rule to place the WTs separately at a range between 5 and 9 rotor diameters, in the predominant wind direction and between 3 to 5 rotor diameters, in the direction parallel to the predominant winds. (see **Figure 44**) In order to calculate the amount of loss due to park effect, we are able to estimate it, by using CFD codes with inputs, such as wind rose, Weibull distribution and roughness length .A typical estimation for a good layout is about 5%. [7]

[48] Wind Farm Wake Effect Investigation Underway. [Online] Marex – Maritime Executive. Published date: Dec 10, 2017

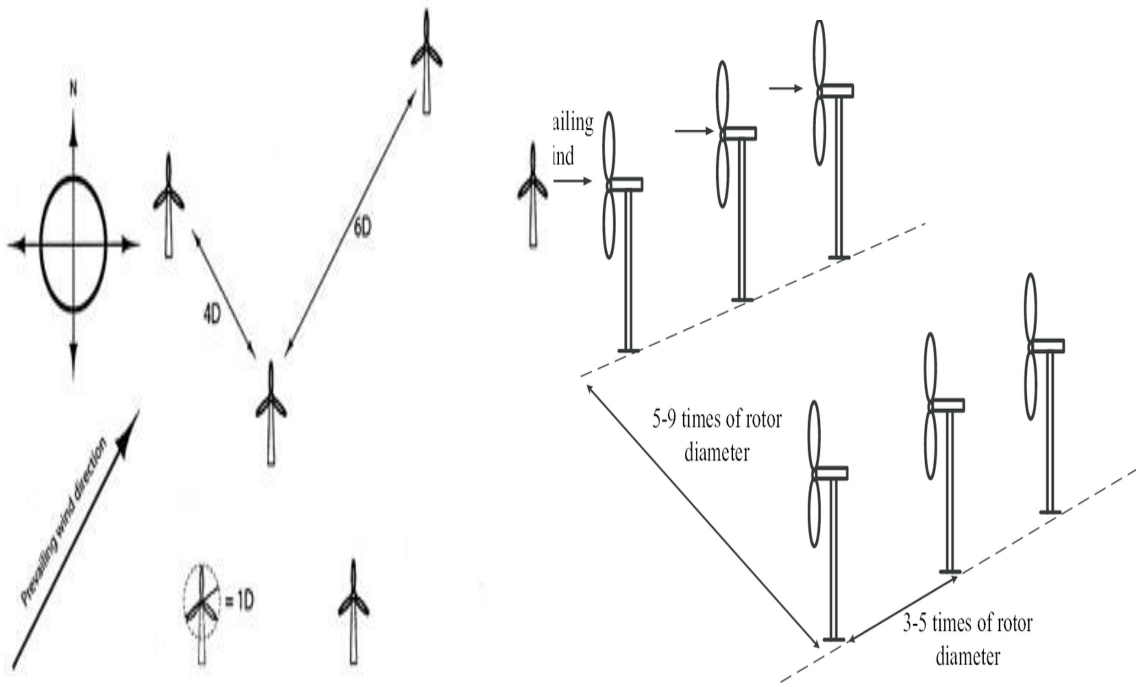


Figure 44 *(left)* Spacing of Turbines[49] *(right)* Wind farm with optimum spacing[50]

Tunnel effect

This type of effect is defined as follows: We have compression of wind on the part of the construction or the hills, where more wind is passing through, and as consequence, we have higher wind velocity between obstacles than the one that wind has before the building or hill . By sitting a wt at a place where this effect occurs, it is an effective way to achieve increase in the wind velocity. Into the notion for the placement of wt we should take into consideration the parameter of turbulence ,which can alter the wind's behavior ,and consequently the wind power output, with simultaneous tear and wear that are produced. [7]

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49 Draft PPS 18: Renewable Energy Annex 1 Wind Energy: Spacing of Turbines. [Online] Planning Portal. Retrieved date: Nov 2, 2018

50 Gupta, N. (2016). A review on the inclusion of wind generation in power system studies. Renewable and sustainable energy reviews, 59, 530-543.

Hill effect

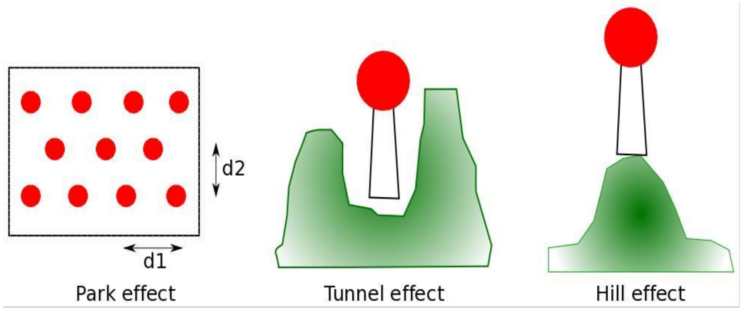

Figure 45 Various Effects[51]

Traditionally, the installation of wts takes place on hill tops or a crest, as it is advantageous to use the accelerated wind of the region. Moreover, we should note that the wind velocities are elevated compared to the rest of the region, which is explained by the fact of the wind's compression at the blowy part of the mount. Additionally, as stated previously the possibility for roughness should not be excluded because of a possible dissimilarity of the mount, that can lead to the loss of the privilege that can be gained by the increase of wind velocity. (see **Figure 45**) [7]

Additional Parameters during installation

Figure 46 Trees' inclination[52]

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[51] Wind Farm Optimization with Turbine Placement Using CFD Simulations. [Online] Ajay Harish – Simscale. Published date: Jul 11, 2018.

[52] The strange Cook pine trees that always lean towards the equator [Online] Richa Malhotra – New Scientist News. Published date: Jun 2, 2017

At this point, we should mention the indications due to nature. Specifically, the inclination of the trees (see **Figure 46**), is considered to be a good indication of the predominant wind direction, and can become of a more direct and fast approach to the target as it is knowledge already available, in contrast to the wind rose, that requires data for about 30 years in order to be useful and accurate. [7]

A rounded mount, with simultaneous minimizing of any objects in the region, is the goal for the optimum performance of our potential wind farm. Additionally, we should not forget the parameter of a good land in the matter of soil, as possible erosion is possible to happen, if we have not chosen the proper ground conditions, in order to withstand the weight of our machinery and the general works that need to be done for the installation. Concerning the meteo data of our specific region, we should possess accurate knowledge of the meteorological conditions of the area and we should not be based on the database from the nearby region, as the parameters of the land are different. [7]

Offshore wind conditions

Now we will examine the behavior of wind at sea or sealike conditions. Here, the roughness is low, compared to the land. However, as much as the wind influence over the area continues to increase, the more tides will start to be created and as a result, we will have an increase in the roughness. After the tides' formation, the roughness returns back to its original levels, and we have a surface with different shapes (some tides al- ready created and some other ones tend to their creation).

To conclude, the overall roughness is really limited, but in order to proceed to any calculations for the creation of any offshore wind farm we have to take into our consideration any alterations that exist on sea's surface, from lighthouse to whatever exist on sea or next to it.

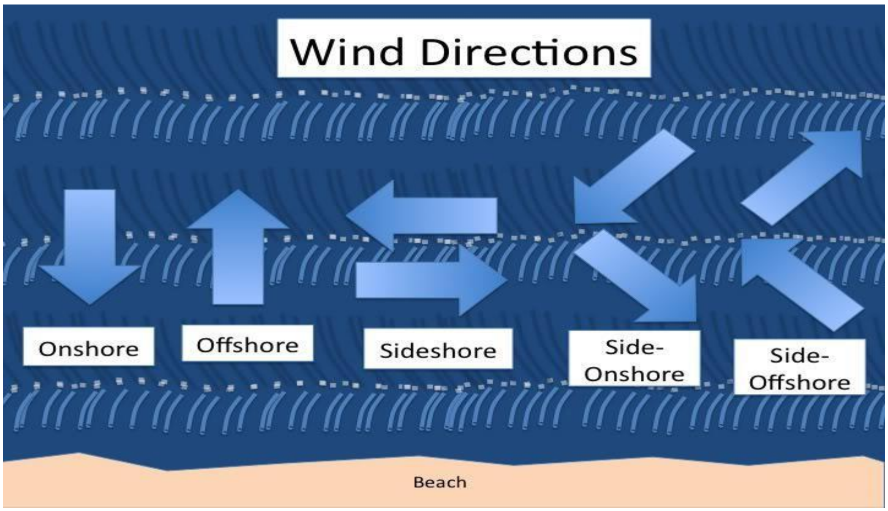

Figure 47 Wind Directions at different wind patters[53]

Consequently, the limitation of roughness will lead to the limitation of wind shear. Furthermore, the wind's turbulence on sea is considered to be lower than on ground, be- cause we observe temperature difference between the ground and the air, that is estimat- ed to be lower above sea than above ground. More thoroughly, there are several temper- ature variations that happen because of difference in altitudes. Additionally, solar radia- tion will reach below sea level, contrary to the land where the radiation reaches the top of the ground. (see **Figure 47**)

Energy estimation

Another essential matter is the overall behavior of wind velocity at its various values, it's about a type of intel that is considered of high importance and which can lead our plan of investment to the maximum possible output, by avoiding any additional expens- es. In order to achieve the most accurate estimation of our wind values, we use the Weibull distribution. (see **Figure 48**) (Muhammad Shoaib, 2016)

[53] Offshore Wind. [Online] Olivier Negrel. Retrieved date: Nov 2, 2018

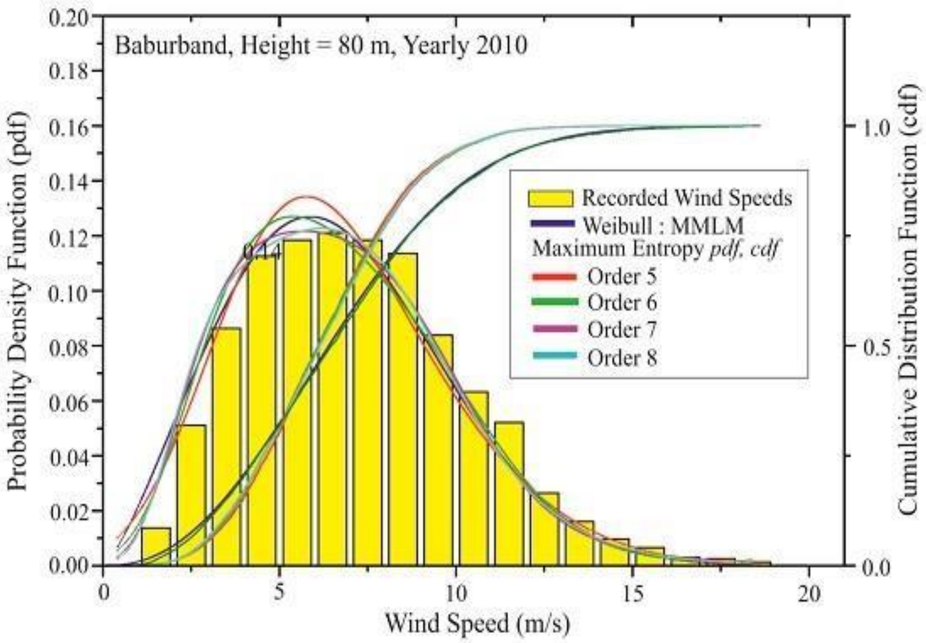

Figure 48 Probability Density Function[54]

At this part, we will make an analysis of this distribution. Firstly, we do not observe any symmetry in our distribution. Secondly, according to the meteorological conditions, and the morphology of the region, we obtain different Weibull distribution. At the case where the shape parameter of the distribution is 2, we have a Rayleigh distribution, which is the most widespread distribution, that the engineers at the wind energy sector are mainly based on. [14]

[54] Shoaib, M., Siddiqui, I., Rehman, S., Rehman, S. U., Khan, S., & Lashin, A. (2016). Comparison of wind energy generation using the maximum entropy principle and the Weibull distribution function. Energies, 9(10), 842.

Betz' Law

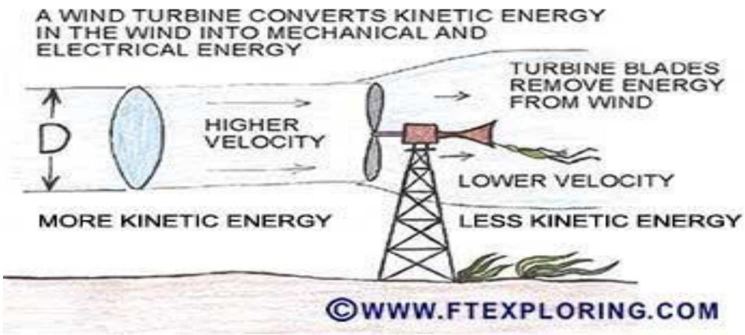

Figure 49 Betz' Law[55]

As it is shown at the **Figure 49**, if we have a kinetic energy (E_k)that enters the wt, this kinetic energy will be reduced after the entrance, as the blades will remove energy from the wind's motion, as it is converted to mechanical energy.

It is necessary to have this balance in order to make all system operate, which means wt and wind moving. Additionally, we should also know that a perfect wt can decelerate the wind by 2/3 of its primary velocity. More specifically, it is stated in Betz' law that we can achieve a conversion lower than 16/27 of the primary kinetic energy of wind to mechanical energy, by the use of wt. In practice, wts are able to reach at maximum value ,75% to 80% of the Betz limit. [7]

Power density

As stated previously, the power is proportional to the 3rd power of wind velocity and to the air density. Moreover, in order to estimate the wind's power density we can make it by the multiplication of each wind velocity's power with the probability of each wind velocity (Weibull distribution). Additionally, elevated wind velocities have as result elevated energy.

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[55] Betz' Law. [Online] David E. Watson - FT Exploring Science and Technology. Retrieved date: Nov 2, 2018.

Cut in/cut out wind speed

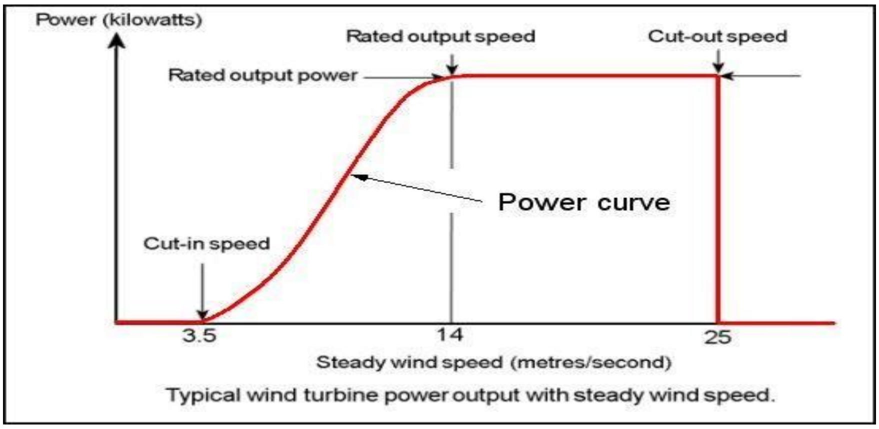

Figure 50 Arbitrary power curve of a wind turbine compared to wind speed[56]

The wt ’s operation is programmed to begin and end at certain values of the wind velocity. More specifically, it begins working at approximately 3-5 m/s (cut-in) and it will cease its operation at a velocity, over 25 m/s, for preventing the cause of any potential breakdown or harm on the local environment. (see **Figure 50**) [7]

Power curve

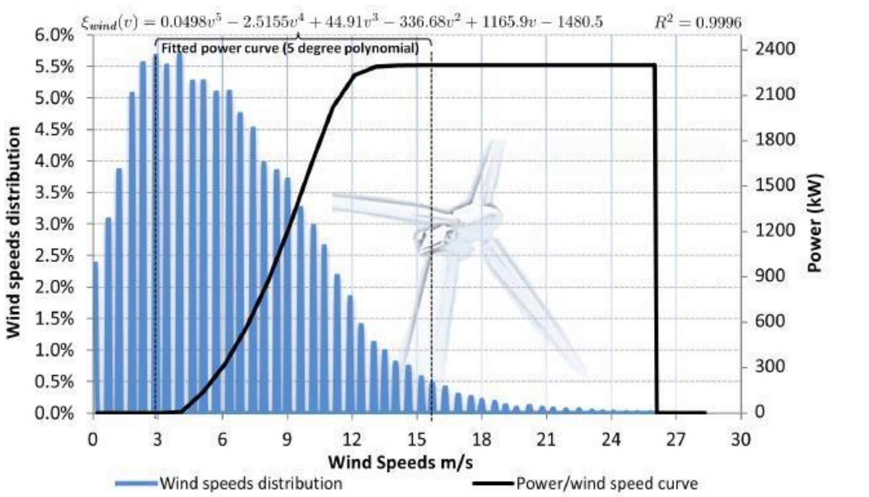

Figure 51 Wind speed distribution and power curve of a 2.3MW wind turbine.[57]

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[56] What if you could you build a wind turbine for hurricane-speed winds? [Online] Paul Dvorak. Published date: Sep 6, 2017

At the right side of the graph (power curve) at the **Figure 51**, the magnitude of the power output of a wt is demonstrated, depending on various wind velocities. In order to proceed to the design of the graph, we make measurements by special equipment, mainly a type of anemometer, which is installed on a mast nearby the wt. At this point, we should point out the caution we should have at the distance, which should be checked, for the prevention of any potential turbulence that can be caused by wt' s rotor, leading by its turn to problematic calculations. [15]

At the case of limited wind velocity, we can make utilization of the calculations by the anemometer. Secondly, we proceed to the collection of power output values, which will lead to the final step, which is their illustration on a graph. Moreover, we should state the possibility of statistical error during wind velocity estimations. Concerning the prerequisite circumstances of the creation of power curve, we need regions with very limited turbulence and the wind direction should be headed to the frontal part of the wt. Additionally, we should pay attention to the atmospheric conditions, more specifically the air conditions, which will be changing through different time periods, and must be taken into consideration for the calculations during the siting and the operation of any wt. (PC Del Granado, 2016)

[57] Del Granado, P. C., Wallace, S. W., & Pang, Z. (2016). The impact of wind uncertainty on the strategic valuation of distributed electricity storage. Computational Management Science, 13(1), 5-27.

Power coefficient

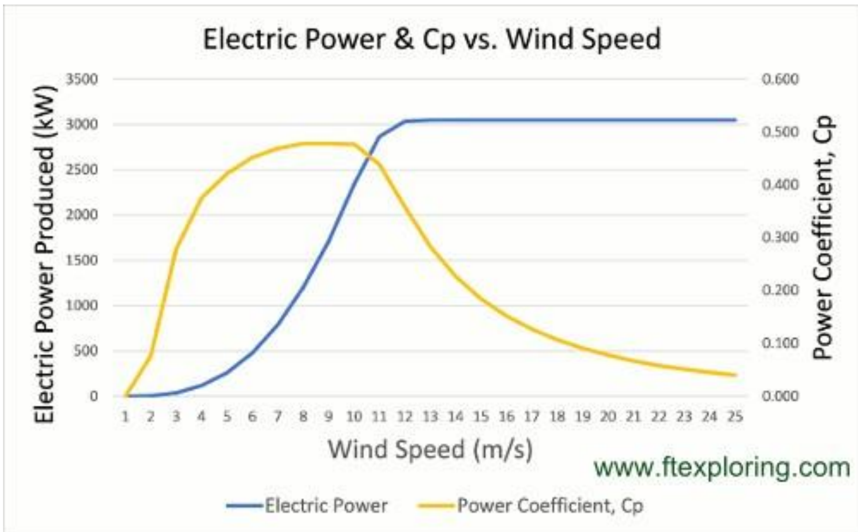

Figure 52 Plot of Power Coefficient, Cp, (yellowish line) and Electric Power Out, Pout, (blue line) versus wind speed in meters per second. The top flat part of the blue line is what is usually called rated power, or max power. Rated power in this case starts at about 13 meters per second[58]

This coefficient is significant for the power estimation, as it indicates the ratio of wind energy conversion to electricity. (see **Figure 52**) In order to calculate the C_p, we should the following:

- Firstly, we make use of the power plot, where we will use the integral of the surface under the curve.
- Secondly, we will use the result of this calculation and we will divide it by the rotor's swept area.
- Finally, we will make the ratio of the number of the previous calculation to m^2.

More simply put, in order to estimate the efficiency of the required wt, we divide the power output by the wind energy input. Furthermore, we should point out that the variation of the wt's efficiency depends on the wind velocities. The choice of wt will depend on the wind resource of the site, as well as the MW output we are aiming to achieve. [16]

[58] Power Coefficient. [Online] David E. Watson - FT Exploring Science and Technology. Retrieved date: Nov 2, 2018.

Capacity factor

An interesting and very crucial index , for getting knowledge about the annual energy output of any wt , is to make use of the capacity factor (cf). In order to define the cf , we create the ratio of the real annual energy output and the maximum possible output.

The main range of the cfs is between 20 and 60 %. Additionally, we should be familiar with the fact that even there is tendency for high cf, it does not certainly give the investment the privilege against a lower cf. More specifically, at a region with high scale wind velocity, it is considered privilege to use a big generator, but it would lead to the minimizing of the cf, however the target of higher annual energy generation will be achieved. (see **Figure 53**) The combination of the limited cf and a big generator is related to the meteorological conditions of the region, but also to the market of the various wts types.

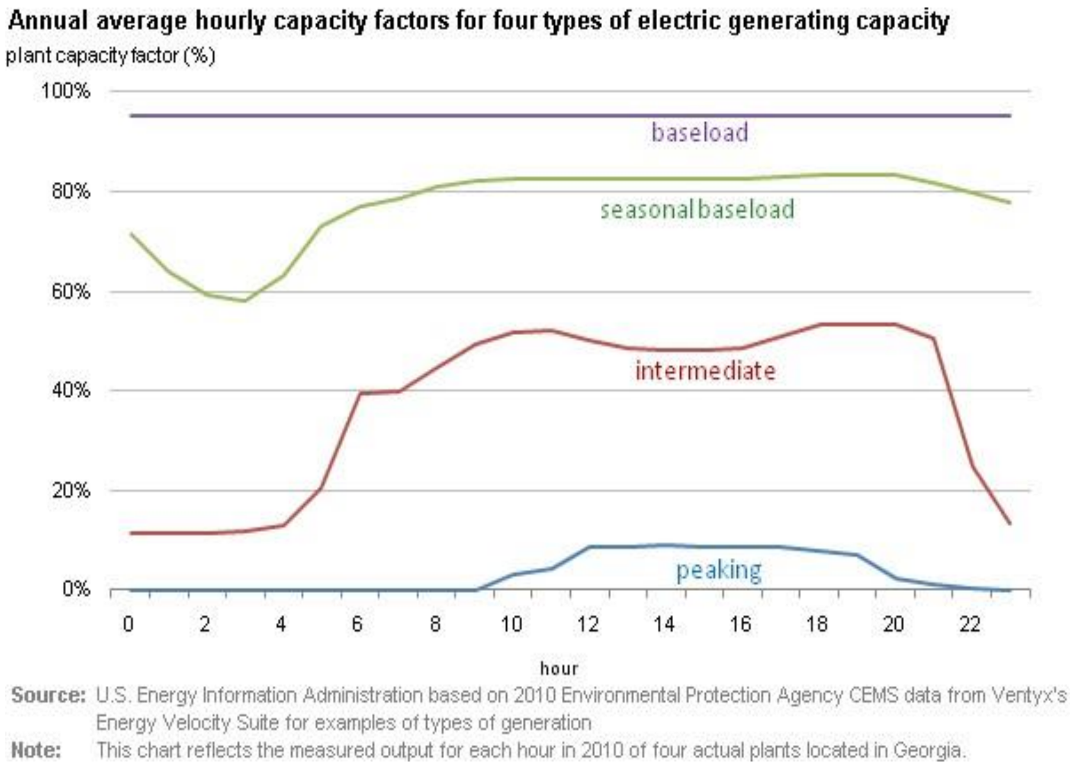

Figure 53 CFs depending on the generating capacity[59]

[59] Electric generators' roles vary due to daily and seasonal variation in demand [Online] EIA Published date: Jun 8, 2011

3.2 Technological approach for the production of electricity from wind

3.2.1 Anemometers

They are the basic equipment for the estimation of wind velocity, most specifically the type of cup anemometer is used, with 3 cups that can measure the air. This equipment is combined with a wind vane in order to measure changes in wind direction. An alternative approach in type of this kind of equipment is the use of propellers at the place of cups, but it is not frequently used.

Anemometers in Use

There are different types of anemometers, such as the ultrasonic or laser or hot wire anemometers. The anemometers with cups are widely used. (see **Figure 54**) [53]

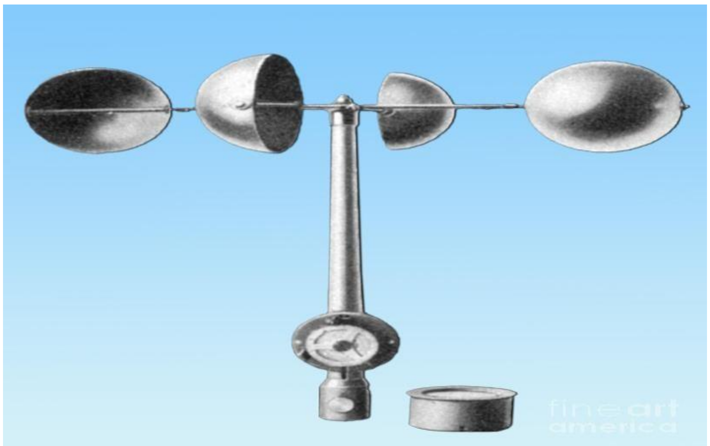

Figure 54 Cup Anemometer

At this point, it is essential to mention that it is preferable to invest in expensive anemometers rather than cheap ones. By this way, we can achieve higher quality in our measurements and eliminate error possibilities during the estimation of energy generation. Obviously, by doing the previous steps, we are at the position of knowing, if the investment is feasible. In order to achieve top class estimation of wind velocities, we have to place an anemometer above a mast that is as high as the selected hub of wind turbine. Therefore, it is possible, by this method, to reduce at minimum any perturbations in air flows that can derive by the mast. At the case where the anemome- ter's placement is neither top (nor bottom), it must be ensured that is in the direction of predominant wind direction to reduce at maximum level the potential shading by the tower.

The location of information, that can be collected concerning anything about wind mo- tion, is in some chips inside a computer, known as data logger. At very extreme cold conditions, a heated anemometer is necessary, with the combination of an autonomous power source. [53]

3.2.2 WT's operation

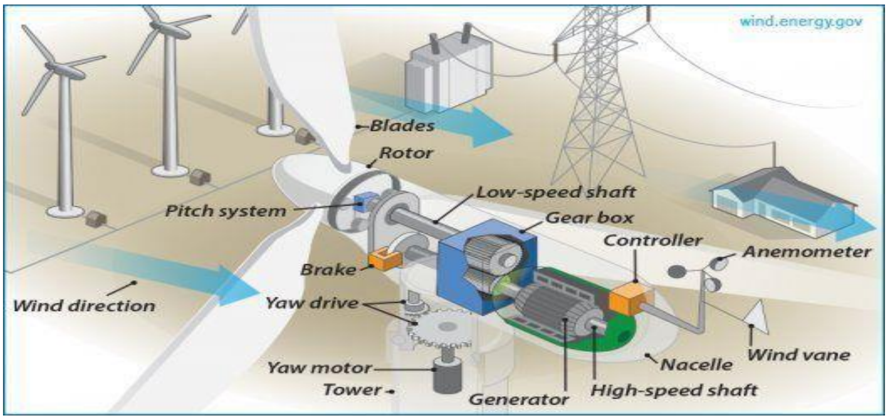

Figure 55 WT components[60]

At this point, we will present briefly of each wt's component's function. (see **Figure 55**) [17]

Anemometer: It is responsible for the calculation of wind velocity and for the transmis- sion of the relative data to the controller.

Blades: At the time of wind's contact with the wt, they raise and make rotational movement, leading to rotor's spin

Brake: It is responsible to cease the rotor's function at case of emergency.

[60] Wind Turbines [Online] US Dept. of Energy. Retrieved date: Nov 2, 2018

Controller: Initiates the wt's function ,when the wind velocity is between 8 and 16 mph, and proceeds to the wt's cease of function at 55 mph, because of probable damage due to reinforced winds

Gear box: It has the responsibility for getting the low-speed shaft and the high-speed shaft. Additionally, it will proceed to the increase in rotational velocity from 30 rpm to 1000-1800 rpm, which is the desired velocity in order to achieve electricity generation. In specific circumstances, it may be not be used, depending on the engine.

Generator: Generates electricity that is 60-cycle AC

High-speed shaft: It conducts the generator's function.

Low-speed shaft: It rotates at 30-60 rpm.

Nacelle: It is located at the tower's highest level and it includes the gear box, the low- and high-speed shafts, the generator, the controller, and the brake.

Pitch: It is responsible for the driving (or the pitching) the blades away of the wind , for the adjustment of rotor's velocity and for the surveillance of the rotor to operate even on extremely low or high wind levels, in order to ensure electricity generation.

Rotor: It is constituted of the blades and the tower.

Tower: It is constructed of tubular steel, concrete or steel lattice and it gives support to the wt's structure.

Wind vane: It estimates the wind direction and gives signal to the yaw drive in order to adjust in most suitable way the wt's direction.

Yaw drive: It is responsible to check if the upwind wts are directed to the wind, at the wind's direction. On the other hand, it is not needed at the case of downwind wts, as it is the wind that does all the work of the yaw drive.

Yaw motor: It supplies power to the yaw drive

WT's aerodynamics

We shall talk at this section about the structure of a wind turbine, and the construction method and the placement of different parts is far from random choice. Everything has its purpose for the total function of the wt, which must be suitable with the external factors that are necessary for our cause. More specifically, the installation of rotor and the hub must be done at the top of the tower, in order to be suitable with the turbulence of the wind, which comes from the back of the tower.

The wind that approaches the wt cause the existence of 2 categories (see **Figure 56**) of forces of aerodynamic nature:

1. drag forces, which follow the wind alongside its direction,
2. lift forces, which have direction that is vertical to wind's

Generally, they can be utilized at the same time or separately, in order to achieve the blades' rotation. [53]

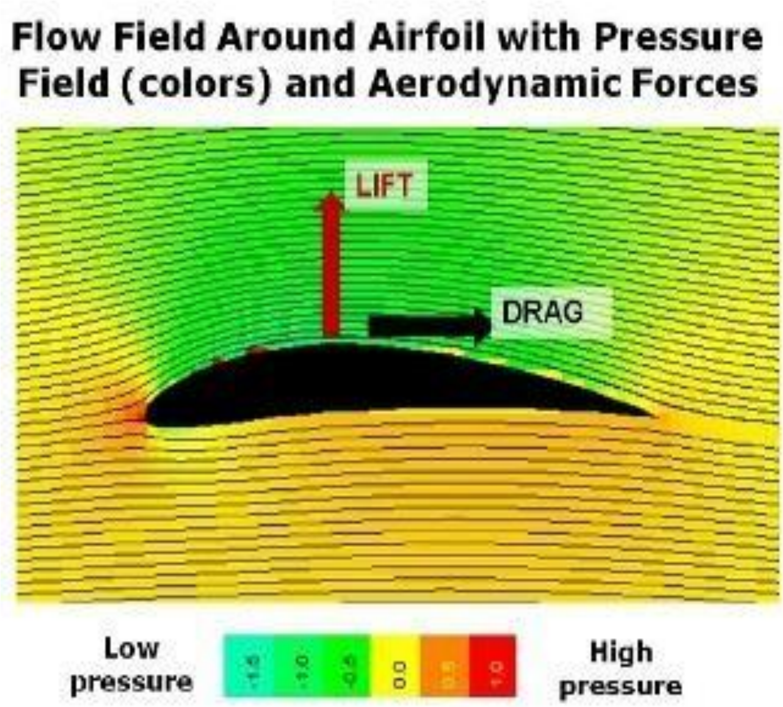

Figure 56 Description of Airflow at the selected region[61]

[61] Lift and Drag. [Online]. Coherent Application Threads. Retrieved date: Nov 2, 2018.

Lift-based and Drag-based WT

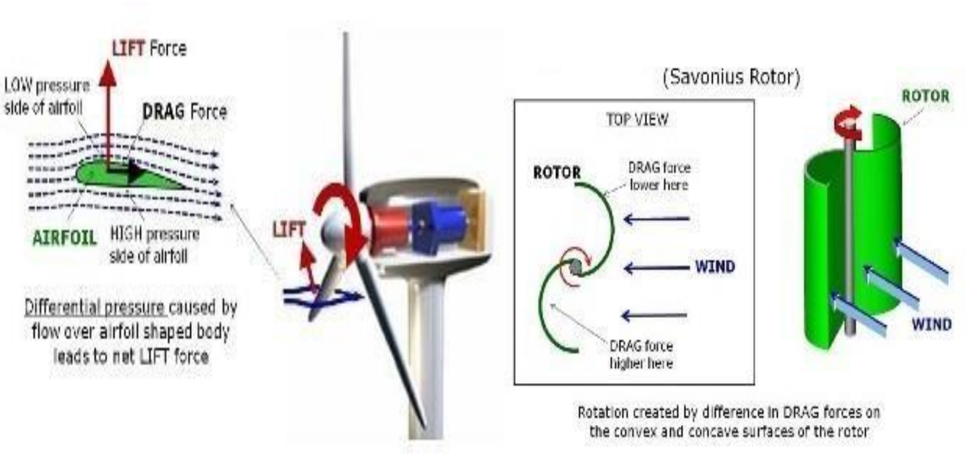

Figure 57 *(left)* Lift-based WT concept. *(right)* Drag- based WT concept.[62]

The Lift-based type is widely used because of the high percentage of energy that can be harvested. (see **Figure 57** *left*) It is actually based on the method of airplane's wings, which is due to the fact that the wind, on the upper region of the wing ,will possess higher velocity compared to the downside part of the wing . However, it has limitations, as it demands certain type of surface, as the type, used on airplanes' wings, which is named as the airfoil surface. [53]

This particular shape has its unique benefits, because it can cause a differential pressure, at the intermediate space of the regions at the upper and lower levels. In addition to that, it has as result the creation of a net force, vertically of wind's route. At this point, we should pay attention at the rotors' direction of the specific wt, in order to keep their ability to respond to the variation of wind velocities, for the ideal harvesting of wind power.

This Drag-based type of wt is the most widely known and used, with a long history, which goes back to the ancient Persia. Additionally, concerning its operation, the wind moves and hits the surface it finds ahead of it, causing its movement in return at wind's direction. (see **Figure 57** *right*) [53]

[62] Lift and Drag. [Online]. Coherent Application Threads. Retrieved date: Nov 2, 2018.

Rotor aerodynamics

We will notice the loss of lift from the rotor blade, at the case we will observe an abrupt wind's angle of attack on the blade is made, based on the phenomenon of stalling, which occurs inside a compressor, at the case of the wind changing its primary moving direction. (see **Figure 58**)

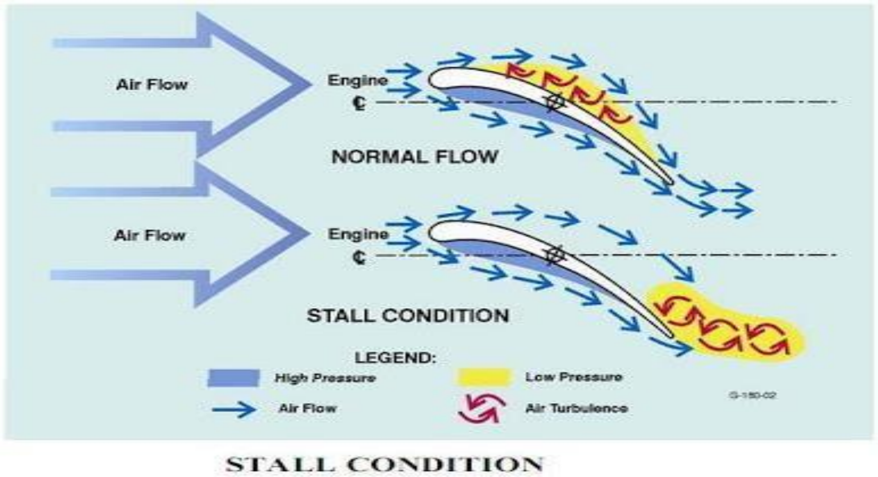

Figure 58 Norman and Stall condition[63]

In order to avoid this situation, we observe the rotation of rotor blade for the purpose of reaching our goal of an angle of attack, with the maximum possible value. Additionally, we have to mention the special case of stall controlled wt, where the construction of the blade should be done in a certain way ,in order to achieve gradual stalling from inside to the outside , at extreme wind conditions. In order to decide properly about rotor blades' profile, we have to be aware of our choices, based on the following criteria:

1. trustworthy lift,
2. stall attributes,
3. and to be able to perform even with a non clear surface (essential for regions with rare raining situations) [53]

[63] Compressor Stall [Online] Adem - Science Natural Phenomena. Published date: Dec 14, 2008

Rotor blade materials

The most usual construction is based on glass fibre reinforced plastics, (GRP), during the construction of any large wts. Additionally, another material that is considered as an alternative choice is carbon fibre or aramid (Kevlar), however it is not a suggested choice for wt of big size. Moreover, wood and wood additives are also considered to be a new alternative option for investment. On the other hand, for wts of limited size it is more preferable to opt for steel and aluminum alloys. [18]

WT's power control

The aim of the wts' construction is the generation of electricity at the least cost and to achieve the maximum output at wind velocity at approximately 15 m/s. In the circumstances of high-scale winds, it is essential to prevent the wt's destruction ,that's why the percentage of energy that exceeded should be removed. Additionally, any wt includes power control system, which is categorized in 2 types. (see **Figure 59**) [49]

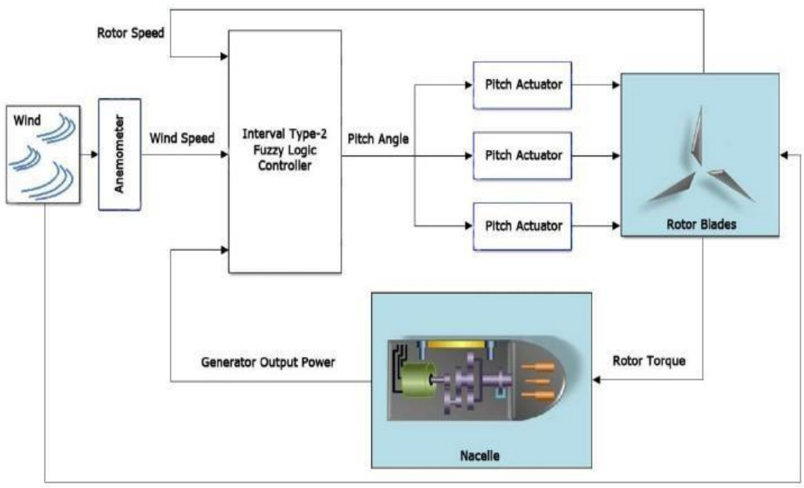

Figure 59 The scheme of Pitch Control System in the wind turbine.[64]

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[64] Bahraminejad, B., Iranpour, M. R., & Esfandiari, E. (2014). Pitch Control of Wind Tur-bines Using IT2FL Controller Versus T1FL Controller. International Journal of Renew-able Energy Research (IJERER), 4(4), 1065-1077.

Pitch controlled WTs

At this wt, there is an electronic controller that is responsible for the calculation over the power output constantly at short periods of time. At the emergency of very elevated value of the output, gives the command to the mechanism, which is driven by hydrau- lics and makes the rotor to get off the wind, but it stops and returns to its original state at the lowering of wind velocity. So, it is essential to have the ability for a constant movement throughout their whole width. Additionally, it should be mentioned that there must be a synchronization of the rotor blades for the suitable pitching amount. Finally, this whole process is done, in order to maintain the rotor blades at the maximum possi- ble angle for achieving the highest possible output, at the general possible variation of the wind velocities. [49]

Stall controlled WTs

This type of wts dispose their blades at a stable and specific angle. The purpose for this design is for the prevention of special circumstances created by the extremely elevated wind velocity, more specifically the turbulence at a part of blade, hidden by wind, at various time periods. Consequently, we achieve to avoid the lifting force on the rotor. Additionally, we should mention the simultaneous action between actual wind speed and the angle of attack, while the first tends to higher values, we have the similar behavior at the 2nd, until the existence of phenomenon ‘stalling’. During the movement alongside the horizontal axis, we have short twist of the blade, in order to keep its progressive stalling. Furthermore, the majority of the current wts are of this type. (eere, 2018)

Active stall controlled WTs

There is a tendency in wts of output of more than 1MW to utilize this type of system. In the technical aspect, the system has similar function to the pitch controlled machines’ s system. The divergence of the active stall system’s similarity begins to occur when the system ’s power equals to its rated power. What happens is that we will have a higher value in the angle of attack, which will have as a result the cause of deep stalling , and then it will conclude by not taking advantage of the surplus amount of wind energy .A high positive aspect of this type of mechanism is the high precision in control management , compared to the passive stall. (eere, 2018)

Rest power control methods

There are some additional methods in power control mechanisms for dated types, there is utilization of ailerons and alternatively, we have the yaw mechanism, for limited scale application. [17]

Yaw mechanism

This mechanism is utilized in order to achieve the wt's rotation in order to follow the direction of the wind. Additionally, at the case of alternative scenario to the possible vertical direction of the rotor to the wind, there will be a yaw error. This is an index that a limited amount of wind energy will be disposed at the swept area. Furthermore, the existence of this error in the overall mechanism of any wt gives the capability to withhold fatigue loads of larger scale, compared to the wts that yawn in vertical and opposite direction to the wind. [17]

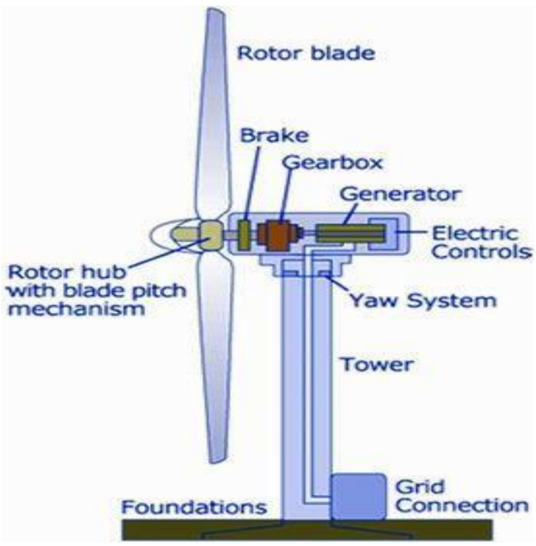

Figure 60 wind turbines pattern with Yaw system[65]

In more details, this type of mechanism has application on any horizontal axis wt , where yawing is utilized. The yawing is a mechanism that its function includes electric motors, with the aim to maintain the yawing so that the wt is always facing the wind. (see **Figure 60**)

WT towers

The nacelle and the rotor are loaded on the towers, whose manufacture is separated in 3 types:

a. Tubular
b. Lattice
c. Concrete
d. guyed tubular

The first type is used for big WTs and they have the shape of a cone, for the purpose of empowerment and material reduction. The second type is mainly used for cost reduction. However, their appearance is not so appealing, and they are not used in the current wt technology. The third type is utilized for wt of limited size, they are preferred for cost reduction and can withstand bad management, but they are not easily accessible, which is considered an essential issue for WFs computability. There is also an alternative type that is a hybrid. It can combine various types from the already mentioned types. The big height in towers is considered an important privilege at regions with increased roughness. Additionally, the lattice and the guyed type have the ability of disposing wind shade of smaller level than the one of massive towers.

[65] Tran, T. T., & Kim, D. H. (2015). The platform pitching motion of floating offshore wind turbine: A preliminary unsteady aerodynamic analysis. Journal of Wind Engineering and Industrial Aerodynamics, 142, 65-81.

Seizing of WTs

For the construction of the wind farm, there is a preference for the vertical region. In order to estimate more precisely the energy output in annual basis, we have to calculate the swept area of the rotor. (see **Figure 61**) [19]

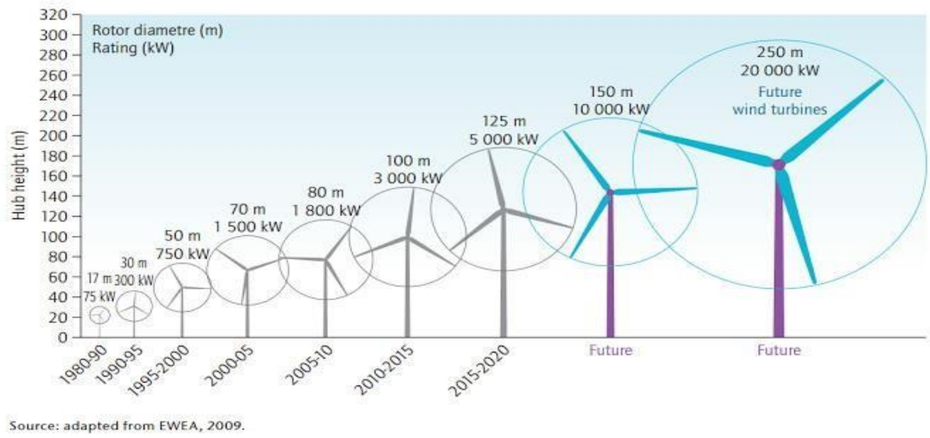

Figure 61 Growth in size of wind turbines since 1980 and prospect. KEY POINT: Scaling up turbines to lower cost has been effective so far, but it is not clear that the trend can continue forever.[66]

WT Additional Precautional Information

The construction capability of any wt is powerful, as it provides life span of 20 years, including their tolerance in extreme weather conditions. As the magnitude of a wt is increased, so does the number of safety devices in them. Additionally, concerning the basic braking mechanism for current wind technology, the most dominant is the aerodynamic type, which is categorized , depending on the type of controlled turbine,

[66] Padmanathan, K., Uma, G., Ramachandaramurthy, V. K., Sudar, T. O. S., & Tamizharasan, T. (2017). Conceptual Framework of Antecedents to Trends on Permanent Magnet Synchronous Generators for Wind Energy Conversion System.

in 2 basic categories:

1. vertical rotation of the blades throughout their horizontal axis (for pitch or active type)
2. vertical rotation of the blade tips (for stall type)

Furthermore, we should mention the use of hydraulic system whose purpose is to give boost the blade(/blade tips) and to initiate rotation till their initial position ,at the end of emergency conditions. Regarding the mechanical brake, there is a type of backup mechanism for the braking. It is not often used in the pitch type turbines, because of the additional limitations to the rotor's movement. [19]

3.2.3 WT Generators

The generator is essential for the operation of any WT. Its function deals with the conversion of mechanical energy into electrical. Additionally, it is coupled with WT rotor in order to provide the torque power. Moreover, we should mention that the WTs, that exist in the market, have frequency power of 50 Hz or 60 Hz. Furthermore, the function of generators is combined with lowering the temperature. This procedure is completed in two ways. Either with the enclosure of the generator inside a tube, with the aid of big ventilator, or, with the utilization of generators that use water cooling. Regarding the design of WTs, there are various options. A method is the use of synchronous or asynchronous generators, and both of these choices can be combined with a connection, directly or indirectly to the central grid. [19]

Synchronous generator

This type of generators is also known as 3- phase generators, as they make use of magnetic field that rotates. (see **Figure 62** *left*) [7]

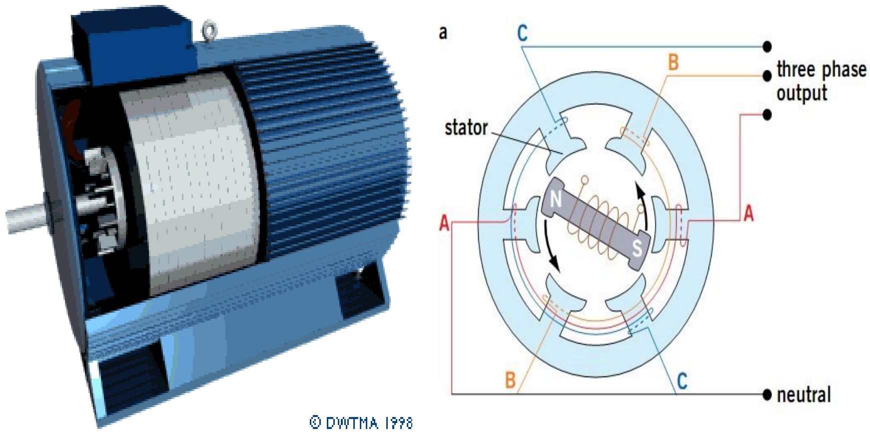

Figure 62 *(left)* Wind Turbine Generator[67] *(right)* 2-pole generator[68].

More specifically, during the time that the one of the three phases has reached its top value, the current at the remaining phases has follows the reverse process, with the voltage value divided by two. The apparatus that is created in this pattern is called (permanent) synchronous motor, as the magnet, existing in the middle of the machine, will complete its cycle, at a specific velocity, which will be harmonized with the simultaneous spinning of the magnetic field. Additionally, this machine is also known as 2-pole motor, as it has at its disposal a North and a South pole.(see **Figure 62** *right*) As the magnet is moving manually, we will receive similar behavior to the generator, and the alternate current will be turned back to the central grid. Furthermore, we should mention that by the increase of the torque, there will be also an increase of the electricity generation, while the generator will keep its velocity, that is given by the central grid that is connected to. This type of generator gives us the capability to operate independently of the central grid. However, in order to make it into action, the spinning speed should be kept stable, in order to maintain the frequency of the generated current. Unfortunately, these types of generators are not considered to be beneficial and in high market preference. This happens mainly because of the elevated prices of enforced magnets and the additional fact that they can lose their properties at extremely enforced magnetic fields. [7]

[67] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

[68] Can magnetism-generated electricity power electronics? [Online] Steven J Greenfield – Quora. Published date: Jan 23, 2018

Regarding their application in the wind power technology, there are often combined with electromagnets, that are directly supplied with power by the central grid. However, because of the fact that the grid supplies alternating power to the wt, there should be a conversion to the direct power, before the line reaches the wt. Regarding the four pole version, the magnets included are 4, but the rotation velocity of the field remains de- creased by 50 %. It is essential to ensure that by doubling the amount of poles inside the stator, the amount of magnets involved inside the rotor also is doubled. [7]

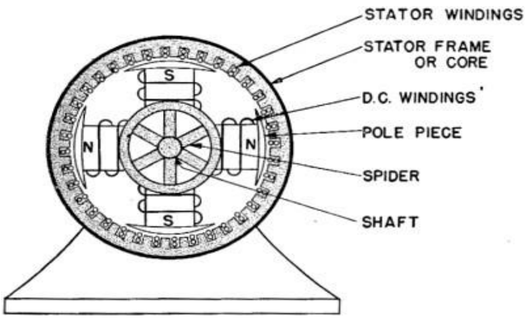

Figure 63 Four-pole generator[69]

The previous process can be evolved and reach the six pole generator. At the **Table 2**, the results of the different patterns and their relative results that can occur are presented.

Amount of Poles	***50 Hz***	***60 Hz***
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

Table 2 Synchronous Generator’s rotations per minute at various choice of poles[70]

[69] Electricity - Basic Navy Training Courses. [Online] U.S. Government Printing Office. Retrieved date: Nov 2, 2018.

At this point, we should mention that the definition of 'synchronous generator speed' has to do with generators' velocity, combined simultaneously by the grid's frequency. Concerning the asynchronous type, the previously defined velocity is identical to the inactive velocity. In the wind power domain, there is a tendency for preference at 4 or 6 poles, because of their benefit at their speed and the financial savings. The generator has the ability to manage the highest possible torque, but that is up to the rotor volume. That's why, there are two options at a specific power output. One option is fast, cost- efficient and with limited size generator, and another option that is slow, cost- burden and sizable enough. [7]

Asynchronous generator

At the wind power industry, there is an increased preference for the majority of wts to include a 3-phase asynchronous generator, that is also known as induction generator that can produce alternating power. It disposes important benefits for the function of any wt, such as the generator slip and a specific overload capacity. The difference of this type of generator to the synchronous type is in the existence of cage rotor. This component has aluminium bars that are attached to each other electrically, with the use of aluminium end rings. Additionally, it has the magnificent ability to be highly adaptive and can be combined with a variety of amounts in poles. (see **Figure 64**) [7]

[70] Windpower Wiki - English. [Online]. Danish Wind Industry Association. Retrieved date: Nov 2, 2018

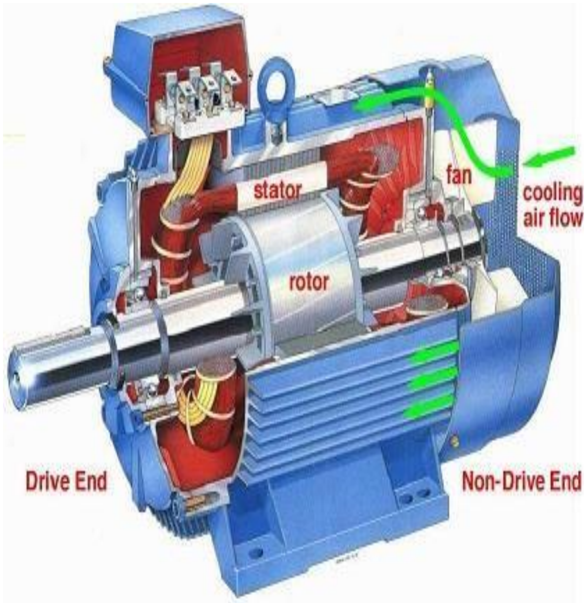

Figure 64 Asynchronous Generator[71]

Regarding their function, we have the creation of a magnetic field that is dependent on the rotor's behavior. More specifically, we have the circulation a reinforced type of current inside the bars, that demonstrate extremely limited resistance to the current. At next step, we proceed to the creation of rotor's magnetic poles, that together with the EM force, both are transferred to the stator. Furthermore, by the increase in the force to turn the rotor, we will have an increase in the power that will be used as EM force, which will lead to its conversion to electrical power and finally gets supplied to the central grid. [7]

The velocity of this type of generator is dependent of the force that is used and exerted on it. Moreover, there is a slight distinction of the velocity in the optimum level of power and at the time of inactivity. This distinction is defined as generator's slip, and its value is defined at 1%. It is considered as essential to be aware of the change in varia- tion in velocity with the simultaneous change in torque value, which can cause limited tear and wear on any gearbox. That is the main reason of greater preference at asyn- chronous compared to the synchronous type. Finally, this kind of generator has alterna- tive approach in the function, compared to the synchronous one, as it is essential that we have the stator magnification by the central grid, sooner than it begins its function. Add-

[71] Motor Efficiencies [Online] C Bracken Meyers – Energy Riot. Retrieved date: Nov 2, 2018

ing to that, it can be used in a stand-alone system, but with the aid of capacitors that will cover the magnification part of the process. It is also demanded to have an excess of magnetism at the time of system's initiation, in order to avoid the use of batteries and electronics [7]

Approaching the amount of necessary poles

Generally, the machinery that we are exploring is often equipped with an increased amount of stator magnets, in order to set to the lowest value, the distance of air gap that separates the rotor and the stator and to make the supply of cooling to the magnets used. There is an issue that comes up at the increase of supply of asynchronous generator with poles. The consequence of this can lead the generator to make different arrangement in nearby magnets. Moreover, there is a preference for the wind power industry to attach two types of generators in the wt that is created, one with limited size for limited winds and another one of increased size for the time period of extreme winds, in order to cover the meteorological data that exist at the required region of investment. Additionally, the current technology on wts has to develop the construction of generators, in order to have the ability to change poles, according to the assembly of the stator magnets that include. At the change of amount of poles that are utilized, there is also change in the velocity of rotation. [48]

Another current tendency, in the new technology used in the wind power industry, involves the creation of generators that constructed as two-in-one, which means operating at two possible frequencies and at two possible velocities. For the reassurance of the correct choice of this dual generator or increased number of poles, we have to be aware of the wind velocity distribution at the required area. In case a double generator is used, we can achieve various benefits, such as the fact that the wt will have the ability to operate at reduced velocity and at conditions of very limited wind. This privilege can make the construction more aerodynamic and minimize the existence of noise, caused by the blades' motion. (see **Figure 65**) [48]

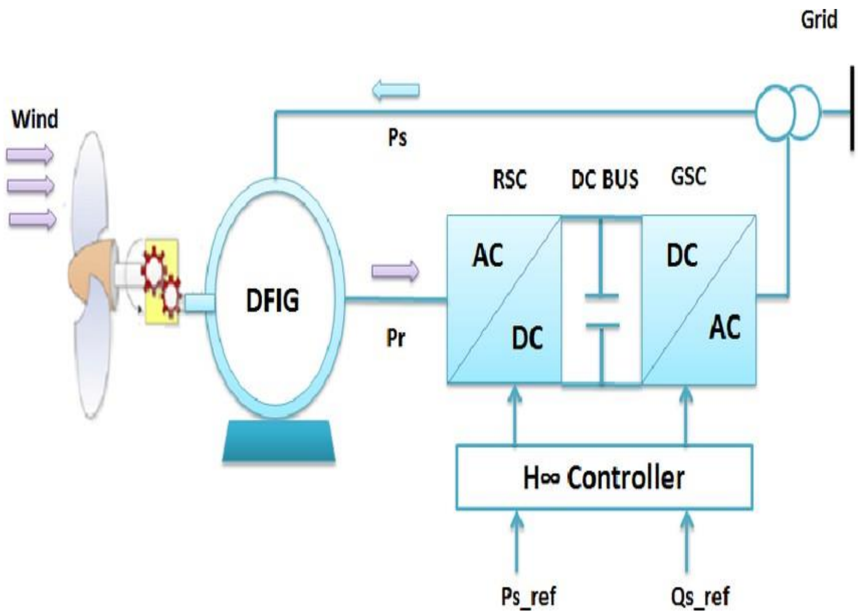

Figure 65 Double-Feed Induction Generator (DFIG-based) wind turbine control proposed scheme[72]

An issue that is bothering the industries for many years is the construction of electric motors, and the limitation of motors' function at specific velocities, which are related to the number of poles used. Because of the generator's slip's size is limited for efficiency reasons, we will have a variation of velocity at 1% difference, between inactive state and optimum state. Regarding the slip, it is related to DC resistance of the rotor, which means that the increase in resistance leads to an increase in slip. Even with the loading resistors onto the rotor and at the same time loading the control system , the issue of communication insists to exist, between the appropriate number of slips and the rotor. This solution of this problem is given by the use of fibre optics and by transmitting of the signal all the way to the electronics , when we have the passing of a stationary optical fiber. Despite the fact that the use of generator at elevated slip will cause excess of heat and by its turn will cause reduction in the generator's performance, it is considered to be beneficial for the improvement of power. This is true, because any expected fluctuations in the power output are normalized, with the slip's variation and the storage or discharge of some energy that will be used for the spinning in the rotor. [48]

[72] Azar, A. T., Vaidyanathan, S., & DeMarco, A. (Eds.). (2015). Handbook of research on advanced intelligent control engineering and automation. Engineering Science Reference.

Indirect grid connection

At direct grid connection, the majority of wts operate at steady and specific velocity. During indirect connection, there is independency of the wt generator at its perfor- mance. The utilized grid at this case is a different one and is a small AC- grid , which is checked by an inverter, in order to have variation in the frequency of the alternating cur- rent, inside the stator. Hence, the wt's function will be done at a fluctuating velocity, and as a result, the production of the specific current will be done at the stator's fre- quency. [48]

Summing up the already known data, we can have a synchronous or an asynchronous generator. The WT can possess a gearbox or not, for the later to be the case of increased number of poles inside the generator. It is essential to convert the specific current before it enters the grid and this will be fulfilled by thyristors or transistors of enforced power. These two options in equipment are categories of semiconductor switches. The alternating current that exits the inverter has different ups and downs, in order to normalize these, we will use particular filters, that are called AC-filter mechanism. [48]

Regarding the indirect grid connection, there are basically 2 benefits that are worth of mentioning. Firstly, there is use of the gusts that can boost the velocity of the rotor . It is important to have the appropriate mechanism that can provides us with the knowledge of distinction between gusts and the optimum wind velocity. Consequently, we can have the ability to minimize the optimum torque and any fatigue loads. A second benefit that can be gained by this connection, is that by the use of power electronics , the reactive power can be audited. This is done, in order to achieve a better power quality, which is quite important at a grid, that operates at low level power. On the other hand, this type of connection has one major drawback, as it demands increased expenses at the construction of power electronics, whose expenditure overcomes the amount money spent in improving the weight of current wts. Another important drawback is that during the conversion procedure , we have loss of energy ,combined with potential concordant deformity of the required current. [48]

Gearboxes

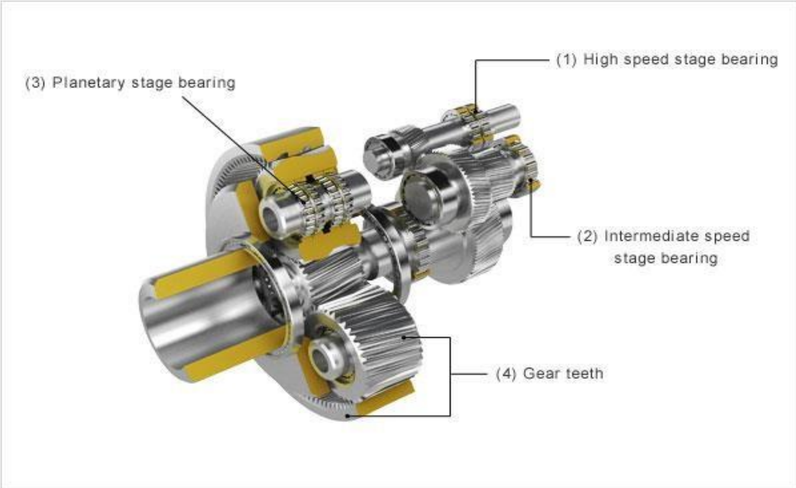

Figure 66 Gearbox[73]

At this section, we will discuss about the importance of a gearbox in the operation of any wt. We cannot directly connect the generator with the power supply of the principal shaft, so the intermediate step is going to be done by the gearbox. With the use of the gearbox, the increased torque power at low velocity, which is created by the rotor, is converted to decreased torque power at increased velocity, which is utilized by the generator. The gearbox has a particular gear ratio of the rotor's rotation to the generator, e.g. at the case of an engine of 600 kW, the estimation of the width of the gear ratio is estimated to be from 1 to 50. [20]

Controllers

Any WT controller includes an amount of computers, whose role is to constantly detect the situation of WT's function and at the same time, gather statistical data. (see **Figure 67**) Adding to that, it is also responsible for switches, pumps, valves and motors, inside the wt. By the increase of the WT's size, it is essential to give hint of their functionality at an increased time period. The communication with the responsible of the WT is done through a communications link. We can observe the presence of a controller at lowest level of the tower and in the nacelle. [20]

[73] Inspections of Wind Turbine Gearboxes. [Online] Olympus Scientific Solutions. Retrieved date: Nov 2, 2018

As stated previously, the fibre optics is also used in the communication between the controllers, as it is the current technology in the communication sector. There are some types of WTs that have at their disposal a third controller, which is located inside the hub. Regarding the monitoring, it has the ability to check for about 500 parameter val- ues ,such as the generator's voltage and the current. Additionally, it has its disposal im- pressive accuracy and at the outside ambient , around the wt's facility, and can calculate anything related to the wt, such as the temperature, the yaw angle and the wind direc- tion, but also gives warning , if the equipment is accidentally open for any reason. In order to achieve an successful construction of any wt , experts show focus on the inter- action of the controller with wt's parts. More specifically, the improvement in the con- trol techniques can play an essential role at the achievement of a higher wind power output. There is a suggestion that states that we should take into serious consideration the regional meteorological conditions , and in order to limit the tear and wear ,at ex- treme situations. [7]

Figure 67 Controller[74]

Power quality

As discussed previously, the controllers have the ability to detect any safety breaches inside the wt and after the control check sends the signal for the initiation of the system. Adding to the known function of the controller, it is responsible for the quality of the power that is produced. Regarding the power control, there is a DSP (digital signal pro-

[74] Off-Grid Wind turbine Controller 5KW – Details. [Online]. Deming Power. Retrieved date: Nov 2, 2018

cessor) that estimates the steadiness of the frequency of grid, of the active and the reactive power. Concerning the precision of the power, it possesses the ability of being able to control a big variety of electricity capacitors that are responsible for the reactive power's suitable regulation. [7]

Knowing the existence of extremely reinforced EM fields surrounding the cables and the generators, the electronics that are specifically utilized in any controller should have enough tolerance to EM fields. However, it essential to prevent the specific electronics from any emission of EM waves, that by their turn can suspend the operation of the rest of the machinery. [7]

3.2.4 WT design

In order to make proper estimations in the wind farm design, it is essential to consider the characteristics of our materials that will be used, such as the strength. Another issue is the magnitude of the blades that are utilized, more specifically the less wide they get the more they can withstand the extreme wind forces that can reach them, like a hurricane wind. Therefore, it is a basic manufacture rule to create limited number of blades, that are long and have limited width, in order to restrict the enforced wind's impact. Additionally, in order to create a WT of good quality, in a region that has extreme turbulent meteorological conditions, we have to make use of components that can with- stand during a long time period and several weather conditions and do not show defects, like cracking that can lead to severe and irreversible damage. That is why we have to be extremely cautious at the selection of our materials for the construction, but at the same time we should pay attention the physical behavior of our different parts, such as the vibration. Furthermore, it is considered equally essential to do properly the estimation of the various forces that are directed on the wind turbine and can cause various physical reactions of the partitions of the machine. [7]

WT axis

There is a high preference on the WTs with horizontal axis (h.a.), because globally any WTs, that are in the market and have connection to the grid, are constructed with a propeller -type rotor laying on h.a. (see **Figure 68**). The reason for the option for the rotor is that it has the ability to convert the linear motion of wind into rotational energy, which is the driving energy for the generator. On the other side, we have the vertical axis WTs, which behave as the water wheels, but there are not at all used, as their disadvantages overcome their advantages.
[21])

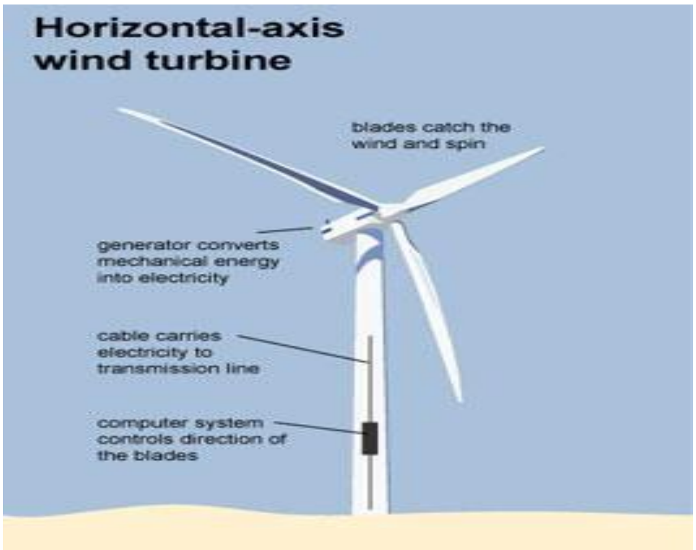

Figure 68 Horizontal-axis turbines[75]

Upwind and Downwind Machines

The current type of WTs is constituted of two main subcategories: the upwind and the downwind. The first category has the ability to prevent the wind shade at the back of the tower. It is considered to be the most preferable design, but it has some considerable disadvantages. Firstly, the wind shade does not disappear entirely, but it does appear at the front of the tower .This incident leads to the fact of power drop in constant and small amounts ,during the time of covering of tower's field by the rotor .Secondly, the rotor should be placed at a location away from the tower and should be constructed as stiff ,accompanied by a yaw mechanism to maintain the contact of rotor with the wind. The second category has different construction, concerning the rotor location. There is no need for the inclusion of a yaw mechanism, at the case of the suitable construction of

[75] Wind Explained – Types of Wind Turbines [Online] EIA. Retrieved date: Nov 2, 2018

rotor and nacelle, when the nacelle will follow wind's direction. Furthermore, we can construct a rotor with increased flexibility , which is a high privilege for the WT, as it can manipulate in the best way possible the increased wind velocity. This will result in making easier the tower's motion. The basic privilege of this type is that it can be constructed with less weight than the first type. On the other hand, there is an issue in wind power's fluctuation because of the rotor getting into the tower's wind shade. This will lead to an increase in the fatigue loads. The big upwind WTs do not have at their disposal a tail, but a yaw mechanism. Additionally, the majority of the current WTs are upwind. [7]

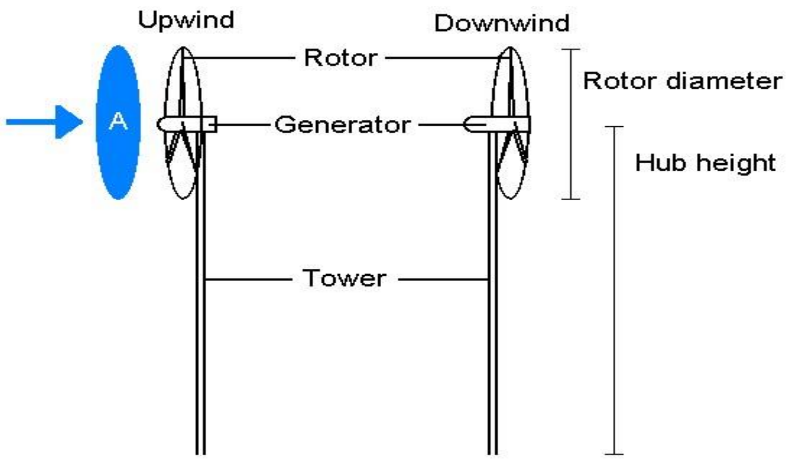

Figure 69 Upwind and Downwind WT[76]

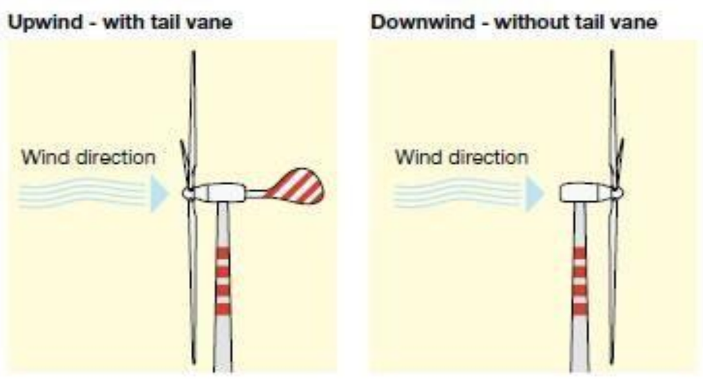

Figure 70 Small Upwind and Downwind Wts with tail vane[77]

[76] Upwind and Downwind wind turbine. [Online] Niall McMaho. Published date: Jan 2016

[77] Upwind/Downwind wind turbine [Online] Gov school agriculture Published date: Jul 2015

Number of rotor blades

In order to assure the construction of highest quality and stability reasons,there is a preference for odd number in the total number .This occurs in order to prevent the blade of the lowest level to enter into the shade zone of the tower and decrease the potential power output, which is gained from the motion of the blade of top level. There are three main patterns in the amount that is preferable for the blades:

1. The Danish Three-Bladed
2. Two-Bladed (Teetering)
3. One -Bladed

Beginning from the first pattern, it is considered as most preferable in the modern wind technology. This mechanism includes the location of the rotor to be held upwind, inside their yaw mechanism. Usually, an asynchronous generator is utilized. Secondly, we shall discuss about the second pattern, which is profitable for decreasing the expenses and the burden of the one blade. However, there is an issue regarding the need for in- creased rotational velocity, which is essential for the noise pollution. Their design is considered to be complicated and demanding as it is necessary to place the rotor on a shaft that is located vertically on the main one. Finally, we will mention the 3rd case, where we make use of only one blade, which is helpful for reducing additional costs for further blades. It is not quite preferable, because of additional weight in order to balance the rotor, which automictically eliminates this type from the option list. Here, we have to pose the natural question, why not more than 3 blades?

The answer is found at the already known from the previous data we have stated so far. More specifically, by the increase in the number of blades, there will be increased rotational force (torque) and decreased the velocity than causes the rotation. What we know so far is that in order to achieve the maximum power output we have to reach the highest possible velocity, but at the same time limited at the highest level the torque. This leads to the conclusion that for the shake of our production we should stick to the limit of 3 blades. [56]

Maximize wind energy output

The principal target for achieving the maximum electricity can be reached by combining technological and financial data. For example, if it comes to the choice of elevated cost in the investment of ideal wind turbine, the people in charge will not really consider the price parameter for the realization of the final investment if the goal is achieved. Additionally, another essential combination to be considered is the generator and the rotor size. In more details, a generator of limited size gives flexibility and reduction of effort, but it does also lead to the harvesting of limited amount of wind energy. On the other hand, a bigger generator gives the potential output required at high wind veloci- ties, but it will also provide the turbine with stiffness at small scale wind velocities. In order to fix this dilemma, the engineers are often driven to the choice of adding a couple of generators in order to cover all the previous parameters. Finally, as far as the tower is concerned, we should mention the importance to dispose a tower of height as elevated as possible, in order to achieve the wind shear, but this investment is affected by the pa- rameters of roughness class and electricity cost. [7]

Noise

The sound that is heard from wts has two potential sources: mechanical and aerodynamic. Firstly, considering the first category, we should point out that the blades that are used behave in a similar way as membranes, and have the capability to repropagate the noise, by the vibrations, and is located at the nacelle and the tower. An interesting current method to deal with this matter is the creation of the chassis frame with some particular holes. Secondly, concerning the other category, it is the result of the wind facing the natural objects at a specific velocity, such as the leaves of trees. The noise can also be created by the contact of wind with various surfaces, e.g. buildings ,and these, by their turn, will transmit the noise. Furthermore, regarding the WTs, this noise is pro- duced by the blades, during the process of the transfer of wind energy to the rotor. The level of noise depends on the smoothness of the blades' surface. Finally, at this point we should mention that although it is not of high importance, a great effort has been done at eliminating the noise parameter. Neither at social sector, there are consequences, taking for granted the specific distances that any wind farm should keep, far away from nearby residential area, nor at the energy production output, where there is zero reduction at the power output. [7]

Offshore foundation types

The aim of this investigation is to achieve the construction of machines with the least expenses. Additionally, the methodologies that can be utilized may be various, such as stall, alongside with the use of CFD technique. The offshore sector is constantly evolving and its power output has achieved 1,5 times the output of an onshore wind farm and consequently there is a high tendency to investment at sea. At the offshore sector, the majority of wind farms make use of technology that utilizes gravity force. There is modern technology, where a tube of steel is used and is located on a flat steel box at sea.

For the appropriate wind farm, the weight parameter should be taken into serious consideration, as it affects, in the good way, the transportation and the installation of bases for the construction of WTs. There are mainly two types of foundations, that they serve as construction types at offshore sector: the monopile and the tripod. [47]

Concerning the first type, it is about a basis that includes a steel pile. This component is installed approximately 20 m., deep inside the sea bed. Moreover, this construction makes the tower increase its length and more specifically below sea level. Additionally, we should point out that there is no need to make works in order to set the sea under- ground ready for the installation. However, there are 2 issues that are essential. Firstly, we need to be equipped with powerful packing tools and secondly, it is not considered as appropriate for regions extremely rocky at the bottom of the sea. [47]

Concerning the second type, it takes advantage of experience gained from steel jackets of limited weight and cost beneficial, applied for marginal fields at sea level. They are included 3 piles that can reach to 20 m. at sea underground, taking into consideration the ground situation and the ice level. The particular construction type is considered to be appropriate for high water underground levels, below the 7m., and can manage the issue of erosion. On the other hand, as mentioned at the previous type, similarly here, there is difficulty in suitability with increased rocky regions at the sea underground level. [47]

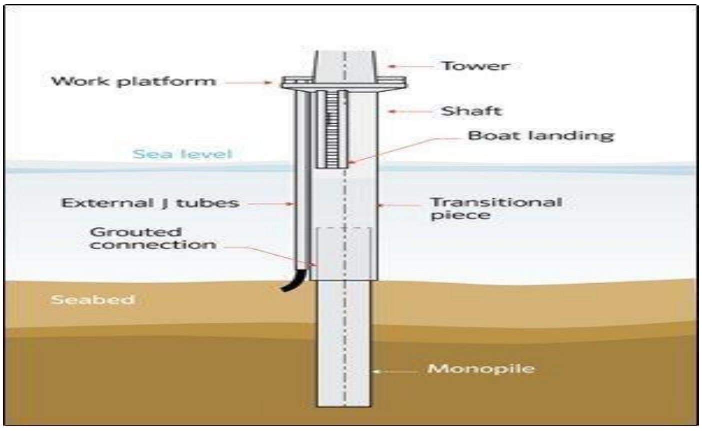

Figure 71 Monopile Foundation[78]

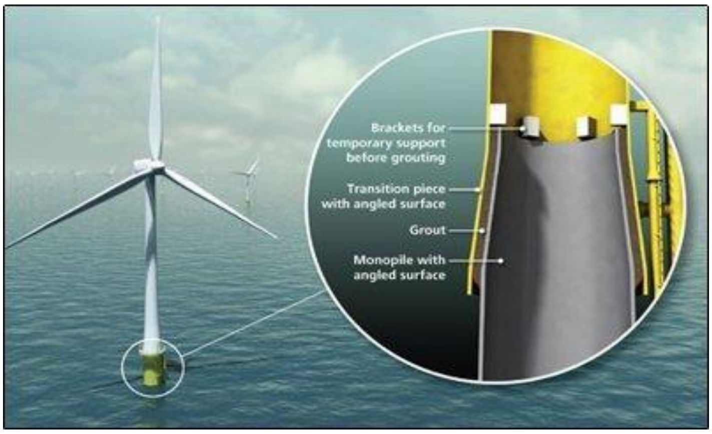

Figure 72 Connection between the transition piece and the monopile[79]

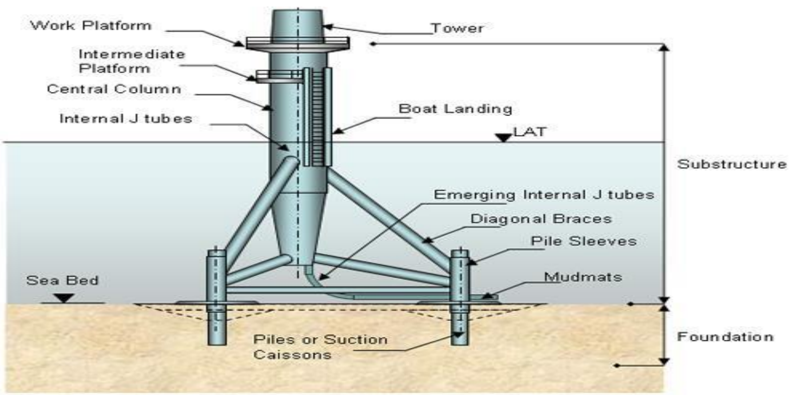

Figure 73 Tripod Structure[80]

[78] Monopiles Support Structures. [Online]. 4COffshore. Published date: Jun 5, 2013

[79] Monopiles Support Structures. [Online]. 4COffshore. Published date: Jun 5, 2013

3.2.5 Electrical Connection data for onshore WTs

In this part, we will discuss about the conditions of the WTs' connection. At general conditions, except for some exceptions, the most WTs are connected to the central grid of the location that the installation takes place, as the provide their power output to the main grid of the greater area. The general meteorological pattern states that the electricity generation is of higher scale at the time period of day, due to the increased winds that appear, compared to the nocturnal period, when they are limited. Additionally, as it is presented below at the figure, the annual mean wind velocity does not remain constant at different years, but it does change, which by its turn lead to the variation in power output at different time periods. (see **Figure 74**) [21]

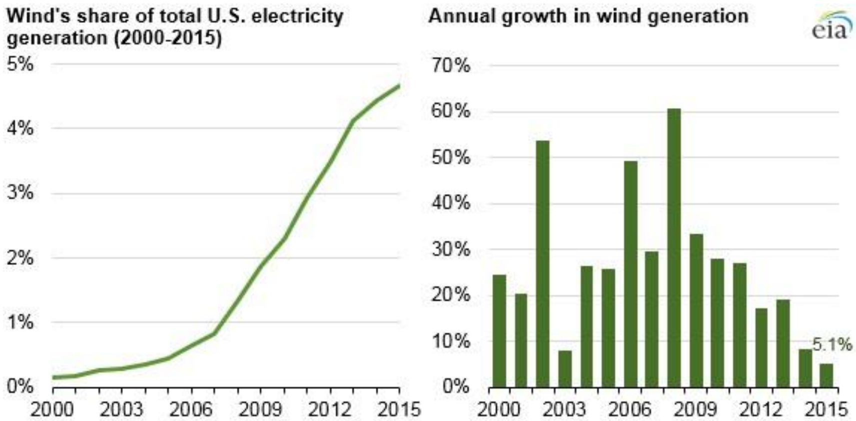

Figure 74 U.S. wind generation grew by 5.1% in 2015, the smallest annual increase since at least 1999[81]

The connection to the grid is activated, depending on the wind velocity. More specifically, it is on, since the wind velocity is increased enough, but it is disconnected at the case of limited wind velocity. It is essential to point out that after the initiation of function of rotor and generator at the appropriate velocity value, the choice of the correct time, to make the connection, plays crucial role in the power output. Additionally, it is

[80] Offshore Support Structures [Online] Garrad Hassan and Partners Ltd – Wind energy The Facts. Retrieved date: Nov 2, 2018

[81] Wind generation growth slowed in 2015 as wind speeds declined in key regions. [Online] Allen McFarland, Cara Marcy – EIA. Published date: Apr 21, 2016

also extremely essential to have the knowledge for the suitable switch ,at the connection time of the wind engine to the central grid. Otherwise, the consequences can be serious for the WT system, as it can be lead to voltage limitation, while the machine will make an attempt to generate power at the highest possible value, in order to compensate for this incident. A second potential issue, that may turn up, is the possibility of additional corruption at the gearbox, at the case that the cut-in performed, as if at a moment the turbine was hit at some point. For the solution of this potential bad situation, the soft starting is utilized at the current technology. By soft starting, we mean the procedure where the WTs, with the use of a type of semi-conductors, named as thyristors, are altering their connection status at gradual level. However, during thyristors' function, there is a percentage of energy of about 2% that is not utilized. In order to keep at the lowest level the unutilized energy part, the WTs include a bypass switch, whose role is to initiate its function at the time that the WT has begun its normal operation. (see **Figure 75**) [21]

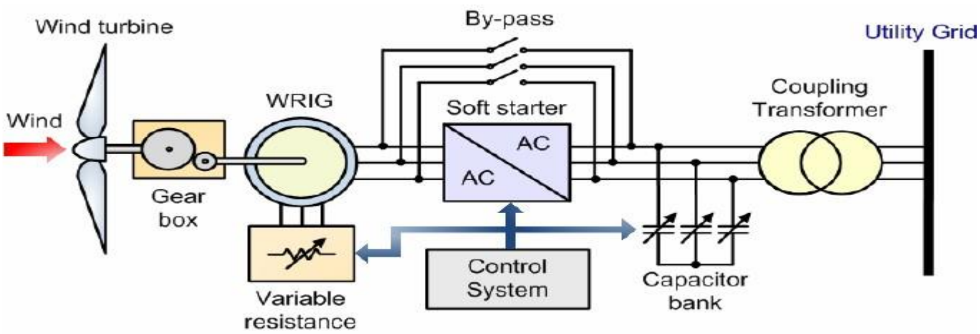

Figure 75 Wind turbine concept: Partial variable speed wind turbine directly connected to the electric grid via a wound rotor induction generator with variable rotor resistance[82]

At the case of low level power grid, there is a chance of voltage limitation (brownout). In order to deal with a potential error of the system, it is considered as essential to empower the grid, for the current transfer of a WT. Another potential consequence of this situation is the flicker phenomenon, which can be dealt with the reinforced WT design with powerful electronic parts. At this point, we should mention the situation of 'islanding', which is a condition when a part of the grid loses its connection from the central

[82] Molina, M. G., & Mercado, P. E. (2011). Modelling and control design of pitch-controlled variable

speed wind turbines. In Wind turbines. InTech.

grid, because of various accidents at the circuit .Before and after the end of the phase of this situation, it is extremely important how the transition will be done. In order to achieve normal transition, the wt is equipped with an electronic controller, which will detect for the physical behavior of the current of the grid. Therefore, at the condition of reaching out of the established limits, the wt will be simultaneously set out of the grid and at next step, its function will be terminated. [22]

3.2.6 Electrical Data for offshore WTs

Let’s state the most important issues that need to be taking into our attention, during the installation of wind farm at sea. First of all, we have the topic of cabling. It is modern technology that connects the wt at sea with the central grid, underground of the sea bed. In order to prevent the damage of the cables, because of various human activities at sea, we should be ensured that are installed well below the sea bed. Secondly, there is the issue of reactive power. In more details, the type of cables used will dispose of an in- creased capacity of electricity. This advantage can be used to provide the parks with re- active power. For the maximum result , it is recommended to include some short of var- iation in the power , depending on the function of the particular grid. At the circum- stances of increased distance during the connection, an interesting solution could be to make use of high voltage current connections, known as HVDC. Furthermore, another important topic is the remote inspection. Radio links and fibre-optics cables are some types of remote inspection technology that is currently used. [22]

Regarding the seize of the wt, the investment at inspection must be relative, e.g. at wts of increased size, they should be equipped with sensors to cover their entire mechanism. This is apparently important to be done, for achieving results with the highest possible maintenance .Finally ,we should mention that at the case of extreme meteorological conditions , we should have arranged the field around the wt farm , in order to be made certain that it can perform.

4. Wind Turbine technology developments

4.1 Worldwide level

This chapter is devoted at the technological progress and innovation of the WTs and WFs in a worldwide level. Some of the ideas are already established, whereas others are still at the research level.

4.1.1 Developments on WT digital technology

Figure 76 Software WINDGEMINI[83]

After the recent development on the field, the creation of a new software that is called WINDGEMINI appeared, and it operates via Internet and is made up by DNV GL. (see **Figure 76**) [23] It can be proved to be an essential support for all the people related and are in charge of wind energy projects. What it does is that it constantly informs about

[83] Wind Gemini [Online] Sun wind Energy. Retrieved date: Nov 2, 2018

specific details concerning the circumstances of any wt' s operation. Regarding its synchronization, it is accurate of high scale, as it collects any information for the whole wind energy installation. At next step, it takes advantage of all information collected, in order to achieve the maximizing of the output of its functions for the final goal of evolving, at the highest possible rate, the reduction of the time, when its function is paused. There is not any issue concerning its suitability according to the wt type, as it can be operative with any of them.

Nanocides and polyethene wind blades

Figure 77 First carbon nanotube reinforced polyurethane wind blades[84]

The absolute goal of the wind energy domain is the highest possible energy output by the generation of wind power that is captured inside the wt. The realization of this target contributes to the development of the wind energy sector, which is moreover evolved to its maximum capability, by the creation of flexible equipment that will be suitable at enlarging the dimensions of the rotors. In order to optimize the energy output, a swept area with dimensions of higher scale is necessary. At the formation of the required area, we should add the prerequisite situation of strengthening the rotors, by the utilization of

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[84] Marcio R. Loos, Cristimari R. O. Loos, Donald L. Feke, Ica Manas-Zloczower. *World's First Carbon Nanotube Reinforced Polyurethane Wind Blades.* OH : Molded Fiber Glass Company Ashtabula, Retrieved in 2018

nanotube composites, which will lead to increasing the blades' size. These composites are made of carbon reinforced polyurethane. This innovative concept will contribute to the development of the wind energy, by evolving some of its most essential parameters. (see **Figure 77**) [18]

Floating technology

In this section, we are going to discuss about the most interesting and most dominant construction on the offshore domain of wind technology, the floating constructions. These particular and remarkable creations are very beneficial and way more effective than the constructions with stable basis. They can be loaded on a depth, of a much high- er scale than the conventional WTs used to be installed on. There are 4 different and interesting constructions, that are in R&D actions and at the stage of current operation or being inserted into the market, and are going to be analyzed further. (see **Figure 78**)
[24]

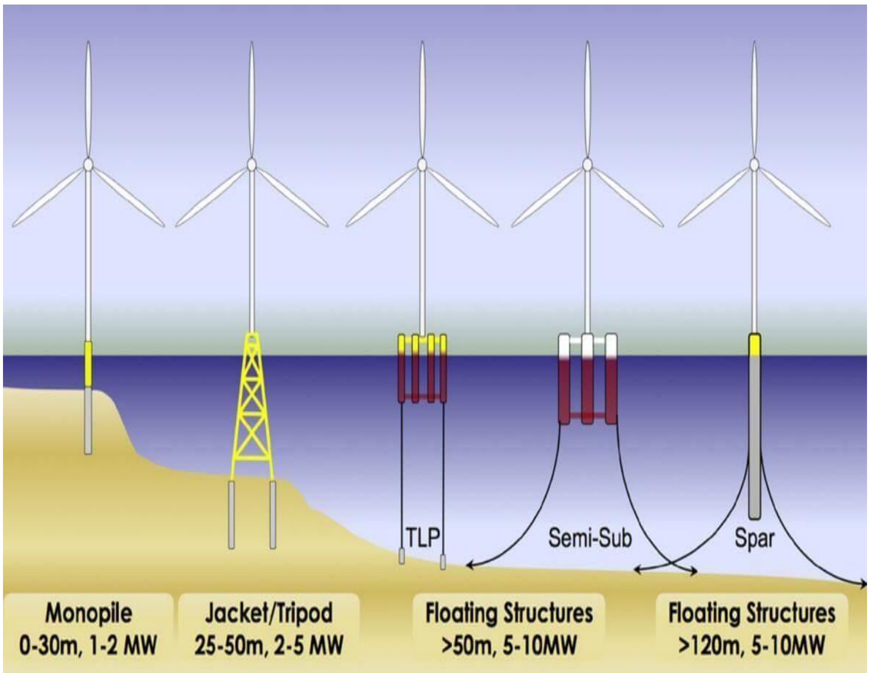

Figure 78 Floating and Conventional Offshore Structures[85]

[85] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

The floating foundations, that will be discussed, are the following:

a. Statoil’s Hywind Scotland (currently performing)

b. WindFloat

c. VolturnUS

d. TetraSpar

➢ Statoil’s Hywind Scotland (see **Figure 79**)

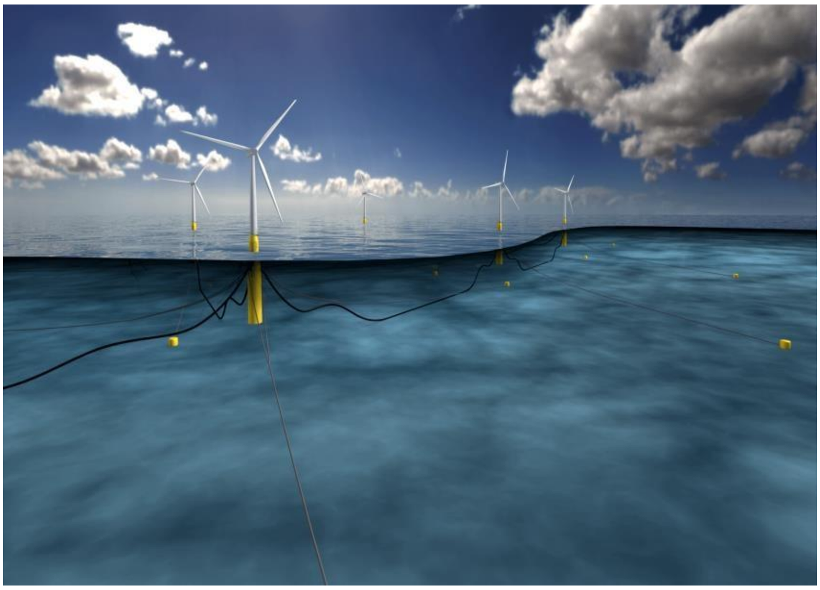

Figure 79 Statoil’s Hywind Scotland WF[86]

This is the first wf, that could operate and stay on the top of the sea’ s surface, was created by Statoil company, and its construction is based on a spar buoy method.

[86] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

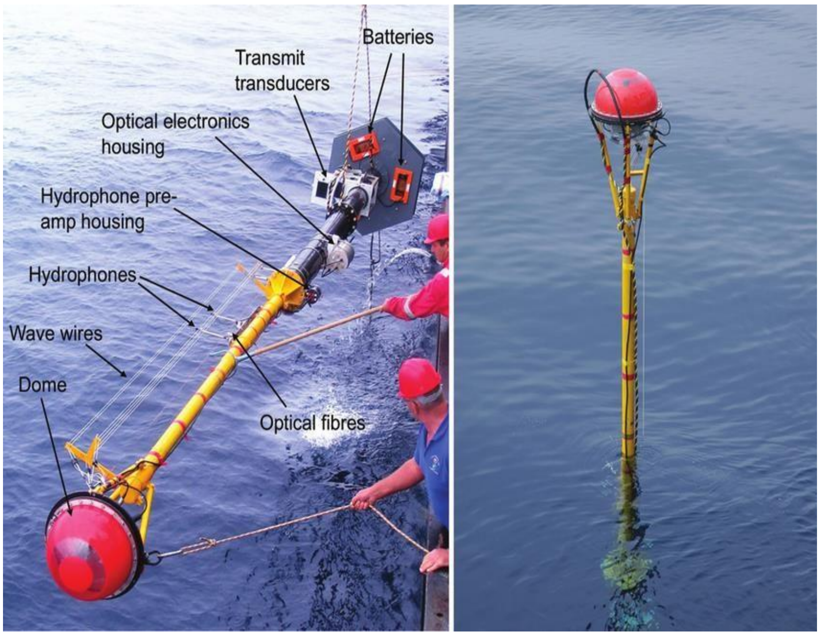

Figure 80 *(left)* Photographs of the spar buoy during deployment with key features labeled. *(right)* Floating free[87]

This construction is being utilized, and it is in high demand for mass production for generation of high scale. In order to respond, in success, to this requirement, there should be done some developments for the increase of efficiency . Additionally, with the construction of the prototype offshore wf of Scotland, the success of the project is showing some great results, in its use in the basis of various wts. The specific project was placed in depth, that ranges between 90 and 120 m, and includes 6- MW conventional wts, that are placed on 5 platforms. Another unique feature is the combination of the exploitation of various forces of nature, such as the waves, the winds, and other powers that derive from wake effects. Regarding its technical details, the construction has a mean velocity of 10 m/s and the length of the cable is 13 km, and is part of this foundation, and connects sea with the land's electrical station. Many further develop- ments are occurring, in order to develop the current concept in much larger scale, in an effort to combine the conditions that are involved in the targeted part of sea and the evo-
lution in practical dimensions of the wts that are used in the Statoil's Hywind prototype.

[87] Brooks, I. M., Yelland, M. J., Upstill-Goddard, R. C., Nightingale, P. D., Archer, S., d'Asaro, E., ... & Brooks, B. J. (2009). UK-Solas Field Measurements of Air-Sea Exchange Instrumentation. Bulletin-American Meteorological Society, 90(5), 9-16.

➢ *WindFloat* (see **Figure 81** and **Figure 82**)

Figure 81 The WindFloat rests at dockside during its recent decommissioning in Portugal. It was deployed in 43 m of water and came online in 2011[88]

Figure 82 The WindFloat during its sea trials was anchored off the coast of Portugal[89]

[88] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

[89] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

Regarding this innovation, that is called WindFloat, it is firstly created by the Principle Power company, has been in operation since 2012, in Portugal, and had successful results, as it could generate 18 GWh, deriving from a Vestas V80, 2 MW wt. Concerning its operation, we have the following. It is a construction that has its one half part above the sea surface and the other one below it. The equipment that is holding the construction at the spot is a drag-embedment anchor. This particular machine choses the appropriate depth in order to complete the anchoring, but not at the bottom of the sea. It had shown some essential features, as it could resist to the extreme weather conditions that occurred in the area. Additionally, its installation can be based on drag anchors, in order to become independent of the pilings, moving away from the conventional way of this process. [24]

The concept had passed the first phase and has proceeded in the second one, that will be completed by 2019 and 2020, when we will have, relatively, the creation of 25 MW construction in Portugal and a 24 MW in France. Moreover, the reduction in cost has been achieved and it is ready for absorption by the market, due the decrease in the construction expenses of the steel hull. The thumb rule, concerning this project, in order to achieve a massive production in generation of high energy, the increase in the wt's size will lead to a higher efficiency. There are some improvements that have happened so far, such as the reduction of mooring system 's size, and there are definitely some other ones that are in progress. [24]

➢ *VolturnUS* (see **Figure 83** and **Figure 84**)

Figure 83 Team Dagher's proof of concept mounted a 20-kW turbine on a floating concrete platform. The initial project was a 1:8 scale of a 6 MW floating turbine launched in the Gulf of Maine in 2013. The next project will be a modest farm of two 6-MW floating turbines anchored about 14 miles off the coast of Maine near Monhegan Island, for which the DOE provided a $39.9 Million grant.[90]

This is also a construction that follows the same standing principle as the WindFloat. It has better design than a typical steel hull design, which can give to it the privilege of exploitation the winds of velocity, that equals to 45 mph. Additionally, due to its ability to handle the transfer of additional water mass, the particular system's wt can be avoid influence by the waves' behavior. Moreover, the effects, that can be caused by the influence of pitch motion and nacelle acceleration, can be much more controlled and get limitations of high level. The latest application of this concept will have finished by 2019, will include two 6 MW full scale hulls and will be located some miles away south of the Monhegan Island, in Maine. [24]

[90] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

Parameter	VolturnUS 1:8	VolturnUS Full-Scale
Draft	2.9 m	20m
Hub Height	12.2 m	100m
Rotor Diameter	9.6 m	152m
Rated Power	20 kW	6MW
Peak Thrust Load	1.37kN	700kN
Hull Material	Concrete	Concrete
Tower Material	Composite	Composite
Water Depth	15-27m	100m
Number of Mooring Lines	3 x catenary chain	3 x catenary chain
Anchors	Drag Anchor	Drag Anchor

Figure 84 The VolturnUS design from the University of Maine uses a floating concrete hull with the turbine on a composite tower. The inset table provides more details on the next phase. More immediate plans are to reach financial close next year, start construction 2018, and be in the water in 2019.[91]

➢ *TetraSpar* (see **Figure 85** and **Figure 86**)

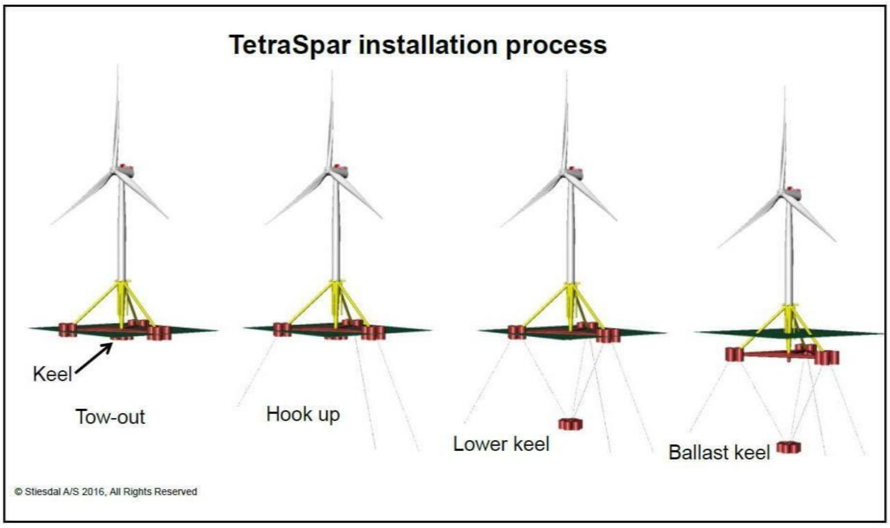

Figure 85 TetraSpar's steps of establishment[92]

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[91] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

[92] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

The 4th innovative construction is created by the combined thoughts that are done in order to make an ideal creation, that will eliminate all misfits by the total floating tech- nology, and will assemble all benefits. There has been a suggestion for a new design, that is called tension leg platform (TLP) . It is light-weighted ,it can also produce wave loads of medium level and limited dynamics. However, there are some issues, that need to be dealt with, such as the complexed and very costly adjustments, concerning the tether, and the constraints of water depth. Thus, a initiative for a discussion has been made, which suggested the exploitation of the benefits of the previous innovation, in the domain of floating technology. [24]

Therefore, 4 features are combined:

- the semi-sub as it is towed,
- the TLP for moderate water depth,
- the Spar for deep water, and
- the fixed-bottom, when there is insufficient water to make a floater possible

Furthermore, another problem that has to be solved is the non pre-calculated oversizing of the floating technology , that makes it unsuitable for a production of high scale. Developments are done in order to reduce the costs of total construction and its operation, which are tested on land and are about to get tested at sea. [24]

Figure 86 TetraSpar foundation[93]

[93] Foundations that float [Online] Paul Dvorak – Wind power engineering. Published date: Mar 13, 2017

The "Wind Tree" innovation

Figure 87 The wind tree[94]

In this section, we will discuss about an intriguing project. It is about the creation of an artificial tree, which is called 'wind tree' (in French approach Tree Vent), as its principal function is the collection of wind energy, that is finally converted to electricity. (see **Figure 87**) This is achieved by the innovative operation of its artificial leaves ,that will work as wind collectors. Under this intelligent concept, the wind energy industry will be able to resolve an issue of high importance. More specifically, the thumb rule of the wind energy operation is the necessity for increasing the final energy output, that has as a prerequisite condition the existence of winds of high scale, at regions that keep the specific standards. The additional matters that the wind industry has to deal with are the height of the building, the spacy area and the increased necessity for service, compared to the solar energy domain. These are the main factors why the wind industry has as its main target to solve the storage of wind energy in limited level. [25]

Here comes the 'New Wind', which is a company located in France, that proceeded to the concept of 'wind tree'. This artificial tree contains 'plastic leaves' (Aeroleaves), which have curves upon them and at the top of each one, there are small blades, that operate and are in charge of wind harvesting. They are made of plastic, in order to ensure

[94] Artificial Wind Tree Uses Micro Turbine Leaves To Generate Electricity. [Online] Good Home Design. Retrieved date: Nov 2, 2018

protection against conditions, such as humidity, that could set the whole construction in jeopardy. This new project takes the wind energy harvesting to the next level, as it is not necessary to achieve wind velocity of high scale, since it was used to be the case as a general rule for a significant energy output. In more details, the specific concept takes advantage of lower than 5 mph of wind's velocity and the dimensions are the following:

- height of 9.144 m ,
- length of 7.0104 m,
- weight of 2.7 T

Moreover, it included the total sum of 54 turbines included inside the artificial leaves. The final energy output of this project is the generation of 5.4 kW of electricity and at annual basis the total amount of 2400 kW. [25]

This was the definitive 'hit' in the market, which has risen the interest of a considerable amount of companies which had led them to begin investing on this intriguing innovation . There is more to it, concerning their unique function. More specifically, the wiring of all wts connected is done in an aligned formation. This particular pattern has been chosen, in order to establish a stable arrangement regardless the conditions surrounding the construction. In more details, the consequences, caused by the malfunction of any wt in the formation, that can lead to the disorientation of the circuit and its limited energy generation, can be prevented. However, there are some issues that remain to be resolved, such as the weight that is very elevated and the necessity for a big space. It was compared to the solar energy domain, where we had the following results. For the generation of the same amount of energy , the cost is considerably lower, but the required space for the installation is another issue. Particularly, it is considered to be a matter of high essence, especially for houses , with lack of access to direct solar radiation. [25]

At this point , we have the intervention by the wind tree concept, where there is a high flexibility at finding solutions at various dimensional issues. In addition to that, there have been discussions over the space matter, where the supply of separate parts of the 'wind tree' to the market is considered as a precise solution to the essence of the matter. Additionally, it has as perspective to reach individuals apart from industries and at the same time reducing the cost that is over the expected standards.

Tesla involvement

Figure 88 “Revolutionary Wind Farm” Project[95]

In this section, we will discuss about the cooperation between two big companies and its outcome in the wind offshore domain. Tesla and Deepwater Wind have reached to an agreement in order to make history and proceed to the breakthrough that the wind industry needs, in order to boost even further the evolution of wind energy and achieve a greater deviation of industry from the conventional fossil fuels , and finally the radical improvement of the current state of earth’s environment. (see **Figure 88**) [54]

In more details, this project will be a conjunction of an offshore wf and a big storage of electricity, in Tesla’s batteries. It will be called ‘Revolution Wind Farm’, which will have as energy output 144 MW of wind power, and will have the capability to supply electricity to 80000 residences. The whole concept’s application is based on the principal idea of altering the conventional utilization of the Tesla batteries, that was done for solar radiation storage and make them useable for wind. This radical idea could boost the level of disposability of wind power, and make the wind energy available at the time period of the day , in order to cover the needs produced by the peak in demand of electricity. [54]

[95] Wind Farm [Online] Media proxy. Retrieved date: Nov 2, 2018

The O-wind turbine

Figure 89 The cardboard prototype of the WT in Morecambe Bay, UK[96]

This particular concept has been produced by 2 post-graduate students of the Lancashire University. Regarding its operation, it benefits from winds of all directions, without changing manually each time the construction' s direction , overcoming by this way the constraint that exists in the wind energy, where its harvesting can be done one-way. Additionally, it has the shape of a sphere, and rotating itself around an axis. This dimensional benefit proves to be an essential tool for dealing with the energy generation in limited level and removing all possible limits at the issue of space. This innovation is studied for further perspectives, for an individual use at any residence, where this O-wt can be mounted on a balcony and take advantage of winds of high scale, that can be reached at this level. (see **Figure 89**) [52]

[96] O-Wind Turbine captures energy even in the middle of dense cities. [Online] Rima Sabina Aouf – Dezeen. Published date: Sep 10, 2018

EnBW involvement

Figure 90 Kite-wind project[97]

EnBW has joined a group of companies with their aim to be the research of Skypower 100 system. This company has started leading the researches on automated kite wt system, which will have initiated till 2020. As time passes by, the researches at the evolution of the system above the scale of 1MW, by leading to the increase of capacity factor and their adaptation at the offshore domain will increase radically. There is a project in progress, will generate 500 kW of wind energy and will be located at the southwestern part of Scotland. Based on a project of 40 kW, there will be research and development for the hybrid prototype of 500 kW. (see **Figure 90**) [46]

Regarding their properties, they have the capability to respond to winds of high scale, at the top level of the atmosphere , and proceed to their collection. Thus, this could widen the horizon of wind energy evolution and extend it to heights that even the most optimistic person could not have foreseen in the past. This occurs as their speed is two times the speed of the winds of the zero height and eight times their density compared to the ground type. Proceeding furthermore to their operation, we have the following information. The system includes a generator, and 2 kites that are tied to the spools of the generator and each of them can reach up to 300 m and rotate at 100 mph. At first, the

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[97] Kite wind farms take off in UK as future of energy. [Online]. Kitty Knowles – The memo. Published date: May 30, 2017

1st kite moves away from the ground and elevating to the sky, which leads to the generator's rotation and consequently to the generation of electricity. Moreover, at the time that the rope used reaches its maximum extension, the kite will be placed at the top of the generator and will be pulled back, by the least possible force. At next step, we have the repeating of the procedure by the beginning. Finally, a secondary kit, that is placed on the other spool of the generator, is placed there in order to assure the stability of the procedure, by making an opposite route. (see **Figure 91**) [46]

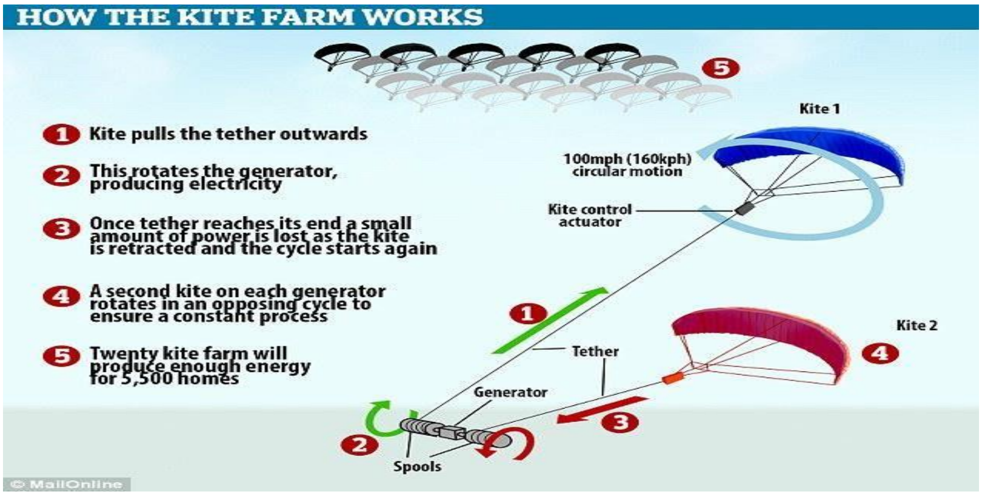

Figure 91 Project's steps of operation[98]

The Kite Power Systems is the company, that will lead in developing the 1st project in England that is based on this concept, in order to turn the English kit power plant operational. This project will make use of 20 kits, that will operate in couples and have as a result the generation of electricity, at the speed of 100 mph. [57]

[98] Forget wind turbines: Giant KITES flying 300 metres in the air will power more than 5,000 British homes by 2020 in a world first. [Online] Harry Pettit – Mail Online. Published date: May 26, 2017

GE involvement

Figure 92 Haliade-X[99]

There are many companies that are involved in the wind energy domain and try to include themselves in the innovative developments that occur in the offshore field, where the interest is growing incredibly and proportionally by time. One of the major leaders, that occupy themselves and lead the way of the latest developments in offshore wind energy, is the General Electric. Thus, one of the great innovations completed by GE, is the creation of the largest wt Haliade-X in England, at sea level. (see **Figure 92**) This new wt is constituted by a generator of 12 MW and achieving a capacity factor of 63%, which can have as result 1,45 times the energy that is generated by the conventional wts that are in the current industry. Additionally, because of the increased size of the blades and the rotor, it will have the ability to resist to extreme meteorological conditions, alongside with some essential features, such as the increase of power output and the re-

[99] HALIADE-X OFFSHORE WIND TURBINE PLATFORM. [Online] GE Renewable Energy. Retrieved date: Nov 2, 2018

duction of the maintenance service. At this point, we should note down the capability to generate electricity even at wind speeds of limited magnitude. The annual power generation is estimated to be 67 GWh, which can make it possible to achieve electricity supply for about 1 million residences! In combination to this features, there is an online tool that is provided by GE, which is named as GE's Predix platform, that can be an essential aid to the people that are supplied with the electricity generated by Haliade-X. This tool will make the information supply easy and approachable by anyone. Another amazing part of this initiative is the fact that the R&D activities will continue evolving, which is shown from the investment of large amounts of cash by the GE, in combination with the one that will be accomplished by Innovate U.K. and the European Regional Development Fund. [27]

MHI Vestas involvement

Figure 93 MHI Vestas - First 10MW wind turbine, in history[100]

Additionally to the GE's Heliade-X construction, we have recently the Vestas company has made another breakthrough in the offshore domain, by the construction of a wt, V164 –10 MW. The recent upgrades concern the reinforcement of its previous version, more specifically have to do with a more powerful gearbox, and an alteration in the de-

[100] MHI Vestas Launches the First 10 MW Wind Turbine in History. [Online]. MHI Vestas Offshore Wind. Published date: Sep 25, 2018

sign, in order to increase the scale of the air flow and the cooling inside the converter. This innovative model of wt will be available at the beginning of 2021. (see **Figure 93**) [28]

Concerning its technical details, we have the following:

- ➢ The rotor diameter of 164 m
- ➢ The he length of wt's blades is 80 m
- ➢ The swept area will be 21,124 m², larger than the London Eye,
- ➢ The height from base to tip will come in at about 187 m

FloDesign involvement

Figure 94 FloDesign's project[101]

Another company that is occupied with wind energy technology is the FloDesign. (see **Figure 94** and **Figure 95**) Regarding its operation, the air circulates through the wt, inside the stator, which is constituted of blades with no motion, and at next step send the wind onto the rotor. Moreover, it is rotated and leads the air through and out of it, with a

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[101] FloDesign Wind Turbine. There's change in the wind. [Online] Watt Now. Published date: Mar 7, 2012

velocity much more limited than the one, at the beginning of the first contact. Thus, what happens at the final stage, is the creation of a vortex, that is made by the union of these different wind types at the front and at the back of the wt.

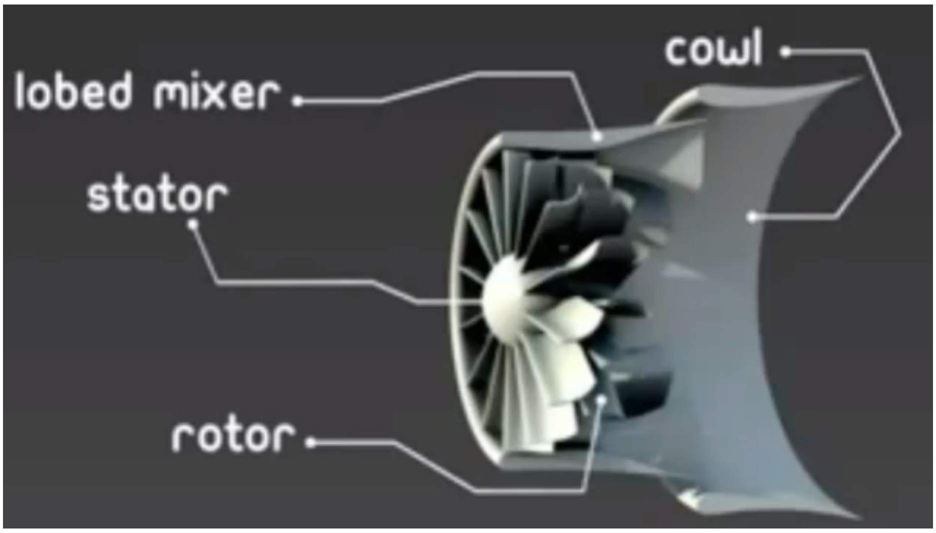

Figure 95 FloDesign's project' components[102]

The result of this final stage is the release of wind that is reinforced and in higher density than its initial state. The potential electricity generation, based on this innovation, is of higher scale than the one that the conventional wt has the ability to achieve. Additionally to what was previously discussed, we are talking about wts that are at a quite particular size, which makes them seem like a compressed edition of the current wts' shape . This could be seen as a benefit of high value, because it can solve the issue of the construction and the transfer to the installation site. Furthermore, it can make the suitable placement of each wts in a small distance between them with the goal to lead to the evolution of this type of wts to a variety of areas. [29]

[102] FloDesign Wind Turbine. There's change in the wind. [Online] Watt Now. Published date: Mar 7, 2012

The Maglev WT concept

The issue of efficiency is of major importance for the wind power industry. In order to prevent its decrease, there are efforts, in progress, for dealing with the existing friction at the inner of the wt. The solution to this issue of great importance is considered to be the levitation of wt's blades, which could make the friction disappear permanently.

The type of the wts, that are considered suitable for the realization of this concept, is the maglev wts. Thus, by them in the project, the magnetic levitation can be also achieved in the wind energy field, besides its application into transportation by train. The result of its impact on the final outcome of the wind harvesting will be the increase of the wt's efficiency by 20%. Additionally, they are the type of engines that can perform and take advantage of winds of limited and increased scale (1.5 m/s , > 40 m/s) and prevent their exposure to wear-and-tear, which is one of the main issues that wind industry tries constantly to deal with. Furthermore, they can perform with zero noise, they are offering protection for the nature and are also beneficial considering their cost. (see **Figure 96**) [30]

Figure 96 Maglev WT[103]

[103] THE MAGLEV: The Super-powered Magnetic Wind Turbine. [Online]. Mahesh Basantani – Inhabitat. Published date: Nov 26, 2007.

At this point, we shall say a few words about their operation. Initially, the vertical blades, inside a maglev wt, are ceased from their performance at the top of the engine, which lead to the prevention of the addition of ball bearings. Moreover, they include one extraordinary feature, which is the utilization of 'full-permanent', that can be incredibly beneficial for the whole mechanism, as it turns it independent of electricity. Furthermore, these particular magnets are also of neodymium type, which also adds the privilege of eliminating any energy reduction, caused by the friction phenomenon, it also adds the increase of the length of its time of life and finally the reduction of the service expenses.

The bladeless WT

Figure 97 Windstalks[104]

In this section, we are going to discuss something that is not seen very often, the combination of innovative breakthrough and artistic design. By this new concept, we can see the wind industry is approaching a new way of dealing with the visual matter, and ceasing to be the center of criticism. This occurs because of its large and noisy engines, that made people increase their skepticism about living or coming through any wind farms.

[104] Fields of Windstalks Harvest Kinetic Energy From the Wind [Online] Ariel Schwartz – Inhabitat. Published date: Aug 18, 2010.

But now, we can be optimistic that the people's opinion is definitely about to come around the matter, and we can see already the results in the city of Abu Dhabi.

In more details, the WTs named as Windstalks, which are of Atelier DNA type. Each one of them is made of carbon fiber-reinforced resin poles, include piezoelectric discs and electrodes that can produce electricity. The height can reach 55 m. Additionally, this design can give the benefit of taking advantage of the most space that is available and include inside it bigger amount of wts of this type. Furthermore, it can give the privilege of nature's protection and become a part of an area that is inhabited, as there won't be any blades. An issue though that is yet to be resolved is the limited electricity generation and its need for quite space in order to achieve the required amount of pow- er. (see **Figure 97**) [31]

Exploitation of sail potential

Another traditional method that can facilitate the process of wind energy harvesting is the utilization of sail. This old but tested method has been taken into consideration and into practice by the Saphon Energy company. In further details, the plan of Saphon is the application of the sail's properties in the construction of a wt that is equipped with sail. This particular type of wt is named as Saphonian. (see **Figure 98** and **Figure 99**) Regarding its properties, there are no blades on it, which are replaced by a sail, that has the potential to create electricity by the wind's collection, with efficiency that equals to two times the efficiency of the conventional type. The system that is used to make the wind collection is the 'Zero-Blade Technology', whose operation has to do with directing the wind inside and outside of the wt, till its conversion to the mechanical energy, via pistons. At next stage of this process, we have the generation of hydraulic pressure, that is then either converted to electrical energy, with the aid of a motor and a generator, or collected in a hydraulic accumulator. This unique ability for storage gives the benefit of omitting the placement of any blades upon the wt. Moreover, there are some radical evolution steps in the issue of efficiency, as there are indications that show that the standard Betz limit is getting overcome more and more, as the technological evolutions are increasing by time. Not to mention, the decreased cost of the construction in the wind industry of this innovation, that is close to 50% lower than the creation of any typical wt. [32]

Figure 98 Saphonian WT[105]

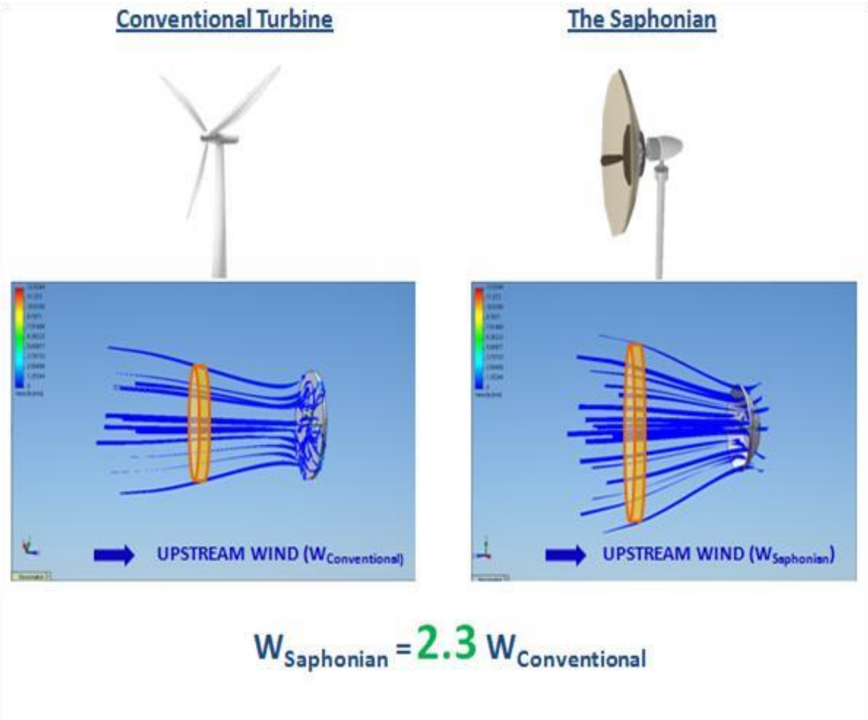

Figure 99 Saphonian WT compared to a conventional wt, regarding the upstream wind's, by CFD coding[106]

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105 Saphonian bladeless turbine boasts impressive efficiency, low cost. [Online] New atlas. Retrieved date: Nov 2, 2018

106 The Saphonian – Illustration. [Online]. Saphon Energy. Retrieved date: Nov 2, 2018.

The Vertiwind design

Figure 100 VERTIWIND project[107]

As stated many times in previous parts of this dissertation, the evolution of the offshore domain in the wind power industry is considered to be done with rapid and huge steps, as the years pass by. The reason for this very rapid evolution in this domain, compared to the onshore, is the increased efficiency, which leads to the generation of electricity of higher scale than the typical production. However, there are some issues that withhold the evolution reaching its true potential. One of these problems is the necessity for the utilization of massive three-pronged steel legs in order to proceed to the anchoring of any wt. (see **Figure 100**) [33]

[107] Offshore floating vertical axis wind turbine. [Online] Polemer Mediterranee. Retrieved date: Nov 2, 2018

Figure 101 The massive three-pronged steel legs, required for the anchoring to the sea bed[108]

This step in order to be completed demands a quite respective amount of expenses, which can be very preventive for the constant development of the offshore field. There are various experimentations and developments that are in progress in order to deal with the reduction of the demanded expenses. A company that has been looking more and more at the center of this issue is the Technip. More specifically, what they have done is that their approach is focused on the part of gravity that creates too much skepticism. Thus, they restate the basis of the wts' creation in a level that is not possible to fail, a constant level. They have introduced the Vertiwind design. In more technical details, we have the following facts. We have lower masts and wts of limited size By this concept, the generator is relocated from its conventional location, which used to be at 60 m. of the ocean surface, and is placed at a much closer level, at 20 m. Additionally, we should notice the spinning is done over the vertical axis. Consequently, we observe the degra- dation of the center of gravity, which leads to the decrease of the depth and the com- plexity levels, at the process of establishing the wt. (see **Figure 101**)

[108] Offshore floating vertical axis wind turbine. [Online] Polemer Mediterranee. Retrieved date: Nov 2, 2018

At perfect conditions , this particular type of wts will be able to float and remain un- fixed. The goal of this concept is the expansion of the offshore domain to countries that have limited ocean depth, below the 35 m. [33]

Flying WT

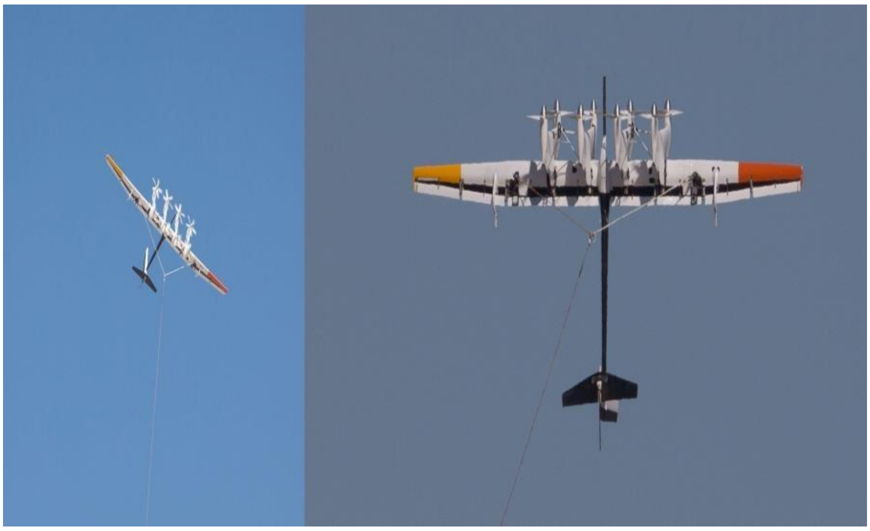

Figure 102 The Makani Airborne Wind Turbine (AWT)[109]

Another innovation that is pushing the wind industry evolution to higher levels than the years before, is the Makani Airborne WT. (see **Figure 102**). This particular model of wt has the feature of reaching for winds and harvesting them at approximately 30 m .It is beneficial concerning the cost and it also has the potential for quick evolution. This type of wt has the ability to have a widened range of reaching the 70% of the land area of the USA, as it was tested, which makes the application of the wind energy on the land particularly extremely beneficial. Additionally, it has the ability to be loaded on floating stage and it also has at its disposal the unique feature of having an approach of the scale of 3 TW of energy, that could be generated by the water of the sea's depths. This offers the wind industry to overcome the traditional constraints in the typical harvesting of wind energy at these levels. Below at the **Figure 103** we can see the comparison between a typical wt and the M600, which is a wt with generation of electricity at 600 kW.

[109] AIRBORNE Wind Turbine. [Online]. Makani Power. Retrieved date: Nov 2, 2018

The Makani company is developing at constant and rapid rate new and improved systems, expanding their capabilities and giving more and more perspectives for a brighter future in the wind industry.

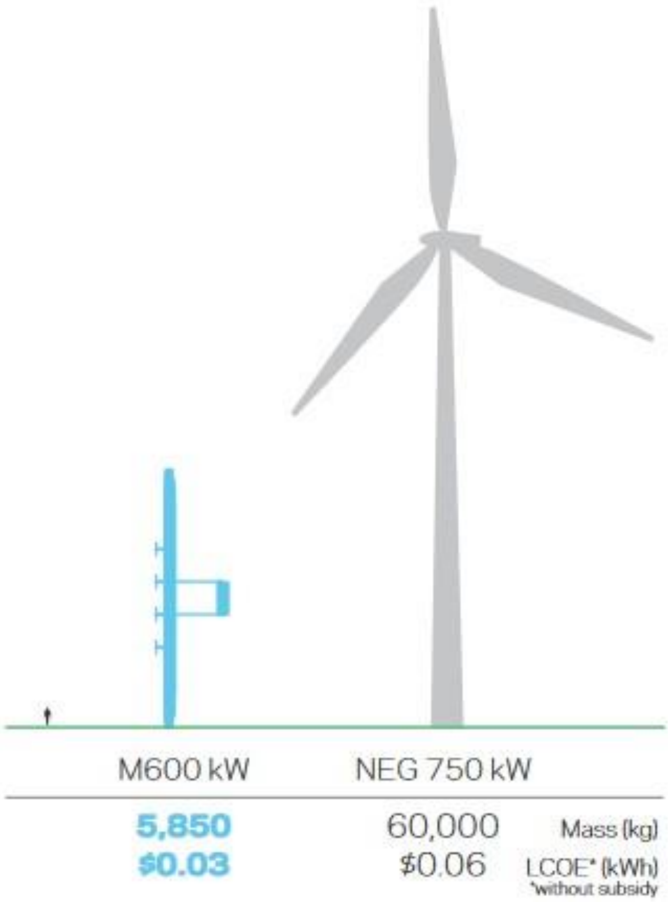

Figure 103 The Makani AWT, the model of M600kW compared to a conventional wt[110]

[110] AIRBORNE Wind Turbine. [Online]. Makani Power. Retrieved date: Nov 2, 2018

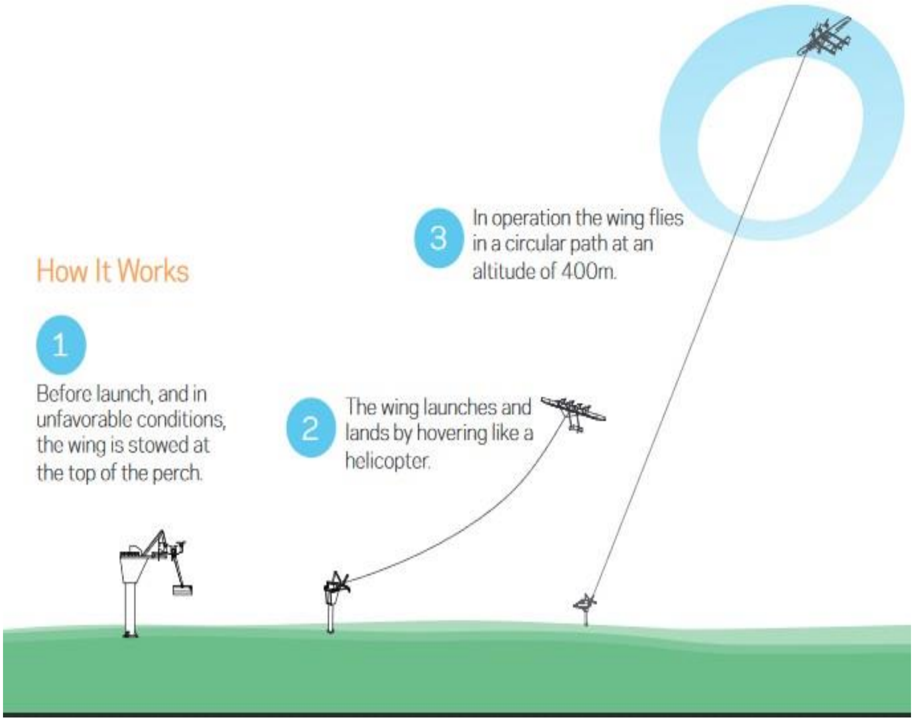

Figure 104 The operation of a Makani Airborne Wind Turbine[111]

Figure 105 Altaeros Airborne Wind Turbine [112]

[111] AIRBORNE Wind Turbine. [Online]. Makani Power. Retrieved date: Nov 2, 2018

[112] The Future of Wind Power: 9 Cool Innovations. [Online]. Derek Markham – Treehugger. Published date: Apr 4, 2012

As illustrated above at the **Figure 104** and **Figure 105**, at this point we are going to discuss concerning another innovation that behaves at quite similar way as the previous innovation, that was presented. The specific engine contains helium and has a shell that is made of plastic. The fact that has the ability to be provided with helium gives it the perspective of reaching high levels of atmosphere, and consequently approaching winds of larger scale than the typical wts and these winds have also a continuity in their intensity. Another essential advantage is that its installation time is done in a timetable that is quite small and the expenses of this process are way less than the conventional types, due to its ability to make wind collection. [34]

The Wind Harvester innovation

By this particular wt, another one effort is done in order to leave of the conventional way of wt's construction. More specifically, its formation is done in a flat level, not in a vertical one, as it was constructed since now. Moreover, it has the ability to generate power from the harvesting of all types of levels of wind velocity, with any constraints lifted. It has at its disposal unique properties, such its flexibility in its construction magnitude, taking for granted its placement in an elevated level that is 1 m. above ground level. Additionally, due to its flexibility, as mentioned, the utilization of oversized equipment can be omitted. The installation of this project has been done in the Derbyshire Peak District. (see **Figure 106**) [35]

Figure 106 Wind Harvester[113]

[113] The Future of Wind Power: 9 Cool Innovations. [Online]. Derek Markham – Treehugger. Published date: Apr 4, 2012

The WT Lens concept

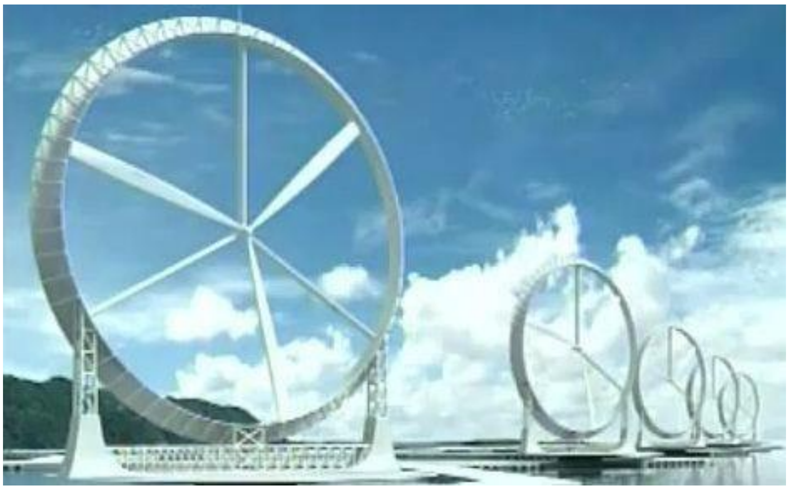

Figure 107 Wind Lens[114]

An interesting innovation that can write its way into making the wind industry to re-approach its current methods in the wt's construction is the Wind Lens. (see **Figure 107** and **Figure 108**). The Wind Lens project has very efficient results that can lead the wind industry to the monopoly of the alternative energy, in the battle against the harmful consequences of the conventional fossil fuels. The efficiency of this new type of wt can reach get to three times more than the efficiency's current state. Furthermore, the benefits regarding the costs reduction are quite considerable. Its operation is based on the placement of lenses at a cycle mode surrounding the wts. In more details, the performance is done, with the creation of a region that possesses pressure of limited scale, at the back of the wt. This particular region has the ability to absorb the wind by the use of the wt, which as result leads to wind velocity of higher scale. Based on the formula of the wind velocity's calculation, the lenses that are used can alter the fluid dynamics that surrounds the wt and lead to a higher power , compared to the typical wt. The evolution regarding its application has to do with the fact that after the first successful testing on land, at the onshore wind domain, it has proceeded to the next level, which is its expan-

[114] The Future of Wind Power: 9 Cool Innovations. [Online]. Derek Markham – Treehugger. Published date: Apr 4, 2012

sion at the offshore. In order to make this application, there have been some adjustments that lead to the construction of a hexagon floating stage, where many wts with lenses can be combined and generate incredible amounts of wind power. [36]

Figure 108 The hexagon floating stage of Wind Lens[115]

The Windspire

Figure 109 The Windspire[116]

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[115] The Future of Wind Power: 9 Cool Innovations. [Online]. Derek Markham – Treehugger. Published date: Apr 4, 2012

At this point we are going to present an additional innovative concept that has been passed through R&D process, in order to discover any positive impact on the wind in- dustry. This concept is called Windspire. (see **Figure 109**) The wts of this particular type has a height of 9.1 m, with vertical orientation and the ability of harvesting of the wind power with no constraints in direction. There have been some developments to the initial application of the concept. At the first stage, it had the ability to produce al- most non-existent noise, because of its orientation of its construction, and with an an- nual power generation of 2000 kWH , in wind with a mean velocity of 11 mph, giving essential aid at the peak time. However, the initial approach demanded concrete equip- ment that has negative impact on the transportation, since it demanded movement in place, and on the installation timetable. These facts raised the expenses, which made the specific wts unapproachable. Apparently, a new approach was ready to happen. The re- alization came to action by the inspiration, based on the aid of Ram Jack, which had as a result a new and powerful system , solving all the issues that were at first came up. This new application system has a helical pile that has a diameter of about 22 m, that made the concept very potential, as the wt could tolerate winds, with velocities of high scale,
and make a great reduction in the installation time. [37]

[116] Wind power coming to city’s waterfront. [Online] Edward D. Murphy – Press Herald. Published date: Apr 27, 2011

The Eddy turbine

Figure 110 The Eddy Turbine[117]

This type of wt is using a vertical axis of rotation. Their purpose of creation was to deal with the issues of the wind shifts and the turbulence, that are of high importance in the wind industry. Another issue that had to be dealt, despite the positive aspects of the vertical orientation, was the rapid corruption of the bearings. In order to battle against this issue, the design of a dual axis was added in the concept, adding stability in a much longer period time than previously. (see **Figure 110**)

Its placement can be done on the rooftops, which is also helped by their particularly small size. Carbon, fiber and glass are the dominant materials in the construction. At annuals standards, the power production can reach 945 kWh. Additionally, it can perform independently of the grid and it performs ideally at 12 m/s , which are also essential features. There are also other sizes at this specific wt type, the Eddy GT and the Eddy VisionAIR5, which generate wind energy at higher scale, producing 1750 kWh/yr and 6000 kWh/yr, respectively. The innovations by UGE company do not stop there. There is the hybrid model, The Sanya, that combines wind and solar energy with the aid of LED, and the most recent one, the Sanya Skypump, where we have the combination

[117] Gowanus Whole Foods Opens with Super-Green Parking Lot Powered by Urban Green Energy. [Online] Kevin Lee – Inhabitat. Published date: Dec 23, 2013.

of the first prototype and the GE's WattStation, in order to supply electricity for elec- tric cars. Below, at the **Figure 111** and **Figure 112** we can see the most recent devel-
opments of UGE, in wind energy. [38]

Figure 111 UGE Sanya SLS - Whole Foods, Brooklyn, NY[118]

[118] Gowanus Whole Foods Opens with Super-Green Parking Lot Powered by Urban Green Energy. [Online] Kevin Lee – Inhabitat. Published date: Dec 23, 2013.

Figure 112 Sanya Skypump in Spain[119]

The power storing island concept

Figure 113 Green Power Island[120]

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[119] Sanya Skypump: World's first wind-powered EV charging station debuts in Spain. [Online] Amir Iliaifar – Digital Trends. Published date: Aug 14, 2012.

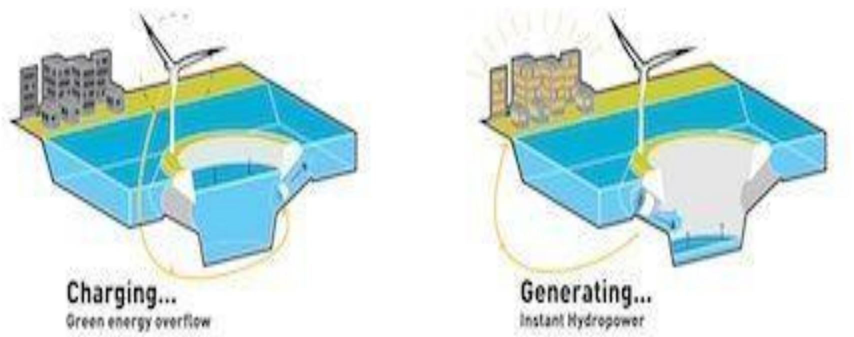

Figure 114 At charging stage and at generating stage[121]

Denmark is one of the leading countries that lead the evolution in the wind industry. Their intensions are to increase and improve at such a high scale the wind industry, in order to get independent of the conventional type of energy, and be completely based on the alternative energy. In order to achieve this target, the principal idea was to create a system, where at times of total lack of wind, the supply of electricity will remain intact . The idea, that was definitely out-of-the box, was the proposal, that suggested the creation of an artificial island, that was called the Green Power Island, that would be utilized for the storage of energy. (see **Figure 113**)

Regarding its operation, we observe the application of actions that are based on the pumped hydro concept, where we have the following processes that are taking place. At first, we have the use of pumped hydro system, where water and gravity are exploited, by the aid of vertically separated reservoirs. Additionally, at periods with limited demand for energy, we have the circulation of water through pumps , by the surplus of energy, deriving from the reservoir of the lower level to the higher one. Finally, as we are approaching the peak demands of energy, we have at the same time, the recirculation of water to the lower level, leading to the production of electrical energy. The radical ap-

[120] A Giant, Man-Made Island Could Act as a Battery for Wind Power. [Online] Brian Merchant – Treehugger. Published date: Jun 30, 2011

[121] A Giant, Man-Made Island Could Act as a Battery for Wind Power. [Online] Brian Merchant – Treehugger. Published date: Jun 30, 2011

proach of Paludan over this concept was impressive. The artificial island will be exploiting the seawater that is circulated, through pumps, inside of a bay. Depending on the level of demand, we will have the appropriate response by the system. More specifically, during demand of limited scale, the wts will lead the system and lead the pumps to during highest demand, we have recirculation of water inside the reservoir, with the aid of wts, leading to production of energy. By this approach, we will achieve the following feature. The placement of the reservoir inside an area of water will make use of a unique reservoir, compared to the two that were used at the previous application. (see **Figure 114**)

At this point, there are some important breakthroughs that are worth mentioning. We have the involvement of the Dutch company TenneT, that have in their immediate goals of their agenda , the investment in the wind energy and more particularly in the development of the offshore domain. The application of their initiative will be taken into action over the North Sea Wind Power Hub, in order to reach its true potential abilities, covering the needs of many millions of citizens, in the next years ahead. (see **Figure 115**)

Figure 115 The North Sea Wind Power Hub[122]

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[122] Artificial Island to Supply Renewable Energy to 80 Million. [Online] Ecotech Institute. Published date: Feb 15, 2018

In more details, the suggestion is to establish a partnership between all European countries (with UK), in order to make a network of creation and supply by the offshore domain, based on the potentials given by the artificial green islands.

Let's discuss about the benefits that can be earned by the probable exploitation of these type of Islands. The constraints that have to be dealt with , are:

1. the space that has low potential,
2. the wind's limited velocity
3. the increased maintenance expenses, and
4. the increased demand for power at the supply, at an increased distance from the WF.

This artificial land could give solutions to the previously referred

problems. The perspectives that are rising ahead are the following:

1. AC to Dc conversion of wind power, and then transferred to the main grid, supplying many households, or
2. We have the creation of the alternative hydrogen, that is created after the conversion of the AC power , in order to cover any transfer of high base, between sea and land.
3. The ratio of power generated will be 60 % more increased, than was until recent developments.
4. The hubs that will connect various countries, will give the ability of making energy accessible to any country, that will be found inside the network of the Island.

The targeted area is the Dogger Bank (see **Figure 116**), because it has many of the requirements, that are necessary for the evolution of this project, as its is considered a central point for North Sea countries. Additionally, the water, at this location, is ideal for the installation of the artificial land, and the wind levels are considerably above the medium level. Moreover, it shows great potential in issues regarding the protection of nature

.

Figure 116 The Dogger Bank's Location[123]

The targeted result, apart from the high reduction of GHG emissions, is the achievement of the creation of such hubs, that will have the ability to harvest about 30 GW, compared to the 6 MW, that is currently at operation. However, the concept is still under development and many suggestions, by various countries, such as Netherlands, are reaching the table of the negotiations, in order to achieve further improvement in the project. [39]

Sea WT – multiple functions

A revolutionary concept, that was inspired by the Dutch company Ecofys, could exceed the conventional frames of the wind industry and put the wind farm utilization in a whole new perspective. (see **Figure 117**) The concept of this project is to create a dual nature for the offshore wind farm. The function has to do with the cultivation of seaweed, that will be surrounding the wts, which will create the opportunities for the feeding of the fish, for the generation of biofuels and wind energy. The fish that will circulate through these areas will also see the seaweeds, that will be created, as a place for resting and protection, but also use them as food.

[123] Wind farms and man-made island in the North Sea could help Europe meet renewable energy targets. [Online] India Block – Dezeen. Published date: Jan 8, 2018

Figure 117 Seaweed Farm, cultivation of seaweed[124]

Figure 118 Seaweed Farm, the borderlines and the formation in sea[125]

The remarkable fact, regarding this initiative, is that there are not any additional needs, such as fertilizers. Furthermore, methane and nitrogen emissions are non- existent and

[124] Is Seaweed the Next Big Thing in Sustainable Food? [Online] Lisa Held - Civil Eats. Published date: Dec 20, 2017

[125] Offshore Wind Farms Could Double As Seaweed Farms. [Online] EarthTechling.com Staff – Tree-hugger. Published date: Mar 16, 2012

can diminish the ocean acidification, with the integration of CO_2 at its interior. (see **Figure 118**) Many tests over the particular project have been made and other new ones are in the way of happening, as they are in progress. [40]

The IceWind WT

The project takes place in Iceland, in order to take advantage of the winds of high scale that are dominant in the area. The inventor S. Asgeirsson had the initiative to exploit the rather particular conditions, and not create an engine that could waste the potential of winds. In order to succeed in making into action this endeavor, the concept of this construction had to lead into a particular construction, that was of limited height and of a considerable width. After the creation of his company, named as IceWind, the specific type of wt has vertical and curved blades, that are placed on a large foundation. The choice of this vertically oriented wt has been done for its known beneficial properties, and in order to respond to the requirements of the winds' behavior, since they reach at mean value 40 miles/h. This particular construction gives the privilege of responding of wts' rotation, at any scale of wind velocity and at any direction.

There are two types of this company, that follow this current concept, the RW and the CW100 wt. The first wt is used for the production of energy, at spots of detection and towers of telecommunication. The second one is created especially for households.

Figure 119 IceWind CW – For residential applications[126]

Figure 120 IceWind RW – For increased energy security[127]

The first type can generate 1 kW, either at an extreme wind behavior or at a wind of limited scale, meanwhile the second one has the ability to withstand winds, whose velocity can reach the Hurricane level, which means between 131 and 155 mph, causing destruction of biblical level. (see **Figure 119** and **Figure 120**)

The range of the electrical power generation, that derives from wind velocity that ranges between approximately 5 miles/h and 110 miles/h. There is a mechanism involved in the engine, that is considered as a safe mechanism, since it prevents the malfunction of the machine. Additionally, due to their loading on the ground or the telecom base, such as tower, they have no influence on the birds, while moving close to them, at any distance. Finally, they do not generate noise, during their operation, and they have no need for service, for their complete lifespan of 30 years. [41]

[126] The IceWind Turbine Is A New Take On Vertical Access Wind Turbines. [Online]. Off Grid world – News. Retrieved date: Nov 2, 2018.

[127] The IceWind Turbine Is A New Take On Vertical Access Wind Turbines. [Online]. Off Grid world – News. Retrieved date: Nov 2, 2018.

The SheerWind Invelox WT

Figure 121 SheerWind Invelox windtube, the steps of the process[128]

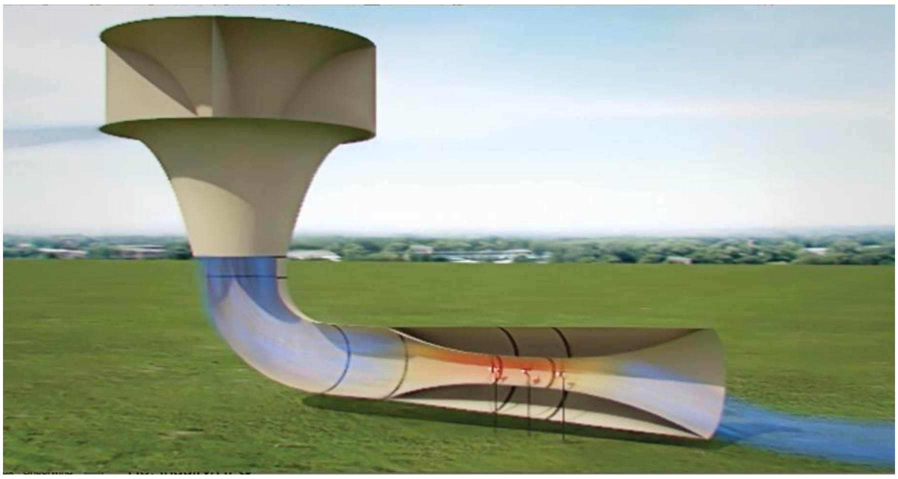

Figure 122 SheerWind Invelox, circulation of the wind[129]

[128] SheerWind Invelox – Futuristic Wind Turbine That Produces 600% More Power. [Online] Surendar AG – Geekswipe. Published date: Sep 23, 2015

[129] Netherland Investment Company to Manufacture and Distribute SheerWind Technology. [Online] Sheerwind – PR Newswire. Published date: Jan 4, 2016

A very unique innovation is now presented, made by the SheerWind company. This project is in motion since 2016, and the results are really remarkable. It has great benefits, concerning the costs and the efficiency, which is something, that demands further discussion. (see **Figure 121** and **Figure 122**)

In order to make this engine working, there has been an extraordinary innovative tube system, that is utilized. This system is named as INVELOX (meaning INcreased VElocity), that is in charge for the collecting, harvesting, increasing of the wind's velocity. Additionally, its final step of its function is the transfer of its generation ratio to the various wts, that are inside the machine. Moreover, the blades included are of compressed size, 84% smaller than the typical ones, and are also placed at ground level, which adds flexibility to the already beneficial engine. This unique construction has privileges, since it can lead to the wind energy generation by exploiting the winds, below the velocity of 2 m/s and can reach quite great efficiency of the wind ratio to electricity, based on the location of its establishment . This is quite extraordinary, concerning its production, as it is not so much influenced by any calm weather conditions, compared to the conventional wts. Furthermore, it can be loaded on places that have abrupt edges, and can make the owner independent of the central grid. There are, as a result, advantages for the environmental protection.

The goal of SheerWind is the exploitation of the benefits given by this unique construction, in order to achieve high energy generation, in combination with the

the results, that are made by the powerful wind energy systems, that are used in the offshore domain. The unique property of this machine is the efficiency, in which it generates electricity, that is 600% higher than the conventional engines, as it exploits the benefits by the Venturi effect, such as the increase at its velocity of the wind, leaving the tube, compared to its initial velocity, and by combining multiple venturi. The developments in the specific project do not stop there, since the Iranian and Danish government requested the application of this engine, in a mass production, as their plan is to equip their countries with these machines, in order to cover all the range of electricity generation and because of their resistance to great natural disasters, such as earth's shaking. [42]

The Revolt WT

A company, that is located in St. Louis of Missouri, USA, named as Revolt Wind is leading the way of the wind industry, with the purpose to initiate a new way, where the industry should approache the supply of wind energy to the people, regardless of their status of life. We are talking about an essential breakthrough, that will make the huge majority of people embrace the new and alternative energy, and more specifically make the wind energy dominant at all types of alternative energy. (see **Figure 123**)

In detail, according to this project, the wind energy can get to any households, since the expenses will be at a limited level. Moreover, how this works? It is about a device that will have a compressed size, limited weigh, which will give to the consumers the benefit of transportation and additionally, they can load it at any place, such as a balcony or a branch of a tree, and proceed to the charging of an electronic device. Only precaution should be at avoiding the contact of this device with any item, while it's performing. Furthermore, it has the diameter of 0.4064 m and the power output that can generate is at 2,2 W. Regarding its operation, the initiation of its function will begin at a wind, with its velocity to be equal to 4 mph, and the useful power, that will be exploited, will begin to be generated at wind, with velocity of 6 mph. No matter what type of kind we will get, stormy or gusty, the operation will remain intact.

The profits that can be gained by this concept are quite various, and we will briefly name some important of them:

- back-up power,
- off-grid applications,
- renewable energy systems,
- marine systems,
- mobile and RV systems

The specific project is in the market since 2017, with developments coming ahead, concerning its size, which will be flexible, in an effort to cover all possible needs of energy demands. [43]

Figure 123 REVOLT WT[130]

4.2 National level (Greece)

The wind power industry has been introduced for a while now in the operation of national mechanism of electricity. Adding to this positive development at the national level, in July of 2018, we have an important and radical evolution, the construction of the 1st factory, that will be creating wind turbines. This fact will put the energetical field of Greece at a whole new level, more specifically in the wind energy domain, beginning to make the greek nation self- sufficient, concerning the wind power. (see **Figure 124**)

130 Affordable, Lightweight and Hanging REVOLT Wind Turbine Powers Your Devices Anytime Anywhere! [Online]. Futureentech – Steemit. Published date : Jun 27, 2017

Figure 124 1st WT factory in Greece[131]

The factory will be located at Mandra of Attica, and it is α subsidiary factory of the EUNICE Energy Group(EEG). This group is in charge of the innovative project ‘TILOS’, which is a hybrid construction, that makes use of the power that is generated by the solar energy of photovoltaics and by the wind energy of wind turbines, in combination with storage capacity, for the increase at the covering of the energy demands of the Tilos island. Furthermore, the specific factory’s surface will be 1300 m2 , where we have the construction of the first wind turbine EW-16 THETIS, that will be analyzed further in the next lines ahead. Additionally, the factory will be able to construct 50 wts at an annual scale, but it will also have the ability of an annual expansion at its production at a percentage of 30 %. The developments will keep on proceeding to a higher scale, based on the pattern of the evolution of the networks of the energy transfer and the energy distribution. This will need the combination of developments in various lev- els, such as the creation of hybrid systems, that will take advantage of the prosperous energy level of an area and lead to the generation of energy at the maximum possible level. Finally, another important evolution of the Eunice group is the creation of the sys- tem S4S (Storage for Sustainability Smart Grid Security and Solutions) .It is combining the use of alternative energy, conventional energy and accumulator, that is operating with a PC, and assembles and analyzes the data and the forecasting for the energy gen-

[131] Greece’s first wind turbine factory starts production. [Online]. Vladimir Sparic - Balkan Green Energy News. Published date: Aug 8, 2018

eration. In addition to that, it combines and compares the data with forecasting data about the consumption of energy and it makes the appropriate adjustments.

These are some of the most important features that S4S provides. We could say that the future of the wind energy technology is predicted to be very promising and constantly evolving. [50]

EW-16 Thetis – The first Greek WT

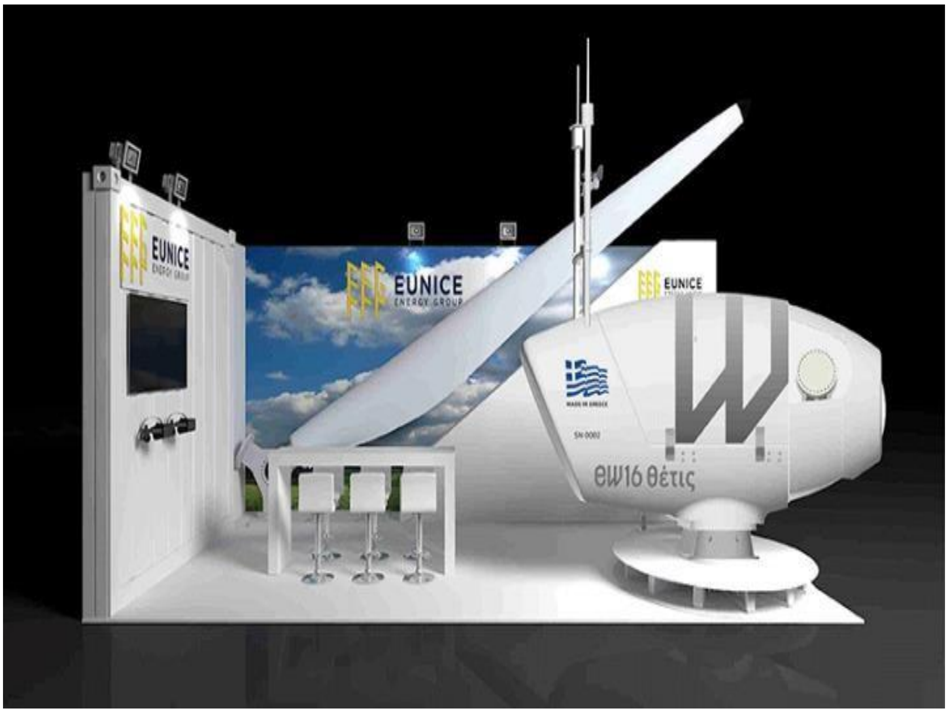

Figure 125 EW-16 Thetis: The first Greek WT[132]

[132] Greece's first wind turbine factory starts production. [Online]. Vladimir Sparic - Balkan Green Energy News. Published date: Aug 8, 2018

Figure 126 EW-16 Thetis: The first Greek WT (visualization 2)[133]

The EW16 is the 1st wt, that has begun its construction in Greece. It is a wt that has the ability to generate electricity of 50 kW , which gives the privilege of covering the energetic needs of about 15 households .The specific project is in conjunction with the project of S4S, that was previously mentioned, and each one is giving extra boost between them. (see **Figure 126**)

In more technical details, EW-16 wt has the following measurements:

- height of 29m,
- the rotor's diameter is 16 m.
- its weight is 15 tons.

[133] Greece's first wind turbine factory starts production. [Online]. Vladimir Sparic - Balkan Green Energy News. Published date: Aug 8, 2018

TILOS project

Figure 127 TILOS -project[134]

This a unique and essential breakthrough, not only about the Greek community, but also about the perspective in the global development of wind energy at the specific type of expansion. By this concept, we are targeting the achieving of the total energy self- efficiency .The beginning of the operation of this project will be in 2019 and it will cover the whole island. (see **Figure 127**)

Until recent developments, in order to supply electricity to this island, we should make use of a pipeline, under the sea surface, and its function was done in cooperation with the Kos island. This particular energetic strategy had a flaw of high essence, since it was seriously affected by the overdemand of electricity, that had bad consequences on society and the companies of the region. This fact had led to a backup plan and the utilization of diesel generators. The consequences were bad, as the fossil fuels resources were overused , leading also to CO2 emissions and other bad impacts to nature. Then, the

[134] Tilos, energy self-sufficiency from renewable sources becomes reality. [Online] PRP Channel. Published date: Sep 12, 2018.

concept had been suggested and had been included in the big general plan ‘ Horizon 2020 ’, with the cooperation of 7 countries and the surveillance of the R&D actions by the University of Piraeus. The project was named TILOS, which meant “Technology Innovation for the Local Scale”.

This project had become successful and had given many perspectives for its application on various European islands, enforcing the energy self- efficiency of the islands. In technical details, the total power supplied by this system is 1000 kW, that derive 800 of them from wind energy and 160 of them from solar energy, in order to cover the periods of year, with increased solar radiation and limited wind, such as August. The most essential part of this creation is the utilization of 2 accumulators NaNiCl2. These devices are not affected by the extreme meteorological conditions and any weather changes and their operation is based on the existence of any alternative energy.

Additionally, they can make different functions, which are the following:

- the utilization of the alternative energy (hybrid) that is generated,
- its storage, and
- its distribution, with the aid of a smart stand- alone micro (autonomous) network, that makes the supply in a constant basis.

The result of this innovative construction will be the exploitation of the stored energy, that will give the privilege for covering for energy demands at time periods, when we have maximum demand. At next step, we will have the appropriate and suitable modifications, in order to make the energy transfer to the households, which will be done by smart meters and a smart station, named as SCADA, with the aim to balance the generation and the consumption. (see **Figure 128**) [44]

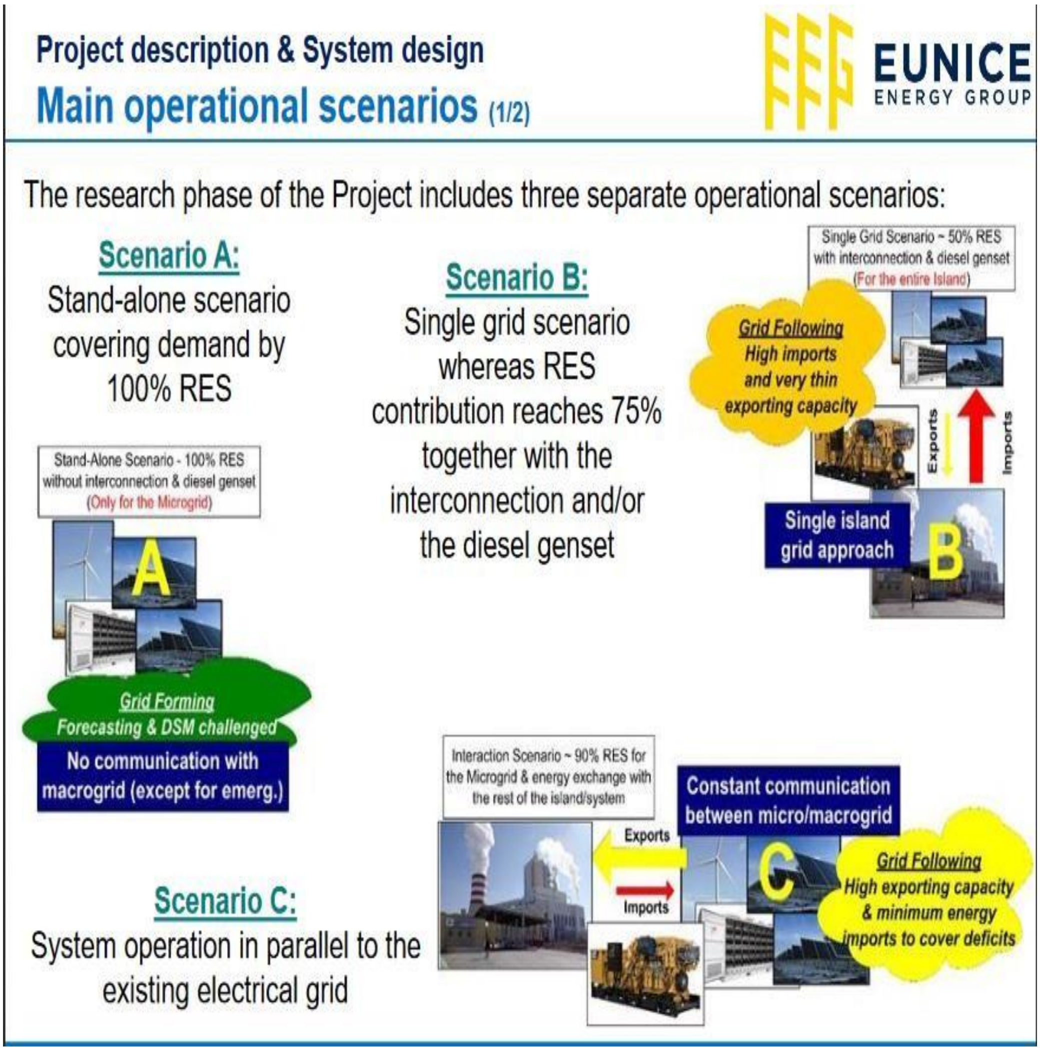

Figure 128 The various scenarios of the hybrid energy distribution[135]

[135] *Systems with RES and battery storage. TILOS project, Greece.* Mantas, Zisimos**.** EUNICE Energy Group, retrieved in 2018.

Kafireas wind project

Figure 129 Kafireas Enel Greenpower's project[136]

The most anticipated and extremely interesting investment by the Enel Greenpower company, named as Kafireas, is taking place in Greece. This particular project is a wf that can generate 154 MW of electrical energy, and it is installed on the island of Evia.

The morphology of the Evia's land is the reason of the application of this concept, as it is a mountainous island. (see **Figure 129**)

After the bureaucracy that has been holding the beginning of the operation, after the period of 7 years, we had the beginning of its construction. The initiation of its function will be in the first months of 2019 and will lead the country's generation of wind energy. A wide range of equipment that is necessary for the supply and the distribution, such a high-voltage (150 kV) line, will connect the construction to the central grid of the continental land. The electrical generation at annual level will be 483 GWh, which will give the privilege of covering the energy demands of 129 thousand residences.

This project will lead to the further evolution of Greece in battling the unemployment, as may new jobs will be created, and the availability of energy will be in high scale, even for the people, with financial problems, and the Greece's economy will also be benefited by it.. [45]

[136] Kafireas, our most expected wind project. [Online]. Georgios Papadimitriou - Enel Green Power. Published date: Jul 18, 2017.

5. Conclusions

Let's make a synopsis regarding the above data that we have assembled. The evolution in wind energy is rapid. All the results that are achieved by these incredible innovations show that this type of alternative energy is leading the way of RES into a new era.

Some of the essential gains of the continuously developing wind energy domain are the reduction of any costs during the manufacturing process, but also of the expenses at the individual level. Regarding the first one, we see that the increase at the power output can be achieved, by the innovations that occur mostly in the construction of the wt , such as the number of blades, or its shape. For example, it could get the kite shape or a round shape, as it was presented in the O- wt prototype . But these are not the only methods, by which the maximizing of the power output can be achieved. As it has been shown from the above summarized review, the offshore wind domain is constantly gaining more and more attention, as the results of the potential of the wind energy harvesting, at the specific domain, are quite remarkable. By the recent developments, it is observed that not only we can generate wind energy of much higher scale than the onshore domain, but we are also at a such high ground of evolution, where each of the obstacles, that used to ground the potential of the wind energy generation, are in the way of their elimination. The innovation of the Vertiwind design is in this direction, solving the extremely huge and costly construction of foundation, that is necessary to utilize, in order to anchor the wt foundation at sea, by giving the wt an essential flexibility.

The evolution does not stop there, but continues its extension at fields, that were not considered in the past as potential investment. The recent innovation of Revolt wt is one of the examples, that are currently in development mode , making the wind power part of the daily routine of the people. Additionally, it shows great potential to conquer any energy development projects, that are in progress, and gain the trust of the consumers, as at the same time the constant rate of decrease of wind energy is occurring .

Additionally , regarding Greece, wind energy is getting more use in the process of the total national energy output. The results are promising, given the fact that the morphology and the wind conditions are quite unique. Moreover, it can give a lot of aid to the construction of some unique developments, that will be proven essential and beneficial in many ways. There are some examples, that are already effective, such as the TILOS project, while the Kafireas project of Enel Greenpower, is in progress, and is very promising.

Finally, we should refer to the goals that are set to be achieved by the United Nations, concerning the climatic changes. There have been done many efforts between the COP21 Agreement of Paris, in 2015, and the COP23 that happened in 2017, in order that the countries, that are involved, are committed to the agreement and achieve the reduction of all the possible harmful issues for the protection of the environment. This is suggested to be done, at high rate, by the increased insertion of the use of RES, which are considered to be a major levier of acquiring the targets that are required, by the COP agreement . Thus, it is considered essential to have a constant increase of the RES in the energy domain, in order to become the dominant type sources of energy and lead to the reduction of the fossil fuels' consumption to the minimum possible level. In order to achieve that, we have to make this alternative type of energy reachable to all, which means achieve a great reduction in costs of installation, production and consump- tion. The next COP conference (COP24) will take place between November and De- cember of 2018, where discussions over the recent developments will be made, and they
will be discussed over the further and general perspective that is put by the COP21.

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