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Abstract

Scientific research and technological development in the field of renewable energies will be carried out around specific programs having a direct impact on the socio-economic reality of the country. The main scientific objectives assigned to each of the programs consist of evaluating renewable energy sources, controlling and optimizing the conversion, transformation and storage processes for these energies and developing the necessary expertise, ranging from study to the realization of the installations on site. The principle of operation of wind energy is based on the transformation of kinetic energy into mechanical and then electrical energy, the wind turns blades which themselves turn the generator of the wind turbine. In turn, the generator transforms the mechanical energy of the wind into electrical energy. The electric current is then transformed and injected into the electricity grid to power our homes. It can be stored for later use.

Keywords

Renewable energy, Wind, Turbines, Blades, Electricity.

Résumé

La recherche scientifique et le développement technologique dans le domaine des énergies renouvelables se feront autour de programmes spécifiques ayant un impact direct sur la réalité socioéconomique du pays. Les principaux objectifs scientifiques assignés à chacun des programmes consistent à évaluer les gisements énergétiques renouvelables, à maîtriser et optimiser les procédés de conversion, de transformation et de stockage de ces énergies et à développer un savoir-faire nécessaire, allant de l'étude jusqu'à la réalisation des installations sur site. Le principe de fonctionnement de l'énergie éolienne repose sur la transformation de l'énergie cinétique en énergie mécanique puis électrique, le vent fait tourner des pales qui font elles même tourner le générateur de l'éolienne. À son tour le générateur transforme l'énergie mécanique du vent en énergie électrique. Le courant électrique est ensuite transformé et injecté dans le réseau électrique pour alimenter nos foyers. Il peut être stocké pour être utilisé plus tard.

Mots clés
Énergie renouvelable, éolienne, Turbines, Pales, Electricité.

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Introduction

In recent years, there has been a growing global demand for clean and renewable energy sources. As the world seeks to reduce its reliance on fossil fuels and mitigate the adverse effects of climate change, wind power has emerged as a viable solution. Wind farms, consisting of multiple wind turbines, have gained significant attention as an effective means of harnessing the power of the wind and converting it into electricity. However, the successful implementation of a wind farm heavily relies on various factors, with the structural aspects of wind turbines playing a crucial role.

A feasibility study is an essential step in assessing the viability and potential success of a wind farm project. This study aims to evaluate the structural aspects of wind turbines, which include their design, construction, and durability. By examining these factors, developers, investors, and stakeholders can gain a comprehensive understanding of the technical feasibility and economic viability of a wind farm.

The structural aspects of wind turbines encompass several key considerations. Firstly, the design of wind turbine structures must ensure the efficient conversion of wind energy into electrical power while maintaining stability and reliability. The structural components, such as the tower, blades, and foundation, must be designed to withstand the dynamic forces imposed by wind loads, turbulence, and extreme weather conditions.

Furthermore, the construction process of wind turbines requires careful planning and execution. The transportation and installation of large-scale turbine components pose significant logistical challenges. The feasibility study evaluates the feasibility of accessing the project site, considering factors such as transportation routes, site preparation, and construction equipment requirements. It also addresses potential environmental impacts associated with construction activities, ensuring compliance with regulatory standards.

Durability is another critical aspect of wind turbine structures. The study ex- amines the expected service life of the turbines, taking into account factors such as material fatigue, corrosion, and maintenance requirements. Understanding the lifespan of wind turbines enables developers to assess the long-term economic viability of the project and plan for maintenance and potential component replacements.

In conclusion, a feasibility study focusing on the structural aspects of wind tur- bines is an integral part of the assessment process for wind farm implementation. By thoroughly evaluating the design, construction, and durability of wind turbine structures, stakeholders can make informed decisions regarding the feasibility and potential success of a wind farm project. This study acts as a crucial guide for developers, investors, and policymakers to ensure the sustainable and efficient generation of clean energy through wind power.

CHAPTER I

History and General Information on Wind Power

I.1 Introduction

Acquiring a stable and clean source of electricity has always been a priority for mankind since the industrial revolution, so founding industries that generate electricity was crucial and a number one goal for everyone to catch up with the increasing need of either homes or industries.

Generating electricity always consisted of transforming a mechanical energy to an electrical one, either by using a vapor or gas(combustion) turbines in thermal centrals, hydroelectric turbine or similar installations in hydraulic centrals, or even nuclear energy which is the most dangerous source among them, in nuclear centrals.

Wind energy became today a reliable complementing option to the conventional energy source; wind energy is becoming an increasingly viable option to supplement traditional sources of power, particularly in regions where existing power plants are unable to meet rising electricity demands. This is due in large part to advancements in wind technology, which have made wind power more cost-effective. In response, the Algerian government has adopted a policy of promoting and supporting the development of clean energy, including plans to construct a wind farm in THE NORTHWEST region of Algeria. This region was chosen for its very fast growing rate which indicate a spiral in energy demand in the near future and high wind speeds, as shown by the first wind map of Algeria. Microclimate studies have been conducted in the region to identify suitable sites for the farm, and the present study uses Wind Atlas website to evaluate the wind resource of the **Oran** region.

I.2 History and Development

I.2.1 History

Wind power has a long history dating back to ancient civilizations. The ancient Egyptians used wind power to propel boats along the Nile River (Fig I. 1), and the Persians used windmills to grind grain and pump water (Fig I. 3). In the middle Ages, windmills in Europe were used for a variety of tasks including grinding grain, pumping water, and sawing wood (Fig I. 2).

The industrial revolution in the 19th century brought about new innovations in wind power, with larger and more efficient windmills being developed for use in industry and agriculture. However, the widespread use of fossil fuels in the 20th century led to a decline in the use of wind power. In the 1970s [1], the oil crisis and increasing concerns about the environmental impact of fossil fuels led to renewed interest in wind power as a viable source of renewable energy. Today, wind power is one of the fastest growing sources of renewable energy in the world, with countries like China, the United States, and Germany leading the way in terms of installed capacity. Wind power is also becoming increasingly cost-competitive with traditional sources of energy, making it an attractive option for both developed and developing countries looking to reduce their dependence on fossil fuels.

Figure I.1: Ancient Egyptian boats [20]

Figure I.2: Netherland windmills [21]

Figure I.3: Ancient Persian Wind Mills. [22]

I.2.2 Development

Wind power generation has undergone significant development in recent years. The first modern wind turbine was built in the late 19th century, but it wasn’t until the 1970s, when the oil crisis led to an increase in energy prices, that wind power began to be seen as a viable source of renewable energy.

In the 1980s and 1990s, wind power technology continued to improve, with the development of larger and more efficient turbines. The first commercial wind farms were built during this time, and the use of wind power began to grow rapidly.

In the early 2000s, advances in wind turbine technology led to the development of larger turbines with longer blades and more powerful generators. This made it possible to generate more electricity from a single turbine, and made wind power more cost competitive with traditional sources of energy [2].

Today, wind power is one of the fastest growing sources of renewable energy in the world. According to the International Energy Agency, global wind power capacity has grown by an average of 19% per year over the last decade. This growth has been driven by declining costs, government support for renewable energy, and the growing need to reduce greenhouse gas emissions.

In addition to onshore wind power (Fig. I. 4); offshore wind power has also seen significant development in recent years. The first offshore wind farm (Fig. I. 5) was built in the early 2000s, and since then, offshore wind power has grown rapidly. Offshore wind turbines have larger capacity and produce more energy than onshore wind turbines.

Figure I.4: Onshore wind turbine installation. [23]

Figure I.5: Offshore wind turbine installations. [24]

As wind power technology continues to improve and costs continue to decline, wind power is expected to play an increasingly important role in meeting the world's energy needs in the future. Many countries have set ambitious targets for wind power generation as part of their efforts to transition to a low-carbon economy (Fig. I. 6).

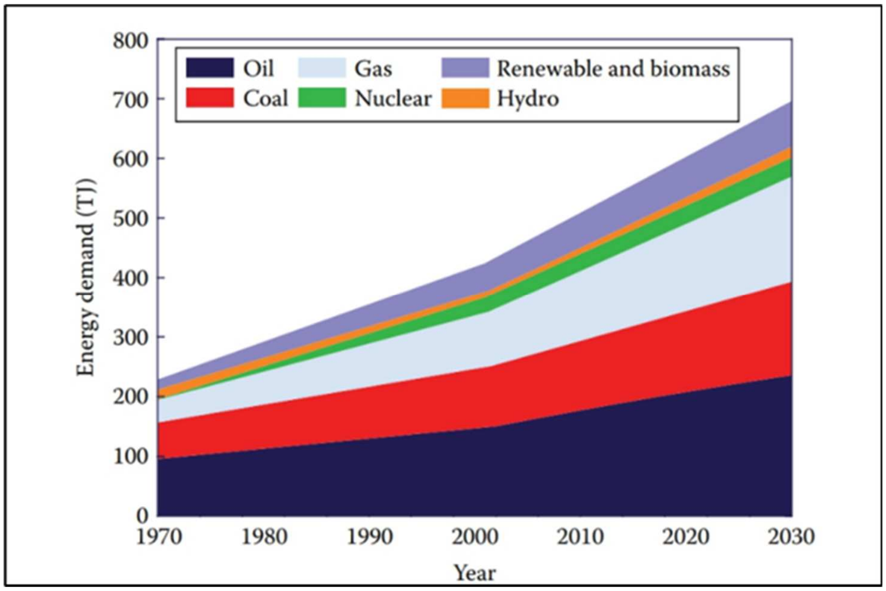


Figure I.6: World Energy Demand since 1970 and Estimate until 2030. [25]

I.3 Different Types of Wind Power Installation

There are two main types of wind power installations:

- Onshore installations.
- Offshore installations.

I.3.1 Onshore Wind Power Installations

Are built on land and are the most common type of wind power installation (Fig I.4).

They typically consist of wind turbines that range in size from small, individual turbines for homes and businesses to large, commercial wind farms with dozens or even hundreds of turbines. Onshore wind turbines are typically smaller than offshore wind turbines (Fig I.7), but they are cheaper to install and maintain. They are also more accessible for repair and maintenance work. The typical size of the turbine's rotor can be around 50-80 meters.

Figure I.7: The comparison between offshore and onshore installations. [26]

- **Onshore Wind Power Development**

Onshore wind power installations are wind turbines that are located on land, typically in rural or semi-rural areas. They are similar in design to traditional horizontal-axis wind turbines (HAWTs), which consist of a rotor with three blades mounted on a horizontal shaft that is connected to a generator. The rotor is typically mounted on a tall tower, which allows the blades to be at a higher altitude where the wind is stronger and more consistent.

Onshore wind power installations are popular due to their relatively low cost of installation and maintenance, as well as the availability of land and easy access to the electricity grid. They are also less complex to construct and maintain than offshore wind power installations, which can help to reduce costs.

One of the main advantages of onshore wind power installations is that they are a reliable and cost-effective way to generate electricity from wind power. They have been widely used for many years, and the costs of manufacturing, installation, and maintenance have been significantly reduced over time, making them more cost-effective than other types of wind turbines.

However, onshore wind power installations have some limitations, such as the noise level and visual impact. They are typically larger and noisier than other types of wind turbines, and their blades rotate at high speeds, which can create a significant amount of noise. Additionally, they are more sensitive to wind turbulence, which can reduce their efficiency and increase wear and tear on the turbine.

Onshore wind power installations can be found in many countries around the world (Fig. I.8), with China, the United States, Germany, and Spain being among the countries with the largest installed capacity. These countries have favorable conditions for wind power generation, such as high wind speeds and large areas of land available for installation.

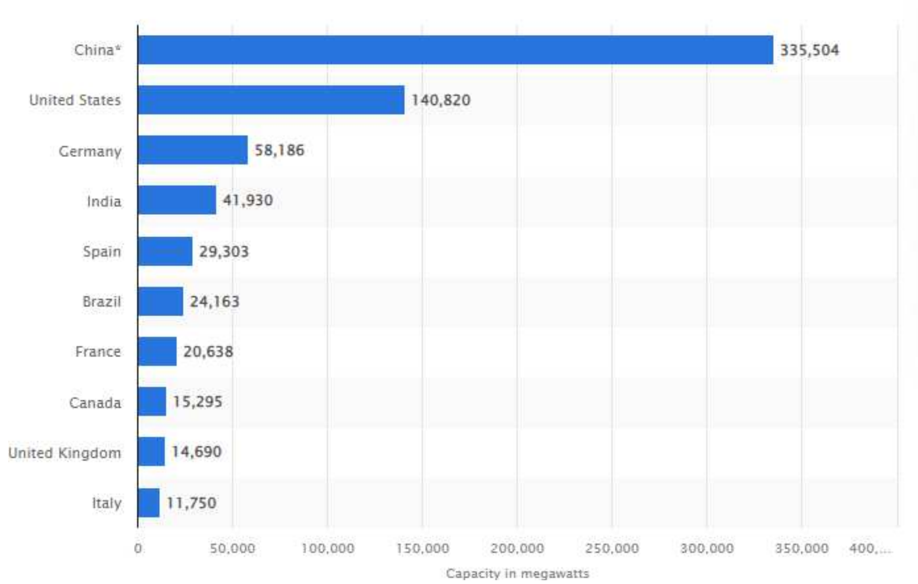


Figure I.8: Onshore wind energy capacity in 2022 by country. [27]

I.3.2 Offshore Wind Power Installations

Are built in bodies of water, typically in the ocean (Fig. I.10). these installations are more expensive to build and maintain than onshore installations, but they also have the potential to generate more electricity due to stronger and more consistent winds over the ocean. Offshore wind turbines are also generally larger than onshore turbines, with some reaching heights of over 180 meters and blade lengths of over 90 meters. The first offshore wind farm was built in the early 2000s and since then, offshore wind power has grown rapidly, with the capacity increasing year by year.

Figure I.9: Offshore wind turbines installation types. [28]

- **Offshore Wind Power Development**

Offshore wind power installations are wind turbines that are located in the ocean (Fig. I.9), typically in shallow waters near the coast. They are similar in design to traditional horizontal-axis wind turbines (HAWTs), but are typically larger and more powerful, due to the stronger and more consistent winds found over the ocean.

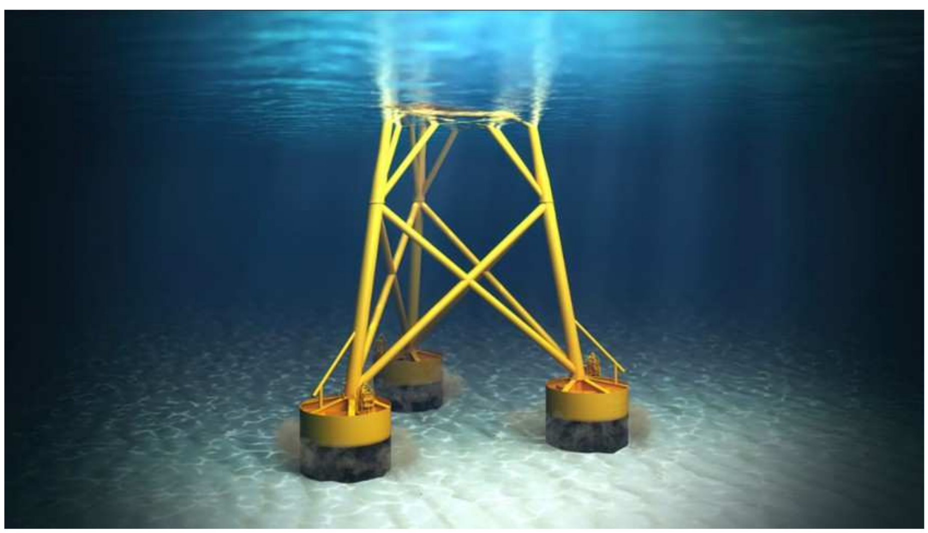


Figure I.10: Undersea view of a suction bucket foundations. [29]

The main advantage of offshore wind power installations is that they can generate a significant amount of electricity due to the stronger and more consistent winds found over the ocean. Additionally, the wind resource is generally more consistent than on land, which means that the turbines can operate at higher capacity factors, resulting in more electricity generated per turbine.

Another advantage of offshore wind power installations is that they are less visible and less obtrusive (Fig. I.11) than onshore wind turbines, as they are located farther away from populated areas. This can also help to reduce potential conflicts with nearby residents or businesses.

However, offshore wind power installations have some challenges, such as the cost and complexity of installation and maintenance. Building and maintaining wind turbines in the ocean is more difficult and expensive than on land due to the harsh marine environment. The turbines need to be designed to withstand the constant exposure to saltwater, waves, and storms. Additionally, the turbines need to be connected to the electricity grid via undersea cables (Fig. I.11), which adds additional cost and complexity.

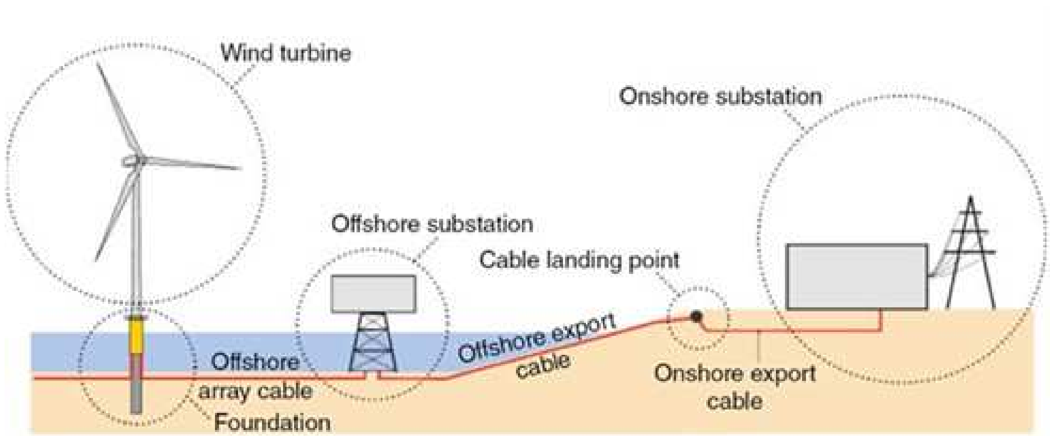


Figure I.11: Sending the power onshore. [28]

Despite these challenges, the offshore wind power industry has been rapidly growing in recent years, driven by advances in technology, increased demand for renewable energy, and supportive government policies. Today, many countries have offshore wind power installations, with Europe being a leader in this field. The United Kingdom, Germany, Denmark, and the Netherlands are among the countries with the largest installed offshore wind power capacity.

Overall, Offshore wind power installations have the potential to generate a significant amount of electricity, but they are also more expensive and complex to install and maintain than onshore wind turbines. With the advancements in technology and the increasing demand for renewable energy, offshore wind power is expected to play a key role in the future of wind power generation.

I.3.3 Vertical-Axis Wind Turbine

Another type of wind power installation, which differs from the traditional horizontal- axis wind turbine (Fig I.12) in the way the blades are oriented. The blades of a vertical-axis wind turbine are mounted on a vertical shaft, which makes them more compact and better suited for use in urban areas or other areas with limited space.

Figure I.12: The difference distance gain between horizontal axis wind turbine and vertical axis wind turbine. [30]

- **Vertical-Axis Wind Turbine Development**

Vertical-axis wind turbines (VAWTs) are a type of wind turbine that differ from the more traditional horizontal -axis wind turbines (HAWTs) in the way the blades are oriented (Fig. I.13). The blades of a VAWT are mounted on a vertical shaft, rather than a horizontal one, which makes them more compact and better suited for use in urban areas or other areas with limited space.

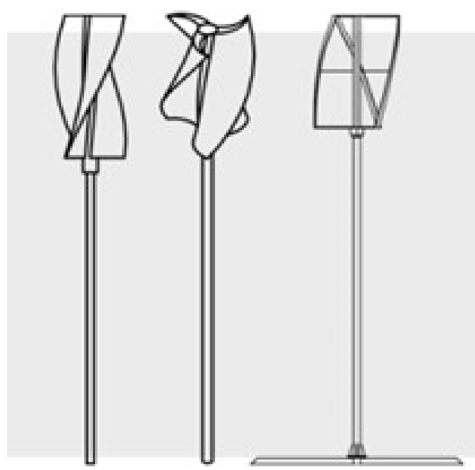


Figure I.13: vertical axis wind turbines. [30]

VAWTs have several advantages over HAWTs (Fig. I.13). For example, because the blades rotate around a vertical axis, they can operate in a wider range of wind directions, meaning they can generate electricity even when the wind is blowing from an angle. This makes them more efficient and can make them more reliable in certain locations. Additionally, they are less affected by wind turbulence, which can reduce wear and tear on the turbine and make them more durable.

Another advantage of VAWTs is that they are more visually appealing than HAWTs. Because the blades rotate around a vertical axis, they do not have to rotate at high speeds, which reduces the noise level and creates less visual disturbance.

However, VAWTs have some challenges, such as the cost and efficiency, which are typically higher compared to HAWTs. They also have a lower power density, which means that they need a larger rotor area to generate the same amount of power as a HAWT. Additionally, they are more complex to manufacture and maintain.

VAWTs have been in development for decades, but they still represent a small fraction of the wind power market. They are mostly used in small-scale projects and in urban and low wind speed areas. With the advancement of technology and cost reduction, VAWTs could have a more significant role in the future of wind power generation.

I.3.4 Traditional Horizontal-Axis Wind Turbines Development

Traditional horizontal-axis wind turbines (HAWTs) are the most common type of wind turbine used for electricity generation (Fig I.14). They consist of a rotor with three blades mounted on a horizontal shaft that is connected to a generator. The rotor is typically mounted on a tall tower, which allows the blades to be at a higher altitude where the wind is stronger and more consistent.

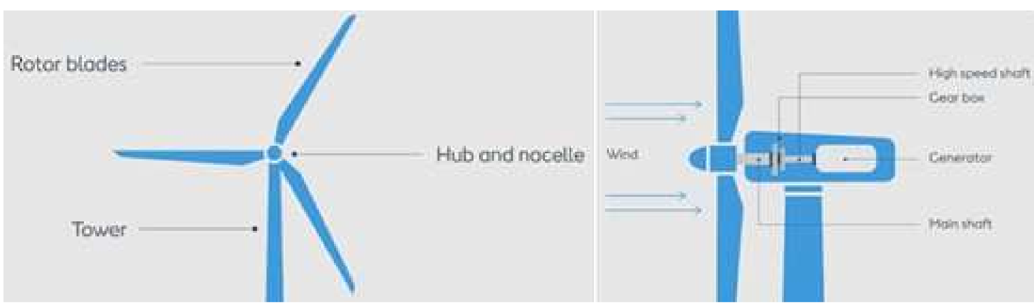


Figure I.14: Horizontal axis wind turbine main components. [31]

HAWTs are designed to capture the wind's kinetic energy and convert it into electricity. As the wind blows across the blades, it causes the rotor to rotate, which in turn drives the generator to produce electricity.

The speed at which the rotor turns is directly proportional to the wind speed, and the amount of electricity generated is directly proportional to the rotor's rotational speed.

HAWTs have several advantages over other types of wind turbines. They are relatively simple and easy to manufacture and maintain, they are efficient and have a high-power density, which means they can generate a large amount of electricity from a relatively small rotor area. They can also be installed at a variety of locations and have a wide range of capacity, from a few kilowatts to several megawatts.

One of the main advantages of HAWTs is that they are well-established technology and have been widely used for many years. This means that the costs of manufacturing, installation, and maintenance have been significantly reduced over time, making them more cost-effective than other types of wind turbines.

However, HAWTs have some limitations, such as the noise level and visual impact. They are typically larger and noisier than other types of wind turbines, and their blades rotate at high speeds, which can create a significant amount of noise. Additionally, they are more sensitive to wind turbulence, which can reduce their efficiency and increase wear and tear on the turbine.

Overall, traditional horizontal-axis wind turbines are a reliable and cost-effective way to generate electricity from wind power. They are widely used in large-scale wind power projects and have been the backbone of the wind power industry for decades.

In addition, there are also **Hybrid Wind Power Systems** (Fig I.15) that combine wind power with other sources of renewable energy, such as solar power, to generate electricity.

I.3.5 Hybrid Wind Power Systems Development

Hybrid wind power systems are systems that combine wind power with other sources of renewable energy, such as solar power, to generate electricity. These systems can help to overcome the intermittency issue of wind power, where the wind may not always blow at a consistent enough rate to generate a steady supply of electricity. By combining wind power with another source of renewable energy, a hybrid wind power system can provide a more stable and consistent source of electricity.

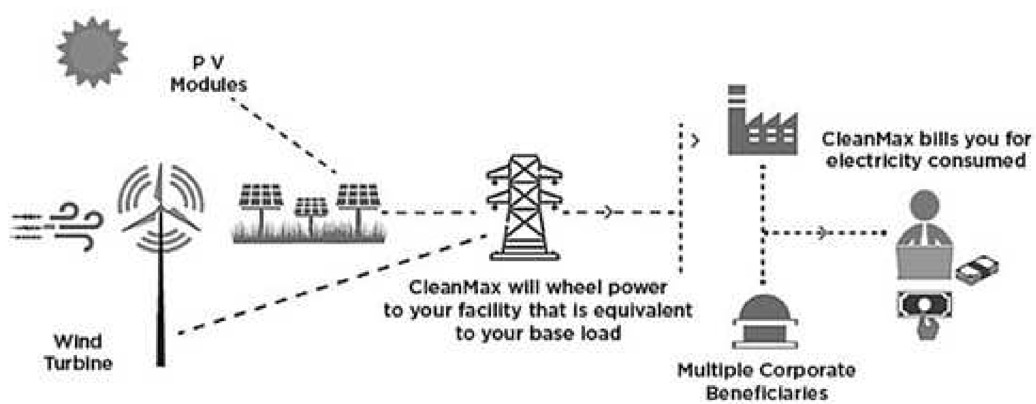


Figure I.15: Hybrid Wind Power Systems. [32]

There are several different types of hybrid wind power systems, each with their own unique advantages and disadvantages. One type of hybrid wind power system is a wind-solar hybrid system, which combines a wind turbine with one or more solar panels to generate electricity. This type of system can generate electricity from both the wind and the sun (Fig I.15), which can help to overcome the intermittency issue of wind power and ensure a more consistent supply of electricity.

Another type of hybrid wind power system is a wind-battery hybrid system, which combines a wind turbine with a battery storage system. This type of system can store excess energy generated by the wind turbine during periods of high wind, and then release that energy when the wind is not blowing strongly enough to generate a steady supply of electricity.

Hybrid wind power systems can also be combined with other forms of renewable energy such as hydroelectricity or biomass. These systems can provide a more stable and consistent source of electricity, as well as reducing the dependency on one source of renewable energy. However, they tend to be more expensive than a standalone wind power installation and can be more complex to install, maintain and operate.

Overall, hybrid wind power systems offer a promising solution to the intermittency issue of wind power, and can provide a more stable and consistent source of electricity. However, the choice of which type of hybrid system to use will depend on factors such as location, wind resources, cost and specific needs of the application.

All of these different types of wind power installations have their own unique advantages and disadvantages, and the choice of which type of installation to use will depend on factors such as location, wind resources, and cost. [4]

I.4 Technical-economic Aspect of Wind Power Installations

The technical-economic aspect of wind power installations refers to the combination of technical and financial factors that determine the feasibility, cost, and profitability of wind energy projects. Some of the key technical factors include the wind resource potential, site accessibility, and the type of wind turbine technology used.

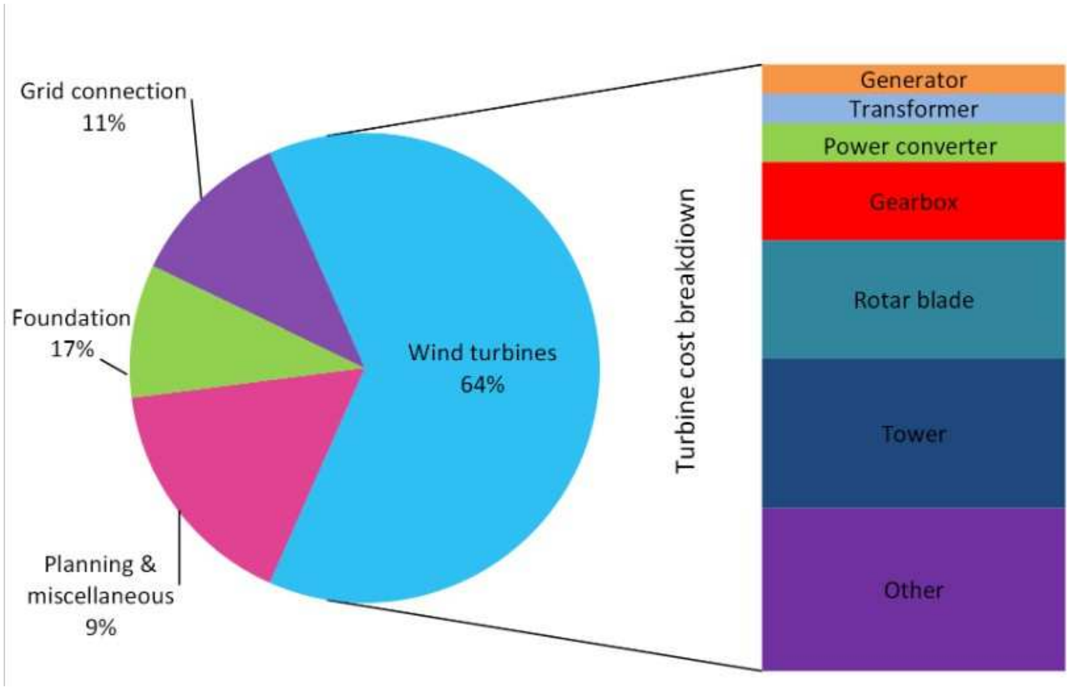


Figure I.16: Typical onshore wind farm installed cost breakdown. [33]

On the economic side, the cost of the wind turbines, balance of plant costs (e.g., electrical interconnection, roads, and foundations), and operating expenses are critical factors in determining the overall cost of energy produced by the wind farm. The levelized cost of energy (LCOE) is a commonly used metric to compare the cost of energy from different sources and is calculated as the total cost of building and operating a wind farm divided by the total energy produced over its lifetime (Fig. I.16) (table I.1).

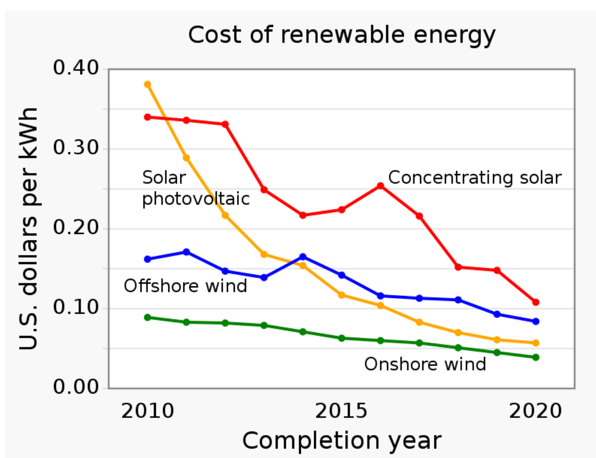


Figure I.17: Cost of Renewable Energy per KWh. [34]

Table I.1: Breakdown and Allocation Costs of a Typical Onshore Wind Farm Installation

	INVESTMENT [E 1000/MW]	SHARE [%]
TURBINE (EX-WORKS)	928	75.6
FOUNDATIONS	80	6.5
ELECTRIC INSTALLATION	18	1.5
GRID CONNECTION	109	8.9
CONTROL SYSTEMS	4	0.3
CONSULTANCY	15	1.2
LAND	48	3.9
FINANCIAL COSTS	15	1.2
ROAD	11	0.9
TOTAL	1227	100

The financial viability of a wind power project depends on several factors, including the cost of borrowing capital, the cost of equity, the project's expected operating life, and the expected price of electricity in the future. Governments often provide incentives, such as tax credits and subsidies, to encourage the development of wind energy projects, which can help lower the cost of energy and make wind power more competitive with other energy sources.

I.5 Wind Turbine's Design Features

Wind turbines are designed (Fig I.18) with several key features that enable them to efficiently capture energy from the wind and convert it into electrical power. Here are some of the most important design features of wind turbines:

I.5.1 Rotor Blades

Wind turbine rotor blades are designed to capture energy from the wind and convert it into rotational energy. The shape, size, and angle of the blades (Fig I.19) are carefully designed to maximize energy capture while minimizing turbulence and noise.

I.5.2 Blade Pitch Control

Wind turbines use a mechanism called blade pitch control (Fig I.18) to adjust the angle of the rotor blades in response to changes in wind speed and direction. This helps to optimize energy capture and prevent damage to the turbine in high winds.

I.5.3 Gearbox

The gearbox is a critical component in the wind turbine that is responsible for increasing the rotational speed of the rotor blades to the speed required by the generator. The gearbox (Fig I.19) is designed to withstand high stresses and loads and must be carefully engineered to ensure reliable and efficient operation.

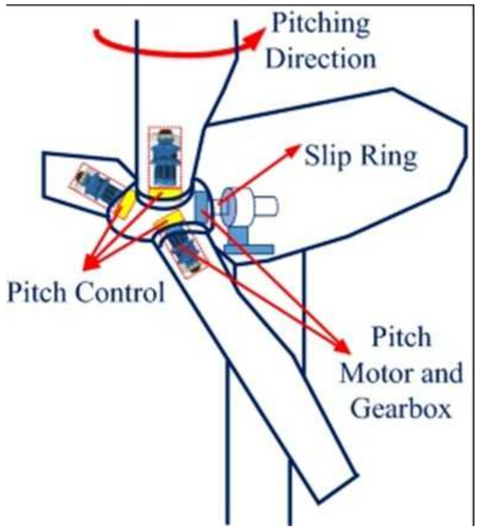


Figure I.18: Blade Pitch Control system. [35]

I.5.4 Generator

The generator (Fig I.19) is responsible for converting the rotational energy from the turbine into electrical power. Wind turbine generators are typically designed to produce alternating current (AC) power, which is compatible with the electrical grid.

I.5.5 Tower

The wind turbine tower is designed to support the rotor blades and nacelle at a height that maximizes energy capture. Towers can be made of steel or concrete and can vary in height depending on the size and capacity of the turbine.

I.5.6 Nacelle

The nacelle is the housing structure that contains the gearbox, generator, and other key components of the wind turbine. The nacelle is typically designed to be aerodynamic to minimize wind resistance and turbulence.

I.5.7 Control System

Wind turbines are equipped with sophisticated control systems that monitor and adjust the performance of the turbine in real time (Fig. I.19). the control system helps to optimize energy capture, prevent damage to the turbine, and ensure safe and reliable operation.

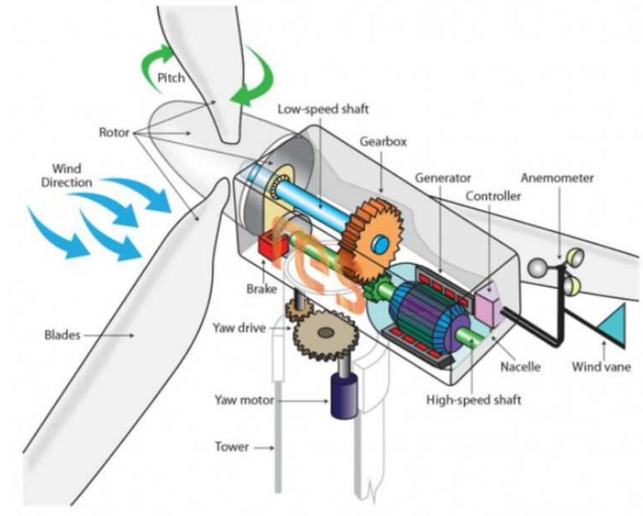


Figure I.19: Horizontal axis wind turbine components diagram. [36]

Overall, wind turbines are designed to maximize energy capture while minimizing turbulence, noise, and other environmental impacts. The design features of wind turbines are constantly evolving as new technologies and materials are developed, with the goal of improving efficiency, reducing costs, and expanding the use of wind power as a sustainable energy source.

I.6 Architectural Aspect of Wind Power Installation

I.6.1 Structure (Materials Characteristics)

Wind turbines are complex electro-mechanical systems that convert the kinetic energy of the wind into electrical energy. The key architectural aspects of wind turbines include the rotor blades, the tower, the nacelle, the gearbox, the generator, and the control system.

The rotor blades are designed to capture the maximum amount of energy from the wind and are typically made of lightweight materials such as fiberglass or carbon fiber. The tower provides support for the rotor blades and the nacelle, and its height is carefully chosen to optimize the performance of the turbine.

The nacelle houses the gearbox, generator, and other critical components of the wind turbine. The gearbox is responsible for converting the low-speed rotation of the rotor blades into the high-speed rotation required by the generator to produce electricity. The generator, typically a synchronous generator, converts the mechanical energy of the rotating shaft into electrical power.

The control system is a critical component of the wind turbine that monitors and regulates the operation of the turbine. It is designed to optimize the performance of the turbine and protect it from damage due to high winds or other environmental factors.

Overall, wind turbines are complex engineering systems that require careful de- sign and optimization of each architectural aspect to ensure efficient energy conversion and reliable operation.

Wind turbines are complex machines that convert the kinetic energy of wind into electrical power. There are several key architectural aspects of wind turbines that allow them to efficiently capture and convert wind energy, including:

- **Rotor blades:** Wind turbine blades are typically made of lightweight materials such as fiberglass or carbon Fiber and are designed to capture the maximum amount of energy from the wind (Fig. I .18, I. 20). The blades are usually shaped like airfoils to generate lift, and their length and curvature are carefully optimized to maximize efficiency.

- **Tower:** Wind turbine towers are typically made of steel or concrete and are designed to support the weight of the rotor blades and the nacelle (Fig. I .18, I. 20). The height of the tower is also an important architectural aspect, as taller towers allow turbines to capture higher wind speeds, which increases the amount of energy that can be generated.

- **Nacelle:** The nacelle is the housing that sits atop the tower and contains the gearbox, generator, and other critical components of the wind turbine (Fig. I .19, I. 20). The nacelle is designed to protect these components from the elements and to allow easy access for maintenance and repairs.

- **Gearbox:** The gearbox is a critical component of the wind turbine that converts the low-speed rotation of the rotor blades into the high-speed rotation required by the generator to produce electricity. The gearbox (Fig. I .19, I. 20) is typically located inside the nacelle and is designed to be robust and durable to withstand the stresses of operation.

- **Generator:** The generator is responsible for converting the mechanical energy of the rotating shaft into electrical power (Fig. I .19, I. 20). Wind turbine generators are typically synchronous generators that produce alternating current (AC) electricity.

- **Control system:** Wind turbines are equipped with sophisticated control systems that monitor and regulate the operation of the turbine (Fig. I .19, I. 20). These systems are designed to optimize the performance of the turbine and to protect it from damage due to high winds or other environmental factors.

Overall, the architectural aspects of wind turbines are carefully designed and optimized to capture and convert as much energy as possible from the wind, while also ensuring safe and reliable operation over the lifetime of the turbine.

I.7 The Main Components of a Wind Turbine Structure

The structure of a wind turbine can be divided into several key components (Fig. I .19, I. 20):

- **Tower 3:** The tower is the main support structure for the wind turbine and is typically made of steel or concrete (Fig. I .19, I. 20). The height of the tower can range from 30 meters to more than 100 meters, depending on the size and capacity of the wind turbine.
- **Rotor Blades 11:** The rotor blades are attached to the rotor hub and are designed to capture the energy from the wind (Fig. I .19, I. 20). They are typically made of lightweight materials such as fiberglass or carbon fiber and can range in length from 20 meters to more than 80 meters.
- **Rotor Hub 13:** The rotor hub is the central hub to which the rotor blades are attached (Fig. I .19, I. 20). It is designed to transfer the rotational force from the rotor blades to the main shaft of the wind turbine.
- **Main Shaft:** The main shaft is a long, steel shaft that runs from the rotor hub to the gearbox in the nacelle (Fig. I .19, I. 20). It is designed to transfer the rotational energy from the rotor blades to the gearbox.
- **Gearbox 10:** The gearbox is a complex mechanical system that is responsible for increasing the rotational speed of the main shaft from the low speed of the rotor blades to the high speed required by the generator (Fig. I .19, I. 20). The gearbox also helps to regulate the speed of the rotor blades to ensure optimal energy capture and reduce wear on the turbine components.
- **Generator 7:** The generator is the component that converts the mechanical energy from the rotation of the main shaft into electrical energy (Fig. I .19, I. 20). It typically consists of a series of coils and magnets that generate an electromagnetic field and produce alternating current (AC) electricity.
- **Nacelle 6:** The nacelle is a large housing structure that sits at the top of the tower and contains the gearbox, generator, and other critical components of the wind turbine (Fig. I .19, I. 20). It is designed to protect these components from the elements and provide access for maintenance and repairs.

Overall, the structure of a wind turbine is designed to efficiently capture the kinetic energy of the wind and convert it into electrical energy. Each component of the turbine is carefully engineered and optimized to ensure reliable and efficient operation over the lifetime of the turbine (Fig. I .19, I. 20).

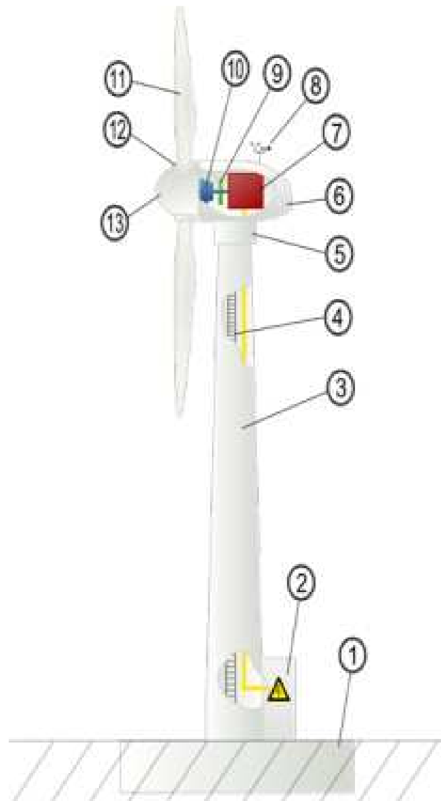


Figure I.20: The main components of a wind turbine structure. [37]

I.8 Foundation Types for a Wind Turbine Installation

Many sustainable foundation types and methods are available for onshore wind turbines. The foundation for onshore wind turbine towers can be grouped into two types:

- **First Type:** Spread foundations. ‘
- **Second Type:** Piled foundations.

In both foundation types, an interface, which is embedded in foundation concrete, must be provided between the turbine tower and foundation to ensure the connectivity and stability. Some instances, the interface decides the type of foundation to be provided for wind turbine tower.

I.8.1 Spread foundation

A spread foundation spreads the loads coming from the wind turbine tower to the soil. It is like a slab foundation and consists of a large plate that provides large area for spreading the loads to the soil. In majority times, the shape adopted in the spread footing is cylindrical or a square prism. The construction materials used to construct a spread footing are reinforced concrete.

As the base area of spread footing is larger, the pressure acting on the soil would be smaller. This decreased pressure on the soil due to large base area ensures that it will not exceed the maximum allowable soil pressure. In addition, there is an advantage of spread footing that it resists the overturning moments caused due to wind and eccentric dead loads. Settlement of a structure is nothing but its vertical downward movement and it depends on the loading and soil conditions. The spread footings help maintaining differential settlements low.

Where strong and stiff soils are encountered, the spread footing can be considered as more sustainable foundation method where in settlements are small. The spread footings are not common in clays, silty clays, unconsolidated fillings and organic soils, which have low modulus of elasticity.

Due to soil pressure at the bottom of the footing, there acts shear force. The reinforcement stirrups must be put in for the footings of insufficient thickness so that the shear failure can be very much controlled. The interface between tower and foundation consists of a “ring” or “bolt cage”. It is necessary to analyze the forces that arise in the interface in the form of tension and compression due to overturning effects. It needs to be provided with extra reinforcement at the interface level to prevent the associated damage.

I.8.2 Shallow foundation

Shallow foundation is one of the groups of spread footing. When a spread foundation is placed on the ground, or just beneath it, is termed as shallow foundation (Fig. I. 21). The base area of the shallow foundation is large enough to prevent the overturning of the wind turbine tower. The construction of the shallow foundation is done in a way that the resultant of all forces should be close to the center of the footing at the base level. This can be achieved by providing a thick heavy construction. This type of foundation is sustainable because it is quite easy to build; little excavation and refilling work is needed [3].

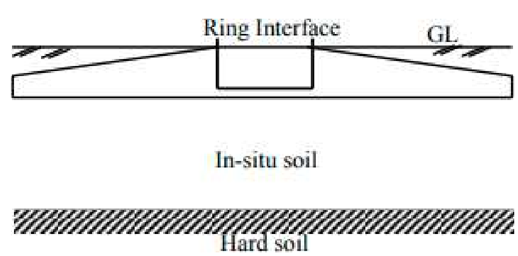


Figure I.21: Spread foundation on the ground. [38]

I.8.3 Gravity Foundation

Gravity foundation is one of the spread foundation types and is placed some depth below the ground surface by excavating the soil. After construction of it, the excavated portion is refilled with either same soil or good soil (Fig. I. 22). For better sustainability of wind turbine tower, it is always suggested to place the gravity foundation on strong soil layer instead of weak/or soft soils. Due to embedment of gravity footing into soil certain depth, the weight of the filling soil placed above the footing base will enhance the stability that the structure does not undergo overturning. It provides sustainability in terms of reduced overturning and amount of concrete required for the gravity footing. The only drawback of this type of foundation is that it requires excavation and refilling activities [3].

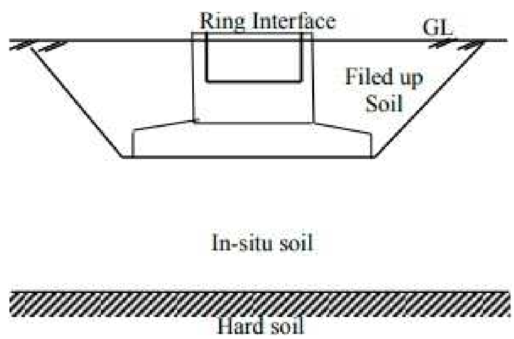


Figure I.22: Gravity type foundation. [38]

I.8.4 Pile Foundations

It is known that the soil properties are not the same at every construction location. The soil properties vary based on the local geology and the weathering type, which the rocks would undergo. The soil type decides whether to opt spread footing or pile foundation for the wind turbine tower. Especially, where huge loads are required to be transferred on to the soil and if foundation soil is weak/or soft, most of the designers recommend going for pile foundations which are very much sustainable to support the structure from overturning and other settlement associated problems. The pile foundations can sustain the tensional effects due to wind imposed bending moments on the structure.

The connection between the piles and the plate is important for the load distribution. Piles are connected to the plate by two means of (i) clamped connection and (ii) hinged connection. In the clamped case, the pile top will experience a large bending moment and in the hinged case, the pile top will not experience it. Pile group foundation consists of a steel plate or concrete plate, which serves as a connection between the group of piles and the experience tension loads. Moreover, sometimes piles can be driven to deeper depths to avoid the failures associated with tension loads.

I.8.5 Placement of Piles on Bedrock

Based on the geological formations sometimes, the bedrock can be identified at reasonable shallow depth. In such situations, for better sustainability point of view of wind turbine tower, the piles can be driven or placed at such bedrock formation levels. It will ensure the minimum settlement because, the settlement that mostly going to occur is due to pile deformations, not by soil compression at pile tip level. In this case, it is assumed that the soil is not going to share any load.

Sometimes, if necessary, piles can be anchored into the bedrock so that they can sustain comfortably the tension loads, which are mostly due to the wind actions on the wind turbine tower. In such situations, estimation of load carrying capacity of anchored piles is a challenging one for the designers and it needs experience in understanding the geotechnical and rock parameters and knowledge on pullout tests.

I.8.6 Piled Raft Foundation

The combination of spread foundation and group of piles is termed as piled raft foundation. The spreading of load in the top portion of soil is achieved with the help of spread foundation and the group of piles in the foundation will transfer the huge loads to the deeper depths. To ensure the load carrying capacity of both spread foundation and group of piles, it is required to see that there should not be any gap left between them and these foundations are surrounded with the soil effectively. Generally, piles are not effective in the cases of firm soil and bedrock because, gaps are left between piles and soil/rock, and this will result in reduced shaft friction load. The number of piles required, and their depth of termination are decided based on the equal settlement concept and pile group capacity. The design of piled raft preferably carried out using finite element method-based software. The stiffness of raft and pile are important while modelling the piled raft analysis.

I.8.7 Types of Foundations for O*ff*shore Wind Turbine Towers

The depth of sea is classified as shallow waters (0– 30 m), transitional waters (30–50 m), and deep waters (50–200 m) [4]. The cost of foundation for offshore wind farms increases significantly as the depth of sea increases from shallow waters to deep waters. Based on the construction location of wind farm in the offshore regions, a suitable foundation type is required to choose for wind turbine tower in order to achieve sustainability. In shallow waters, gravity type and monopile type foundations are used commonly.

Monopile type foundation is used most commonly rather than the gravity type foundation. Gravity type foundation is expensive to construct in sea depths beyond 10m. In sea depths more than 10m, a monopile type foundation and a multipod type foundation are commonly constructed. Multipod includes both tripod and jacket combination. Multipod type foundations are generally preferred in sea depths beyond 30m in order to minimize the foundation cost. The sea depth governs the selection of type of foundation for offshore wind turbine tower, Distance from Shore and the capacity of wind turbine. High economic feasibility and sustainability can be achieved, if multipod type foundation is deployed in deep seas region, which is located very far from shore. The different sustainable foundation types which are in practice for offshore wind farms are discussed in the following sub sections.

I.8.8 Gravity

A gravity-type foundation derives stability from its self-weight and is the first kind of foundations used in offshore wind farms. It consists of a large circular pile with a concrete plate structure resting on the seabed especially in shallow waters close to shore (Fig. I. 23). Initially, in most wind farm projects in offshore, the gravity type of foundation was used, because of the availability of mature construction expertise and installation technology that can minimize the risk [5].

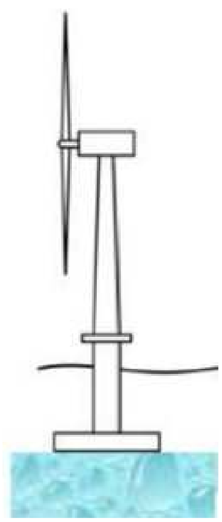


Figure I.23: gravity-type foundation. [38]

I.8.9 Monopile

Monopile type foundations (Fig. I. 24) have gained lot of popularity in the re- cent past especially in European offshore wind farms. The reasons for high use of monopile type foundations in the North Sea, Europe are: (i) installation in shallow waters where sea depth is less than 30m, (ii) the soil available at the farm sites is sand and gravel, which needs no effort to drive the piles.

This monopile type foundation technology is the most economical one for water depths less than 30m and for seabed of sand and gravel type [6]. Monopile type foundations can reduce the maintenance cost of materials [7]. Installation of monopole for wind farms in the offshore regions require jack-up barges, which cause consider- able vibration, noise, and develops suspended sediment. The marine ecosystem at the installation site can be disturbed.

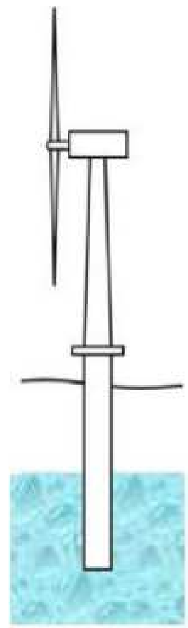


Figure I.24: Monopile type foundation. [38]

I.8.10 Suction Caisson

A suction caisson type foundation is an eco-friendly foundation because; it does not require any heavy equipment for piling or installation. It looks like an upside- down bucket (Fig. I. 25). Installation of this type of foundation does not produce high-level vibration, noise and suspended sediment. It is an economical foundation technique, because it can be installed very quickly with simple procedure [6].

Suction caisson can reduce the steel weight by 50 per cent as compared with a monopile [8]. The construction cost of tripod suction caisson foundation is half of the construction cost of foundation made with jacket piles for the same seabed geology [9]. As per the construction and installation perspectives are concerned the suction caissons can be considered as an excellent foundation choice for the offshore wind farms.

I.8.11 Multipod (Tripod and Jacket)

Space frame substructures such as tripod and jacket structures can provide the required strength and stiffness (Fig. I. 26). Tripod and jacket structures are effective in transitional water depths with relative short penetration length. These types of foundations reduce the construction costs when installed in transitional water depth. The weights of tripods and jackets used in multipod are low and hence it is an economical foundation [6]. Multipod can be more effective than monopile. In the extreme events of hurricanes and typhoons, the multipod type of foundation is most preferred than monopile and suction caisson, because these foundations need larger embedment depth and size.

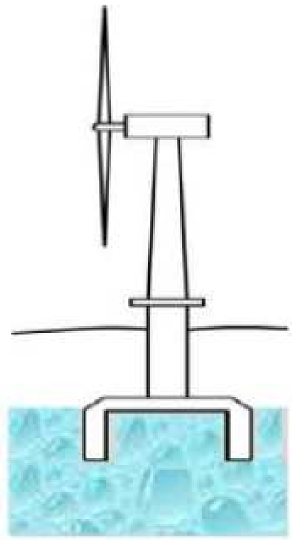


Figure I.25: Suction caisson foundation. [38]

I.8.12 Floating Substructures

These types of foundations are still in development stage and are classified into three categories namely: (i) Ballast stabilized, (ii). Mooring line stabilized and (iii) Buoyancy stabilized foundations. Floating structures have many advantages in deep waters in cost (Fig. I. 26), construction and installation [10].

Ballast stabilized foundations are reliable and economical [11]. Floating units are arranged with a certain geometrical pattern by using cables. A stabilized barge is mainly used for the buoyancy stabilized foundation. The stabilized barge is connected to the seabed by using anchors [12].

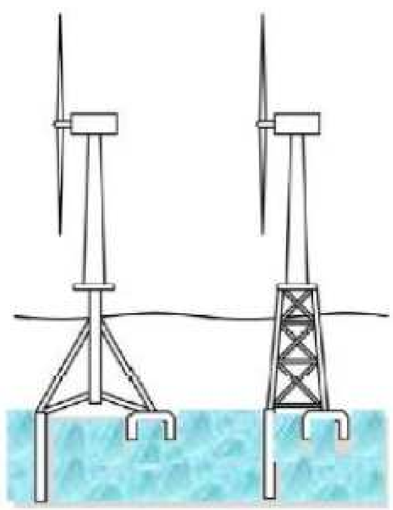


Figure I.26: Multipod foundation (Tripod and Jacket type). [38]

I.9 Stabilization of Soil for Wind Turbine Tower Foundations

Heavy weight wind farms transmit huge loads on to the soil through the foundation. To sustain such huge loads, the soil should have enough bearing capacity. Generally weak/soft soils will have low bearing capacity and these sites are straightaway cannot be used for building the foundations for wind farms. Hence, soil properties such as soil stiffness, shear strength and permeability are required to be improved. There are many different methods for doing this. The most common methods that are followed to improve the site conditions are compaction/densification methods and methods of soil reinforcement.

The settlements of soil can be minimized by exposing the soil to preloading and/or compaction. Also, vibratory methods can be employed to control the settlement of soil. By dynamic consolidation process, dropping of heavy weights on the ground or by depth vibration with vibrating machines, the in-situ soil can be dandified.

By using additional materials, the in-situ soil can be reinforced or strengthened. Permeation grouting method is the one such method, in which the grout material is sent with force in order to occupy or fill the voids in the ground. This permeation grouting method reduces the permeability and hence controls the settlement and increases the strength of soil. Jet grouting method is another similar method, which uses column-like structures made of soil-grout mixture. These jet grout columns are produced from the designed depth to the ground surface by rotating the drill rod at a controlled rate and at the same time a jet of grout filling the spaces between the soil particles. These elements are not really columns but columns-like soil improvements.

Deep soil mixing is another method used to improve the soil. A machine equipped with a mixing tool is driven down in the soil rotating. The mixing tool is then slowly retracted, still rotating and at the same time lime and cement is blown into the soil mixing with the soil. The lime reacts with the water in the undrained soil forming a new product with lower water content, much higher stiffness and stronger. This might be a suitable method if the soil quality is not good and the distance to the bedrock is at too great depth. If poor soil is involved within the shallow depth, then this soil can be replaced with better soil and compacted to achieve the desired geotechnical properties of soil.

I.10 Conclusions

From the discussion on various types of foundations for on land and offshore wind farms, it is clear that gravity type foundations can sustain from the loads effectively and are most applicable especially in shallow waters and on land. Suction caisson foundations are cost effective solutions in deep water wind farms and they can be easily installed. The tripod or jack up multipod systems are 50 per cent less cost than the monopole foundation for locations of similar geology. In the recent times, floating wind turbine concept is developed for deep-water wind farms.

The technical-economic aspect of wind power installations involves a complex interplay of technical and financial factors, including the wind resource potential, the cost of the wind turbines, and the cost of borrowing capital, among others. Proper consideration of these factors is essential for the success of wind energy projects and the growth of wind power as a source of renewable energy.

CHAPTER II

FEASIBILITY STUDIES OF THE WIND TURBINE INSTALLATION

II.1 Introduction

As we embark on a feasibility study for the installation of a wind turbine system, it is essential to thoroughly evaluate the generated energy aspect while considering both the internal and external factors that may contribute to wind turbine failure, we can develop strategies and recommendations to optimize energy production and minimize risks.

II.2 Energy Aspect

II.2.1 Movement / Energy transformation

Wind is caused by differences in pressure created by the uneven heating of Earth's surface by the sun. Radiation from the sun causes land to gain thermal energy. The air above the land also gains thermal energy and expands, becoming less dense and rising.

This movement causes an area of low pressure at the surface, creating a vacuum that draws air in. Cooler, denser air flows toward the low-pressure area at the surface to fill in the space left by the risen, heated air. This creates a convection current and thermal energy is transformed into kinetic mechanical energy in the form of moving air or wind.

A wind turbine transforms the mechanical energy of wind into electrical energy. A turbine takes the kinetic energy of a moving fluid, air in this case, and converts it to a rotary motion. As wind moves past the blades of a wind turbine, it moves or rotates the blades. These blades turn a generator. A generator works as an inverse of an electric motor; instead of applying electrical energy to turn it and create mechanical energy, it uses mechanical energy to turn and create electrical energy (Fig II. 1). Generators spin coiled wire around magnets to create an electrical current.

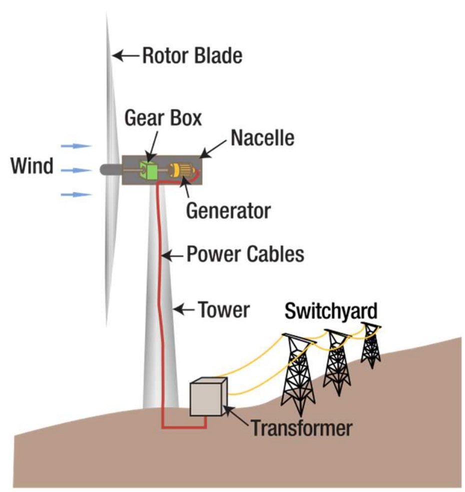


Figure II.1: Energy transformation process.[39]

Simply put, windmill energy transformation is the process of transforming wind power into electrical energy. This can be broken down into six steps:

- **Erecting the turbine :** In order for the windmill energy transformation process to initiate, we need a functional turbine to be erected in a location with abundant wind ;
- **The wind causes the rotor to spin:** The wind pushes on the rotor blades, causing the rotor to spin. This is a fairly simple process that can be recreated using a kid's wind spinner ;
- **The spinning rotor turns a generator :** The kinetic energy of the turning blades and spinning rotor is used to turn a generated that is located behind a gearbox;
- **The generator generates electricity:** Simply put, the generator converts kinetic energy to electrical energy. A generator consists of a magnet spinning inside a coil, or vice versa ;
- **The energy is stored in a battery:** Wind turbines generally come with a battery attached to them to store the energy generated. Some batteryless turbines transmit the power to a transformer directly ;
- **The electrical energy distribution:** This step completes the windmill energy transformation process. The power is distributed through the grid or directly to where it is needed.

Once a turbine is operational, the wind energy can be converted into electrical power, depending on the strength and direction of the wind.

II.2.2 Windmill energy transformation process efficiency

The windmill energy transformation process is inefficient. This is because the blades of a windmill convert energy from the wind into rotational motion, which is then used to power a generator. A certain amount of energy is lost during each step of the process.

For example, the resistance of the rotor itself can cause a certain amount of kinetic energy to be lost, requiring the wind to push harder on the blades in order to turn it. A large amount of energy is also lost in heat and sound. Wind turbines can be very noisy when they are operating at high speeds.

Overall, only a small percentage of the wind's energy is actually used to generate power. The rest is lost as heat or noise.

Wind turbines have been around since mid-19th century, but they have only become mainstream in recent years. The technology has come a long way since then, and there are now many different types of turbines that can be used to produce electricity. The windmill energy transformation process efficiency is only going up with modern technology.

II.3 Problems Realizations

II.3.1 External problems

Problem 1: Extreme weather conditions

- **Problem analysis:**

  Wind turbines are designed to withstand high winds, but severe storms, hurricanes, or tornadoes can exceed their operational limits and lead to turbine failure. Lightning strikes can also damage electrical components.

Table II.1: Distribution of reasons for accidents caused by nature. [13]

Cause	Count
Nature (strong wind)	32
Nature (lightning strike)	9
Nature (storm)	4
Nature (other)	3
Nature (cyclone)	2
Nature (tornado)	2
Nature (cold)	1
Nature (due to collision)	1
Nature (strong wind, lightning strike)	1
Nature (strong wind, snow)	1
Structural (bolt failure)	1
Structural (smashed barge)	1

In autumn 2021, an operator of wind farm with Enercon machines in southern Germany halts all nine turbines as root cause investigated, while blade of same model also damaged in France.

Figure II.2: Broken Enercon and Nordex wind turbine blades in Germany and France due to a storm. [13]

- **Suggested solutions**

Currently, both onshore and offshore wind farms have the capacity to with- stand up to category 3 storms, through built-in mechanisms, which lock and feather the blades – twisting them so that they no longer catch the wind and rotate when wind speeds exceed 55 miles per hour. Once the storm has subsided, the turbine returns to full functionality, meaning a full guided and operational.

Problem 2: Foundation and structural issues

- **Problem analysis**

The foundation and supporting structure of a wind turbine must be robust enough to withstand the loads and vibrations generated by the rotating blades. Weak foundations or structural defects can cause misalignment, excessive vibrations, and ultimately, structural failure. In short, No structure can remain standing without a solid foundation.

Figure II.3: Turbine failure due to weak foundation. [40]

Problems in the foundations usually materialize as cracks in the concrete. In many cases, they are caused by the cyclical nature of foundation loads – with a lifespan of 20 to 25 years the foundation can be exposed to millions of loads cycles. These cracks can be radial or circumferential, and appear both in the pedestal (the visible part of the foundation, where the tower connect to the foundation) and in the buried part of the foundation.
Usually, these cracks tend to appear soon (1 or 2 years) and they do not pose a danger to the stability of the wind turbine. However, water could infiltrate them damaging the reinforcement bars.

- **Suggested Solutions**

Every now and then, we still hear stories of foundations that need some kind of intervention due to mistakes during design and/or execution. Unfortunately, there is a lot of secrecy on these issues. Unlike other civil engineering products (e.g., roads, dams, etc.) problems with wind turbines foundations are generally hidden, probably because they are mainly private investments and probably the companies experiencing an expensive problem prefer to have as little publicity as possible.

From several studies I have been able to found on the topic, it seems that towers and foundations are accountable for less than five.

The position of cracks can be defined with ultrasonic devices. These technologies use the echo of sonic waves to create Three-dimensional images of the foundation. In practice, a crack will appear as a discontinuity, reflecting the wave to the receiver.

So knowing the amount of damage that is done to our foundation will be our deciding factor, It's important to note that not all cracks are created the same: shrinkage cracks or cracks in the grouting due to an excess of material are usually less critical than the appearance of voids (for instance below the load spreading plate or the bottom flange of the anchor cage).

Problem 3: Environmental factors:

- **Problem analysis**

Environmental factors such as high humidity, saltwater exposure (in coastal areas), or extreme temperature variations can accelerate corrosion, leading to electrical or structural failures over time.

Figure II.4: Wind turbine anchor bolts (foundation bolts) affected by corrosion and Mold. [41]

- **Suggested solutions**

To address the impact of environmental factors on wind turbines, here are some potential measures that can help mitigate the effects and prevent corrosion-related failures:

- 1- Protective coatings: Applying appropriate protective coatings to the turbine components can help shield them from moisture, salt, and other corrosive elements. These coatings should be specifically designed for wind turbine applications and provide effective corrosion resistance
- 2-Corrosion-resistant materials: Using corrosion-resistant materials in the construction of wind turbine components can significantly reduce the effects of environmental factors. For example, using stainless steel or other corrosion-resistant alloys for critical parts exposed to harsh conditions can help increase their lifespan.
- 3-Sealing and weatherproofing: Proper sealing and weatherproofing of turbine components, such as electrical connections and control cabinets, can prevent moisture ingress and minimize the potential for corrosion. Sealing techniques may include gaskets, weather-resistant seals, and cable glands.
- 4-Regular inspection and maintenance: Implementing a comprehensive inspection and maintenance program is crucial to detect and address any signs of corrosion at an early stage. This includes routine visual inspections, monitoring of corrosion-sensitive areas, and regular cleaning to remove debris or salt buildup.
- 5-Environmental monitoring: Installing environmental monitoring systems can provide real-time data on factors like humidity, temperature, and salt concentration in coastal areas. This information can help opera- tors identify conditions that may accelerate corrosion and take appropriate preventive measures.
- 6-Cathodic protection: Cathodic protection is a technique that can be employed to prevent corrosion by applying a sacrificial anode or an impressed current to the metal surfaces. This helps to counteract the electro- chemical reactions that cause corrosion.
- 7-Design considerations: Incorporating design features that minimize the exposure of vulnerable components to harsh environmental conditions can help reduce the risk of corrosion-related failures. For example, designing effective drainage systems and protective covers can limit moisture accumulation.

It is important to note that these measures should be implemented in accordance with industry standards and guidelines, and tailored to the specific environmental challenges faced by the wind turbine installation.

Problem 4: Blade damage

- **Problem analysis**

Blade damage in wind turbines can occur due to various factors. Here are some common causes of blade damage:

- 1- Lightning strikes: Wind turbines are often tall structures and can attract lightning strikes during thunderstorms. A direct lightning strike or even a nearby strike can cause damage to the blades, leading to cracks or structural issues.
- 2-Bird and bat collisions: Birds and bats can collide with rotating wind turbine blades, especially in areas with significant bird or bat populations. These collisions can cause significant damage to the blades, affecting their structural integrity and performance.
- 3-Ice buildup: In colder climates, ice can accumulate on the blades during winter. The added weight of ice can cause unbalanced forces and strain on the blades, leading to cracks or structural damage.
- 4-Manufacturing defects: Occasionally, manufacturing defects or material weaknesses can be present in wind turbine blades. These defects can result in premature wear, cracks, or even blade failure over time.
- 5-Fatigue and stress: The continuous rotation of wind turbine blades subjects them to cyclic loading and stresses. Over time, this cyclic loading can lead to fatigue, resulting in the development of cracks or other structural issues.
- 6-Wind gusts and extreme weather: Strong wind gusts, especially during severe storms or hurricanes, can impose excessive loads on the blades. If the loads exceed the design limits of the blades, it can result in blade damage or failure.
- 7-Debris impact: Wind turbines are vulnerable to debris such as rocks, ice fragments, or loose objects being thrown by strong winds. The impact of such debris can cause blade surface damage, leading to erosion, dents, or even structural impairment.

- **Suggested solutions**

To protect against the causes of blade damage in wind turbines, several measures can be implemented:

- 1- Lightning protection systems: Installing lightning protection systems, such as lightning rods and conductive pathways, can help divert lightning strikes away from the blades, reducing the risk of damage. Grounding systems are also essential to dissipate any electrical energy safely.
- 2-De-icing systems: In cold climates, de-icing systems can be installed on wind turbine blades to prevent ice buildup. These systems may use heating elements or coatings that prevent ice formation, reducing the risk of unbalanced loads and structural damage.

- 3-Quality control and manufacturing standards: Implementing stringent quality control measures during blade manufacturing can help identify and rectify potential defects or weaknesses early on, reducing the likelihood of premature wear or failures.
- 4-Structural design and material improvements: Continual advancements in blade design and materials can enhance their durability and resistance to fatigue, allowing them to withstand cyclic loading and environmental stresses more effectively.
- 5-Wind turbine monitoring and control: Implementing comprehensive monitoring and control systems can help detect potential issues in real- time. This includes monitoring blade conditions, detecting stress levels, and identifying any anomalies that may indicate impending damage.
- 6-Regular inspection and maintenance: Conducting regular inspections and maintenance procedures, including visual inspections, non-destructive testing, and structural integrity assessments, can identify any signs of damage or wear and allow for timely repairs or replacements.

By implementing these protective measures, wind turbine operators can minimize the risk of blade damage and ensure the long-term reliability and performance of their turbines.

Other problems that can cause wind turbine failure

There are several external problems that can affect wind turbines and potentially cause their failure. Here are some common issues:

- Poor maintenance: Inadequate maintenance can result in mechanical or electrical failures. Regular inspections, lubrication, and replacement of worn-out parts are crucial for the smooth operation and longevity of wind turbines.

- Grid connection problems: Wind turbines are typically connected to the electrical grid to transmit the generated power. Issues like voltage fluctuations, grid failures, or improper synchronization can cause malfunctions or even damage the turbine’s electrical components.

- Wildlife interaction: Wind turbines can pose a risk to birds and bats. Collisions with spinning blades can cause significant harm to wildlife populations. Mitigation measures, such as careful turbine placement and advanced monitoring systems, implementing bird and bat deterrent measures, such as visual markers, noise-emitting devices, or even radar systems, can help reduce the likelihood of collisions with rotating blades.

II.3.2 Internal Wind turbine failure causes:

Internal problems within wind turbines can lead to failures. Here are some common internal issues that can cause turbine failures:

Figure II.5: A flock of birds crossing a wind farm.[42]

Problem 1 Gearbox failures Problem

analysis

The gearbox is 13% of the overall cost of a typical onshore wind turbine, making it a costly and heavy part of the wind turbine, "There are around 1,200 incidents of gearbox failures reported each year – one failure per 145 turbines." (According to a specialist renewable energy underwriter, 2014). [15]

If a gearbox is to be replaced, the plant outage can last between a few days to as much as two months, depending on parts availability, the top failing components in wind turbine gearboxes are:

- Bearings at 70%
- Gears at 26%
- Others at 4%.

It is a common problem that gearboxes in wind turbines, more than those in any other application, tend to fail prematurely. It has been known that at some wind farms, up to half of all gearboxes have failed within a few years. There are numerous reasons for this, including the relative newness of the industry, the rapid evolution of turbines to extra-large sizes, poor understanding of turbine loads, and an emerging, unexplained failure in turbine bearings, called axial cracking.

Statistics show that there is a 60% combined drive-train failure rate, and that the top gearbox failure is due to the high or intermediate speed shaft bearing axial cracks.

This has been thought to be down to the wind turbine drive trains undergoing severe transient loading during start-ups, shutdowns, emergency stops and during grid connections. It is this load casings that results in torque reversals that can prove damaging to bearings. This is due to rollers skidding during the sudden relocation of the loaded zone. Seals and lubrication systems must be suitable to work constantly over a varied temperature range to prevent the ingress of dirt and moisture.

Though there is no single reason why wind turbine gearboxes fail prematurely, the gearbox's reputation for a high failure rate is largely due to the engineering challenges of assessing the non-torsional loads that pass through the gearbox, which affect the gears and bearings.

Some common reasons for wind turbine gearbox problems can include:

- An extremely low service factor
- Dirty or water-contaminated lubrication
- Site conditions such as capacity factor, restriction, wind levels etc.
- Transient loads lead to sudden accelerations and load-zone reversals
- Uneven load sharing and high edge stresses due to improper bearing settings

Other parameters important for wind power generation must also be considered carefully including: efficiency, power, slip, performance, effective cooling all at full and partial loads and the ability to withstand environmental stresses. When failure is realized, sometimes the only solution is to exchange the component.

Service providers can provide services to maximize the production, availability, reliability, and performance of major components such as turbine gearboxes and generators. However, downtime due to component availability, production and reliability results in unexpected incalculable costs.

This list of unforeseen circumstances and incurred costs can be eliminated with the help of reliable bolting systems.

Suggested solutions:

Maintaining the gearbox in a wind turbine in good condition is crucial to ensure reliable and efficient operation. Here are some key maintenance practices for gearbox maintenance:

- 1. Regular inspections: Conduct routine visual inspections of the gearbox to identify any signs of wear, leaks, or abnormal conditions. Inspect the housing, seals, bearings, gears, and lubrication system for any indications of damage or degradation.
- 2. Lubrication maintenance: Proper lubrication is vital for gearbox performance and longevity. Follow manufacturer guidelines for lubrication intervals and use recommended lubricants. Regularly check oil levels and condition, and perform oil analysis to detect contaminants, water ingress, or signs of degradation.
- 3. Vibration monitoring: Implement vibration-monitoring systems to detect excessive vibration levels in the gearbox. Unusual vibrations can indicate misalignment, gear wear, or bearing issues. Analyze the vibration data regularly and take corrective actions if abnormal levels are observed.
- 4. Bearing maintenance: Bearings play a critical role in gearbox performance. Monitor bearing condition through inspections, temperature measurements, and lubrication analysis. Replace worn or damaged bearings promptly to prevent further damage to the gearbox.
- 5. Alignment checks: Misalignment can lead to increased stress and wear on gearbox components. Regularly check and adjust the alignment between the gearbox and other connected components, such as the rotor or generator, to ensure proper alignment and minimize unnecessary strain.
- 6. Filter and seal maintenance: Clean or replace filters regularly to prevent contaminants from entering the gearbox. Inspect and maintain seals to prevent oil leaks and ingress of moisture or dust, which can adversely affect gearbox components.
- 7. Maintenance of ancillary components: Pay attention to ancillary components, such as couplings and shafts, which connect the gearbox to other parts of the wind turbine. Inspect and maintain these components to ensure proper functioning and alignment.
- 8. Training and expertise: Ensure that maintenance personnel are trained in gearbox maintenance procedures and have the necessary expertise to handle gearbox-related tasks effectively. Stay updated with the latest maintenance techniques and industry best practices.

Problem 2 Generator failures

Problem analysis:

The generator in a wind turbine is responsible for creating the electricity by converting mechanical energy into electrical energy. When the generator fails, no power is produced, costing the wind farm operator valuable revenue. There are several reasons why the generator can fail, including wind loading, weather extremes, and thermal cycling. Mechanical or electrical failure of the bearings, excessive vibration, voltage irregularities, and cooling system failures can lead to excessive heat and fire. Lastly, manufacturing or design faults, improper installation, lubricant contamination, and inadequate electrical insulation can also cause the generator to fail. A comprehensive maintenance and repair program will improve the reliability and longevity of the generator, avoiding costly shutdowns and unexpected repairs.

Suggested Solutions:

The simple way to maintain any equipment is to do a regular preventive maintenance, meaning you can practically apply the same solutions for the gearbox failure such as regular inspections, vibration monitoring, lubrication control and other basic tasks that can be so beneficial to our equipment in addition to:

- 1. Thermal monitoring: Monitor the temperature of the generator using sensors and thermal imaging techniques. Elevated temperatures can indicate is- sues such as insufficient cooling, overload conditions, or insulation problems. Address any temperature anomalies promptly to prevent further damage.

- 2. Electrical testing: Perform regular electrical tests, such as insulation resistance measurements and partial discharge analysis, to assess the condition of the generator's electrical insulation. Early detection of insulation breakdown can help prevent major failures.

Problem 3 Control system malfunctions Problem

analysis:

The control system regulates and monitors the operation of the wind turbine. Malfunctions in the control system can affect turbine performance and even result in shutdowns or unstable operation.

Control system malfunctions in a wind turbine refer to issues within the system responsible for regulating and monitoring the turbine's operation. These malfunctions can arise from sensor failures, communication errors, software glitches, power supply issues, control loop failures, faulty actuators or motor control, and human error. Sensor failures can lead to inaccurate data, while communication errors disrupt data transmission. Software glitches and power supply issues can cause unexpected behavior and system instability.

Control loop failures result in inefficient turbine operation and faulty actuators or motor control components lead to improper positioning. Human error during maintenance or configuration changes can also cause malfunctions. Detecting and addressing these malfunctions promptly through monitoring, maintenance, and diagnostics is crucial for ensuring the reliable and efficient operation of wind turbines. [16]

Suggested solutions:

While it is challenging to completely eliminate the risk of control system malfunctions in wind turbines, there are measures that can be taken to prevent and minimize their occurrence. Here are some ways to help mitigate control system malfunctions:

- 1. Robust design and redundancy: Implement a robust control system design that incorporates redundancy and backup components. Redundancy ensures that critical functions have duplicate systems or backup mechanisms in place, reducing the risk of complete system failure.

- 2. Regular software updates: Keep the control system software up to date with the latest releases provided by the turbine manufacturer or supplier. Software updates often include bug fixes, security patches, and performance enhancements, reducing the likelihood of malfunctions.

- 3. Comprehensive testing and validation: Prior to commissioning or after significant modifications, conduct thorough testing and validation of the control system. This includes functional testing, simulation, and field-testing to ensure the system operates as intended and can handle different operating conditions.

- 4. Cybersecurity measures: With the increasing use of digital technologies, it is important to implement cybersecurity measures to protect the control system from potential cyber threats. This includes network security protocols, firewalls, intrusion detection systems, and regular security audits.

II.3.3 Other problems that can cause wind turbine failure

- 1. **Electrical system faults:** Problems within the electrical system, such as faults in power converters, transformers, or switchgear, can disrupt power generation and transmission. Electrical failures may result from component failures, insulation breakdown, or poor connections, requiring troubleshooting and repairs.

- 2. **Fatigue and material degradation:** Wind turbines are subject to cyclic loading and stresses that can lead to material fatigue and degradation over time. This can cause cracks, corrosion, or structural weakening, eventually leading to component failures if not detected and addressed.

- 3. **Blade and rotor system issues:** Internal problems within the blade and rotor system can cause failures. This includes structural failures, delamination, blade misalignment, imbalance, or pitch system malfunctions. These issues can reduce turbine efficiency, cause vibrations, and potentially lead to catastrophic blade failures.

II.4 Conclusion

To mitigate internal problems, wind turbine operators focus on regular inspec- tions, condition monitoring, maintenance protocols, and implementing robust qual- ity control during manufacturing. Advanced monitoring and diagnostic systems are used to detect early signs of internal and external issues and enable proactive main- tenance and repairs. Continuous research and development also aim to enhance the reliability and durability of wind turbine components.

CHAPTER III

MODELISATION OF WIND TURBINE

III.1 Introduction

Introduction The success of a wind farm project depends on accurate and reliable modelling of wind turbines. The modelling process involves simulating the behavior of wind turbines under different operating conditions and analyzing their performance. In this chapter, we present the modulization of wind turbines within the context of a feasibility study for a wind farm implantation. We conducted three simulations, one using ANSYS CFX and the other with Abaqus, and the third one using Ashes in addition to incorporating theoretical calculations. This chapter aims to provide an overview of the wind turbine modulization process, discussing the simulation methodologies employed and the theoretical calculations used for validating the results.

Our main goal for this chapter is choosing our model dimensions, and applying them to our simulation, and later on initializing the it with given conditions such as our area's wind speed and material type and other settings.

III.2 Study model

III.2.1 Choice of model and localization.

The choice of wind turbine model and their location depends on several factors, such as climatic conditions, wind availability, geographical constraints, local regulations, environmental considerations, and energy needs.

Location selection

The choice of wind turbine model and their location depends on several factors, such as climatic conditions, wind availability, geographical constraints, local regu- lations, environmental considerations, and energy needs:

- The first consideration is the wind potential of the site. It is necessary to assess the wind speed and direction (Fig III.1) over a significant period of time to determine if the Arzew site is windy enough to produce a satisfactory amount of energy.
- The topography of the site plays an important role in the performance of our wind structure. Areas with mountainous terrain (Fig III.2) are of particular significance.
- The proximity to an existing power line is another important factor to consider. Easy connection to the electrical grid facilitates the integration of wind energy into the overall power system and reduces connection costs.
- Regulatory constraints: It is crucial to verify local regulations regarding wind turbine installations. Some regions may have restrictions on the maximum height of wind turbines, minimum distances from residential areas, or pro- tected zones.

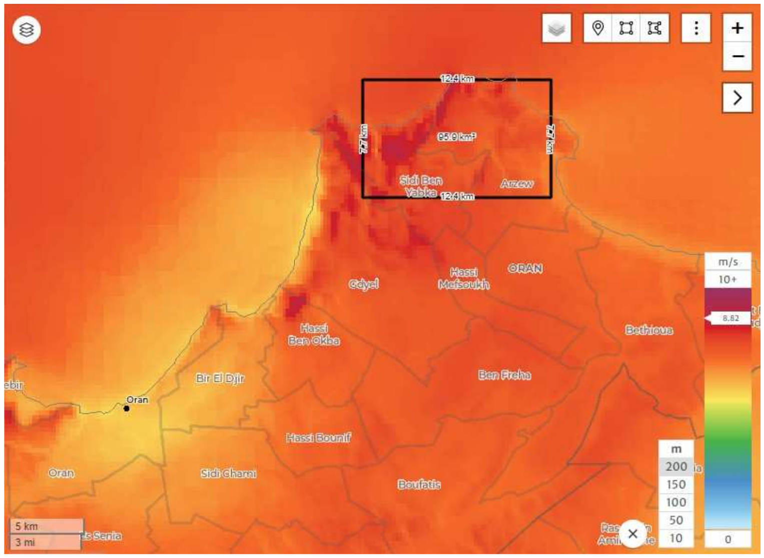


Figure III.1: Wind speed at an altitude of 200 meters in the Arzew region.

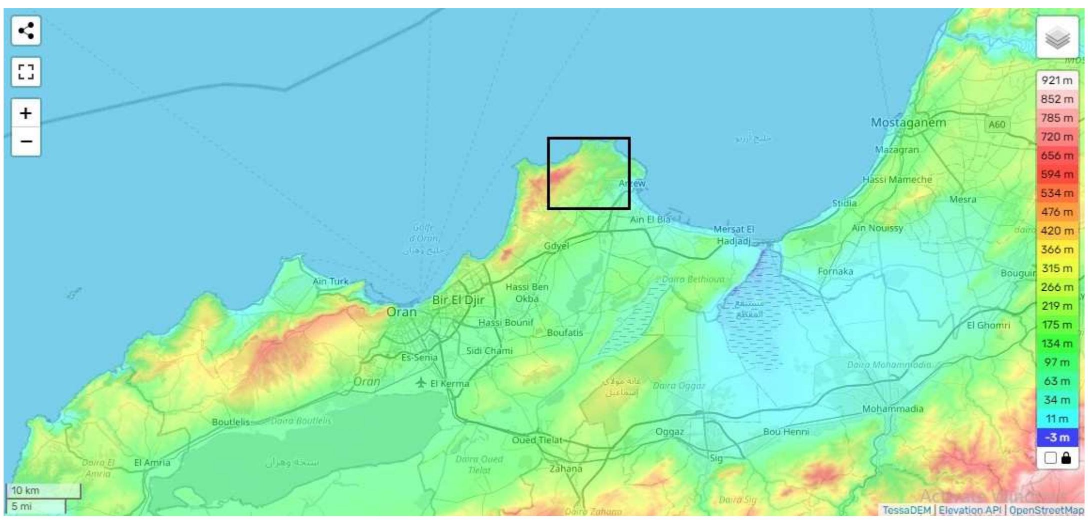


Figure III.2: The topography map displays the altitude of the designated area.

- The environmental impact of wind turbine installations must be taken into account. It is necessary to conduct studies to assess potential effects on wildlife, flora, migratory birds, and local ecosystems. Mitigation measures may be necessary to minimize these impacts.
- The accessibility to the site is an important factor for the transportation of wind turbine equipment during the installation phase and for subsequent mainte- nance. Proximity to roads, ports, or waterways can facilitate the transportation of wind turbine components.

The choice of model

Our choice of model is based on several criteria such as:

- The architectural features of our wind structure.
- The structural characteristics of the structure.
- The location where we will build our structure.
- The various loads applied to the structure (wind speed, type of foundation that acts as an anchor).
- Shear forces that represent extreme cases such as earthquakes and/or storms.

III.2.2 Model dimensions (choosing which dimension suits our case).

the dimensions of a model are crucial and primarily determined based on the actual data. The fundamental formula for wind power plays a vital role in this determination

$$P = \frac{1}{2}.A.\rho.V^{3} \tag{III.1}$$

Where:

- P= the power generated (W),
- A= the swept area (m^2),
- P= the air density (kg/m^3),
- V= the wind velocity (m/s).

To effectively manage wind power, one can manipulate two key factors: the swept area and the wind velocity achieved through altitude. Increasing the size of the swept area results in the generation of higher power output. Similarly, elevating the altitude contributes to an increase in wind speed. It is widely acknowledged that higher altitudes exhibit greater wind speed gains, thereby enhancing the overall potential for power generation. These factors play a critical role in the design and optimization of wind power models, ensuring efficient utilization of wind resources, that’s why we ended up choosing the following dimensions (Fig III.3)

In order to determine the diameter of the rotor, an existing model in the Ashes software was utilized as a reference.

It is essential to select a tower height that surpasses double of the blade length. In this particular case, a tower height of 130 meters has been chosen. By ensuring that the tower height exceeds the rotor diameter, several advantages can be obtained. Firstly, a taller tower allows the rotor to operate in a less turbulent and more consis- tent wind flow, as it reaches a higher altitude where wind speeds tend to be stronger and more consistent. This leads to increased power production efficiency. Secondly,

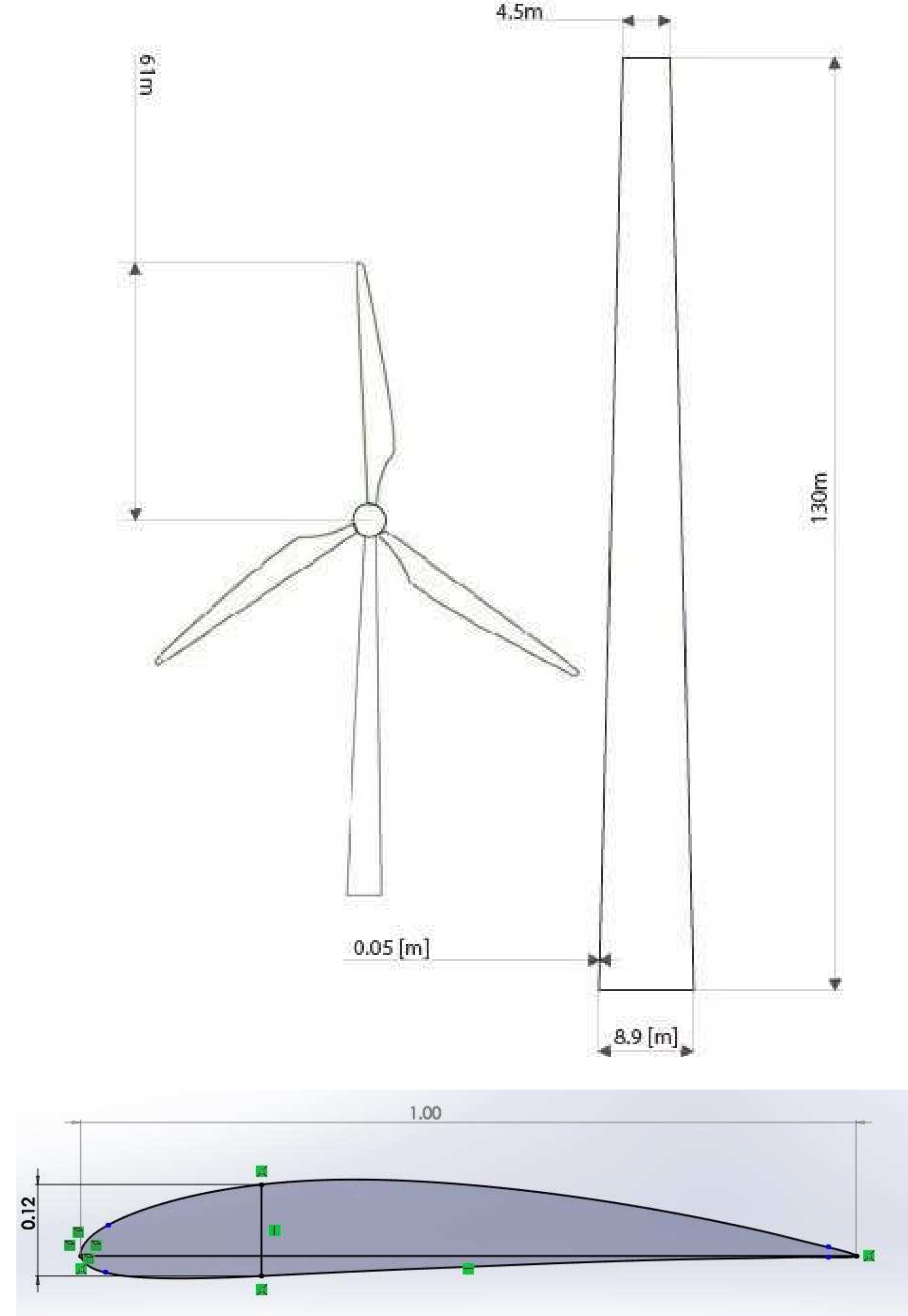


Figure III.3: Real Model of Turbine

a tower height greater than the rotor diameter helps to minimize the occurrence of blade tip losses, where the blades experience drags and reduced efficiency when operating too close to the ground or structures.

III.3 Modelisation

III.3.1 Calculations approach

In our work, to perform our simulation, we need to follow the following steps:

- Identification of input parameters of the problem and configure them:
  - Dimension
  - Wind speed
  - Fixation (anchoring)
- Implementation of the model and transforming it into a computational model using the software (**SOLIDWORKS, ABAQUS, ANSYS**) (Fig III.4-III.8-III.12).
- Execution of our simulation (Fig].
- Analysis of the results (Fig IV.1-IV.8]).

III.4 modelisation and Simulation of our wind turbine

III.4.1 SolidWorks modelisation:

To create a rotor part of a 3-blade wind turbine using SolidWorks, you can follow these general steps:

- Create a New Part: Open SolidWorks and create a new part document.
- Create the Blade Airfoil: Sketch an airfoil shape on the cross-section of the blade. This will define the aerodynamic shape of the blade. Use reference airfoil data or specialized airfoil tools to create the desired shape.(in our case we used KineticTurbineCalculator)

Table III.1: scaling factor for our air foils

N	RADIUS [M]	CHORD LENGTH [M]
1	6.0	10.1512
2	12.0	8.1253
3	18.0	6.1041
4	24.0	4.7909
5	30.0	3.917
6	36.0	3.3036
7	42.0	2.8524
8	48.0	2.5078
9	54.0	2.2365
10	60.0	2.0176

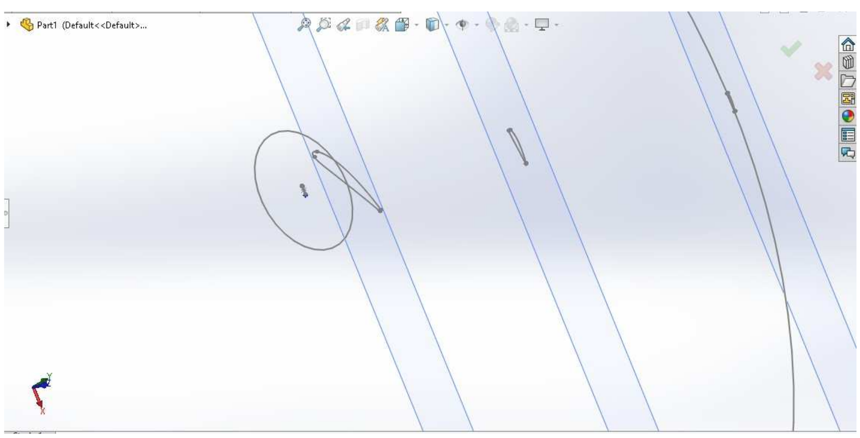
Table III.2: scaling factor for the twist angle

N	RADIUS [M]	TWIST ANGLE [DEG]
1	6.0	32.1134
2	12.0	18.2293
3	18.0	11.3827
4	24.0	7.5516
5	30.0	5.144
6	36.0	3.501
7	42.0	2.3115
8	48.0	1.4119
9	54.0	0.7082
10	60.0	0.143

These are the setting for the **NACA_4412** air foil, which was selected by the program mentioned earlier. With given results we are able to import our air foil design to solidworks instantly by going through some simple steps (featured options
> Curves > import > select file generated by kineticTurbineCalculator of NACA_4412

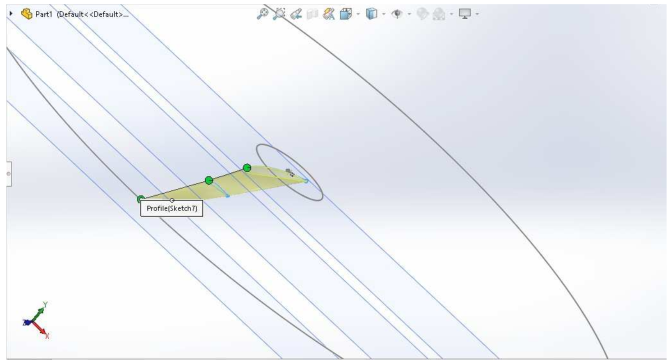
So, after creating the air foil we attach it to a sketch or at least a plane, after that we split the entities to create desired settings such as entering and exiting areas for wind and create a mid-point and move our entities to the starting point of the plan by matching the mid-point and the start of the plan (we will need that later for scaling and rotating as a reference point)

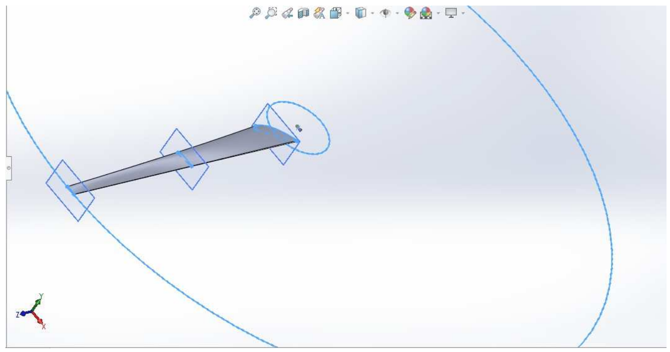
We create multiple plans (up to 10 plans for better design of our blade) ,in our case we settled for 3 plans (6m,30m,60m) we moved our entities that we created earlier, scaled them, rotated them, all according to given results by KineticTurbineCalculator

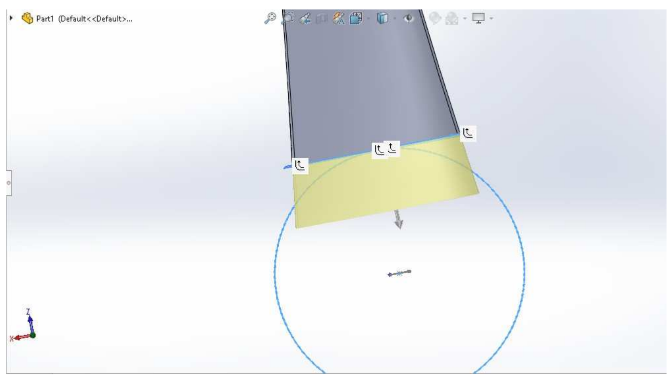


We created 2 circles linking all planes to function as a guide to our surface loft that can be created between two closed surfaces located in different planes (two air foils scaled and rotated) but crossed by the same plane (where we drew the 2 circles)

Now we have to extend the blade’s length towards the hub area, create the hub which is a 12m diameter hub, we multiply the created blade twice to get our 3 blades.







Now we merge our blades with the hub area combining both parts and creating a common area. And by that we ended creating our wind turbine geometry.

Next step was creating a fluid domain that surrounds our wind turbine, we did that in two simple steps, first created a mini-cylinder that functions as a rotor area just to simplify our wind turbine geometry to easily apply our boundary conditions to both inlet, outlet, and open space. This part includes our Blade. This combined geometry is to be saved separately as: Rotor part.

The second step was creating a Cube fluid domain that surrounds our rotor area which is respectively larger than the rotor fluid domain because it will represent the free area around our wind turbine (wind starting point and flow direction). This part doesn't include a Blade so overlapping with the first part isn't an option. This combined geometry is to be saved separately as: Stator part.

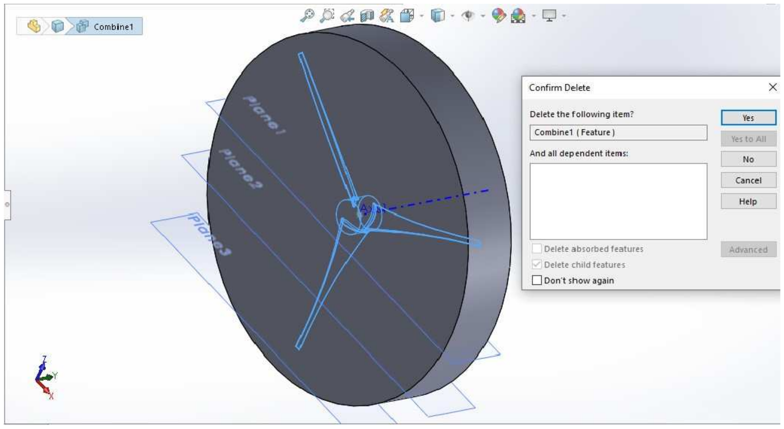


Figure III.4: combined domain of blade/cylinder in SOLIDWORKS

And with that we concluded the required part for the CFD simulation, we can now save our work and exit solidworks.

III.4.2 Simulation tools

Abaqus:

Abaqus is a widely used finite element analysis (FEA) software for simulating and analyzing complex mechanical systems. In wind turbine tower frequency analysis, Abaqus helps model the tower's behaviour and determine its natural frequencies. This information is vital for ensuring structural integrity and stability, allowing engineers to design the tower to avoid resonance and withstand external dynamic forces. Abaqus provides the tools to create a detailed tower model, define material properties, apply loads, and conduct simulations for analysing its static behaviour.

Ansys (CFX):

ANSYS is a comprehensive suite of engineering simulation software widely used in various industries for virtual prototyping, product design optimization, and per- formance analysis. It provides engineers and designers with powerful tools to simu- late and analyze the behavior of physical systems, enabling them to make informed decisions and optimize their designs before physical prototyping.

One of the solvers included in the ANSYS software suite is the ANSYS CFX solver. CFX is a computational fluid dynamics (CFD) solver specifically designed to simulate and analyze fluid flows and heat transfer phenomena. It utilizes advanced numerical algorithms and turbulence models to accurately predict and visualize complex fluid dynamics behavior, such as flow patterns, pressure distributions, and temperature gradients.

Ashes:

Ashes is an aeroelastic software that performs highly accurate dynamic analyses of onshore, offshore bottom-fixed and offshore floating wind turbines thanks to stateof-the-art engineering models. Ashes has been used by wind turbine designers, researchers and academics for more than 10 years, and is continually being enhanced to ensure that it meets the requirements of wind turbine engineers over the world[17].

III.5 Model simulation

III.5.1 ashes simulation

The Ashes software provides a comprehensive platform for wind power simula- tion and analysis. By studying the performance and characteristics of the existing model within this software, we can gain valuable insights into the optimal rotor diameter for our wind power system. Through simulation and analysis, we can as- sess factors such as power output, efficiency, and overall system performance under varying wind conditions. By leveraging the capabilities of the Ashes software, we can make informed decisions regarding the rotor diameter, ensuring that it aligns with the specific requirements and objectives of our wind power project. This ap- proach allows us to integrate empirical data and advanced computational modeling to enhance the accuracy and reliability of our simulations, leading to a more effective design and implementation of the wind power system.

It comes with a predetermined designs with the ability of changing some param- eters to desired settings.

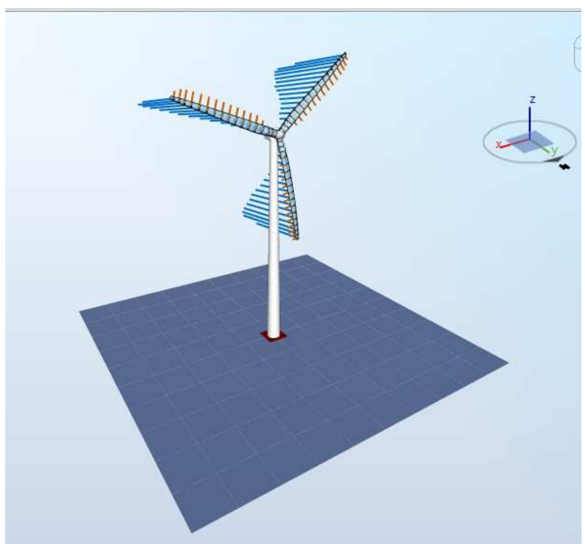


Figure III.5: Animated 3D model for a wind turbine in ASHES

We have changed the parameters of the turbine to the required settings that we have decided before, including the turbine geometry and wind speed.

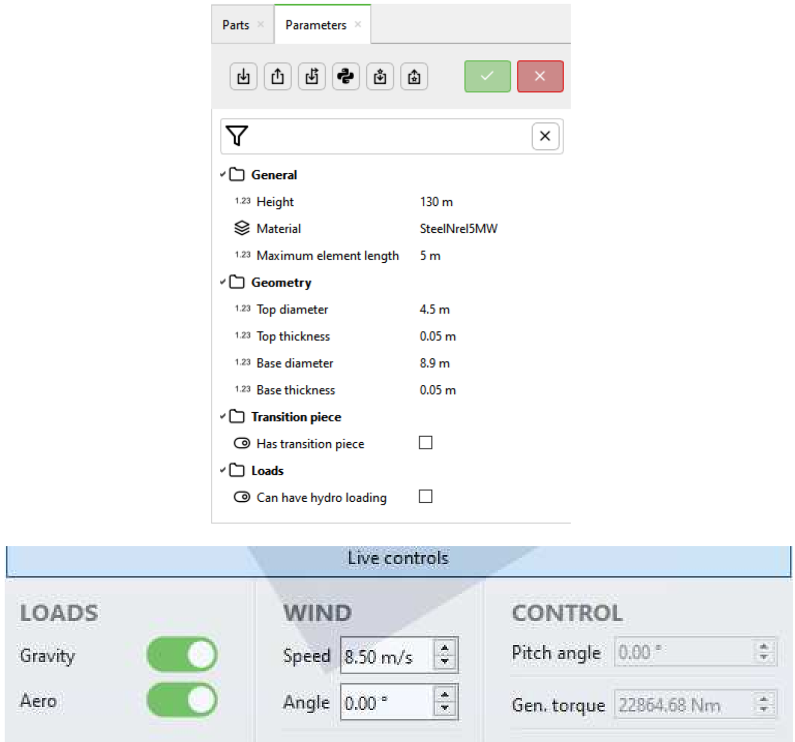


Figure III.6: Input parameters in ashes

After that we ran the simulation and extracted the following graphs

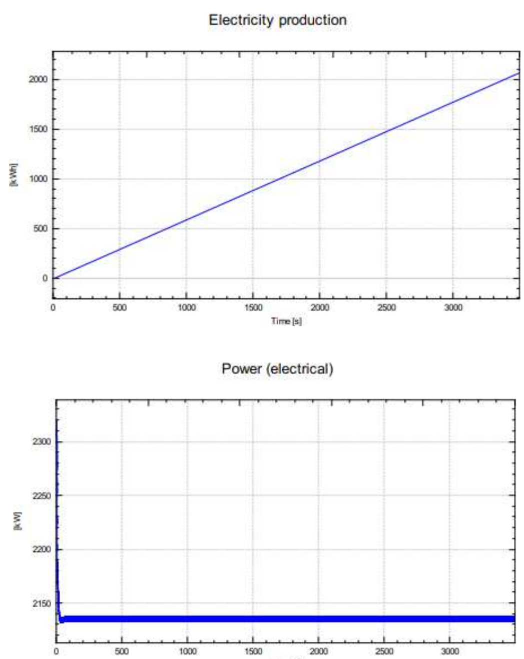


Figure III.7: electricity production and power output by unit of time.

Also, we extracted the eigenvalues for the natural frequency of the turbine.

III.5.2 Frequency analysis (static analysis)

To set up the simulation in Abaqus for wind turbine tower frequency analysis, we would typically follow these general steps:

- **Geometry Creation**: we create a 3D model of the wind turbine tower in Abaqus. This involves defining the tower's shape, dimensions, and any other relevant geometrical details as mentioned before

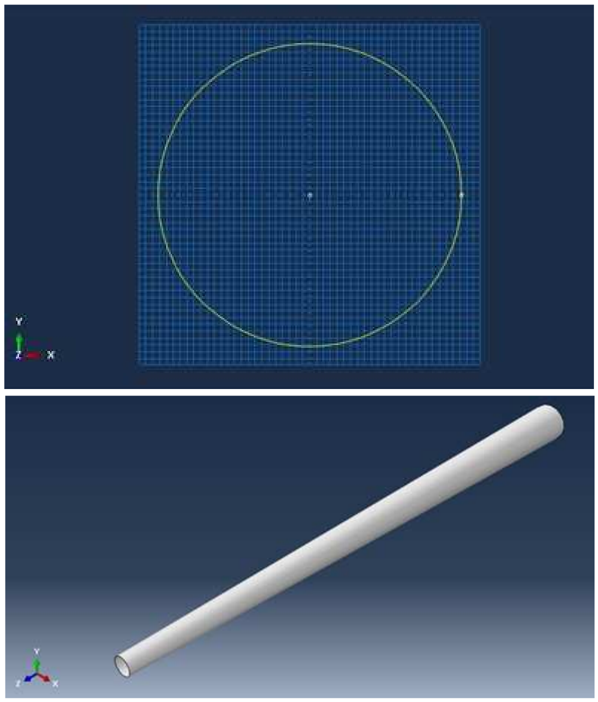


Figure III.8: Tower geometry creation

- **Material Properties**: Following that, we assign appropriate material properties to the tower components. This includes specifying the mechanical properties such as Young's modulus, Poisson's ratio, density and section thickness.

Table III.3: materiel mechanical properties

PROPRERTIES	VALUES
YOUNG'S MODULUS	200 GPa
POISSON'S RATIO	0.3
DENSITY	7850 kg/m^3
SECTION THICKNESS	0.05 m

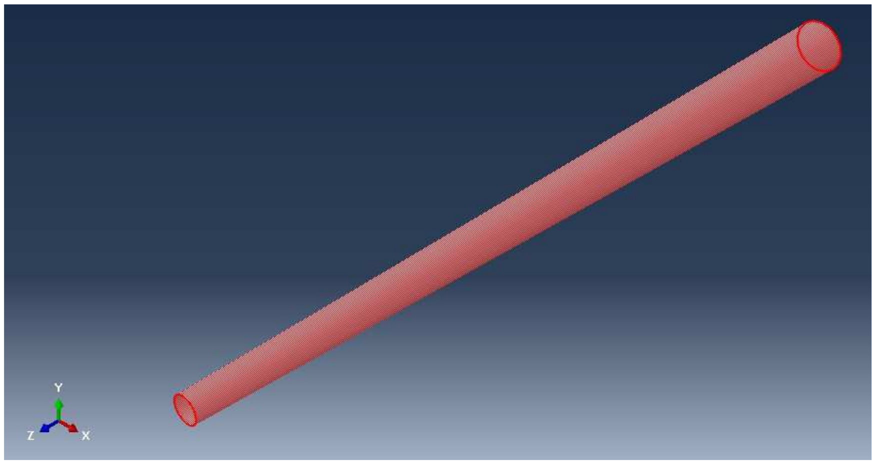


Figure III.9: assigning the materiel properties with the geometry

Afterwards we configure the analysis step, in our case we choose the fre- quency analysis and set the number of eigenvalues to 4 modes

- **Boundary Conditions**: We apply appropriate boundary conditions to the tower model. These conditions simulate the tower's interaction with the envi- ronment. For frequency analysis, commonly used boundary conditions include fixing the base of the tower to restrict its motion and applying a natural mass on top that represents mass of the nacelle.

The applied boundary conditions are as follow

- At the base: encastrement
- At the summit: nacelle load m=85000 kg

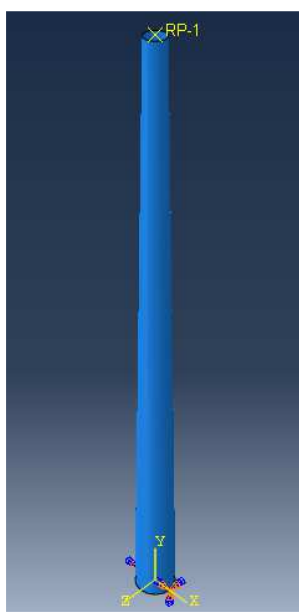


Figure III.10: applying bondary conditions

- **Mesh Generation**next step is to generate a finite element mesh for the tower model. This involves dividing the geometry into smaller elements to discretize the structure. Ensuring that the mesh is fine enough to capture the desired level of detail while keeping the computational requirements manageable, in our case we have got 2993 element and 9021 node.

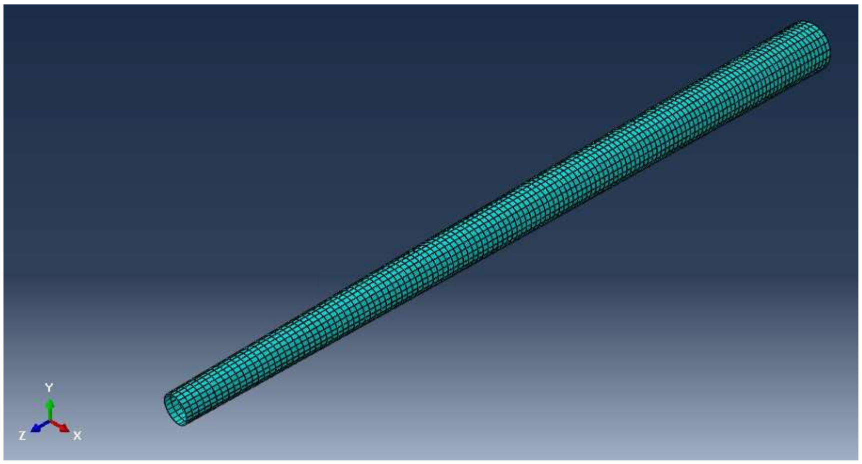


Figure III.11: mesh model

- **Run the Simulation**: the final step is to Submit the simulation job to the Abaqus solver to perform the frequency analysis. The solver will calculate the natural frequencies and corresponding mode shapes of the wind turbine tower.

III.5.3 CFD simulation (Computational Fluid Dynamics)

We head now to ANSYS's Workbench and import the two prior created parts by SOLIDWORKS as geometries (Rotor Part & Stator Part), both of those can be reviewed and even edited using design modeler starting from workbench. After checking our imported geometries and there were no problems, we add 2 Mesh cellules which requires the downstream data (geometry) for it to function properly and generate a meshing, and that happens to be our desired goal for now.

We properly create our named selections as inlet, outlet, opening and interfaces before meshing for we are going to need to know which face is which later on when applying boundary conditions.

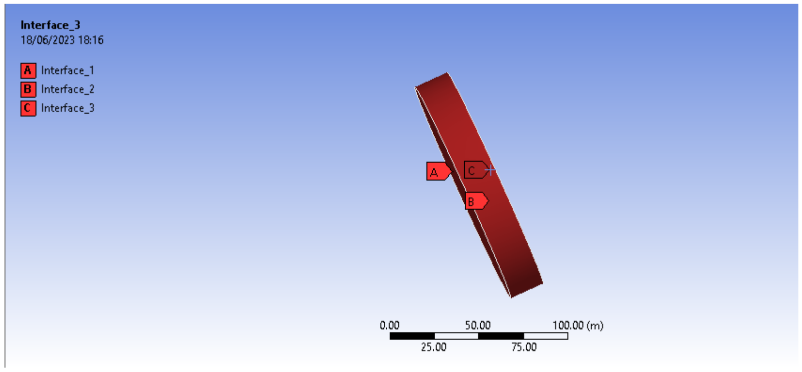


Figure III.12: creating named selections for rotor in Ansys.

After naming our selections we can start with meshing, and change details of mesh to desired settings that works with the desired solver, in our case it is Ansys CFX.

We settled for a min element size of 1 meter in our third attempt at the moment because we ended up having around "17 million element" in previous settings that surely would give better results but require better and more powerful device to initialize the simulation without overflowing the CPU.

Our meshing for the rotor part had around 705k elements, though we created an inflation between the cylinder domain and our Blade to get smaller elements the closer we get to our blade.

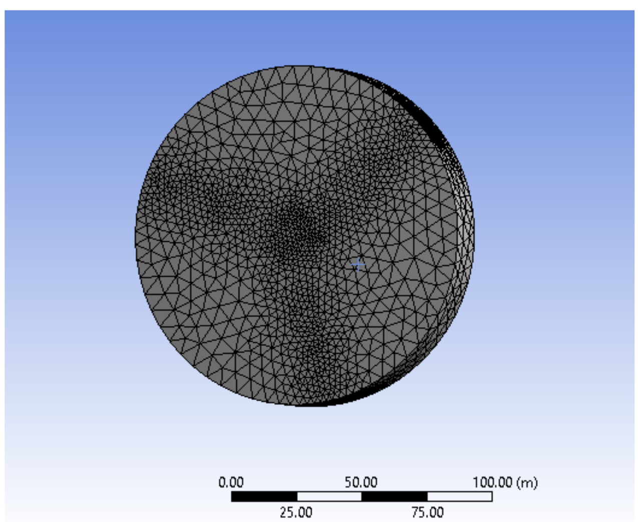


Figure III.13: mesh model for rotor domain

We repeated these steps for the stator part too, but with less nodes/elements because what is relevant in our case is the rotor area, meaning we created named selections for each and every face while respecting previous plan vectors directions, following Y axis as we did for the rotor too.

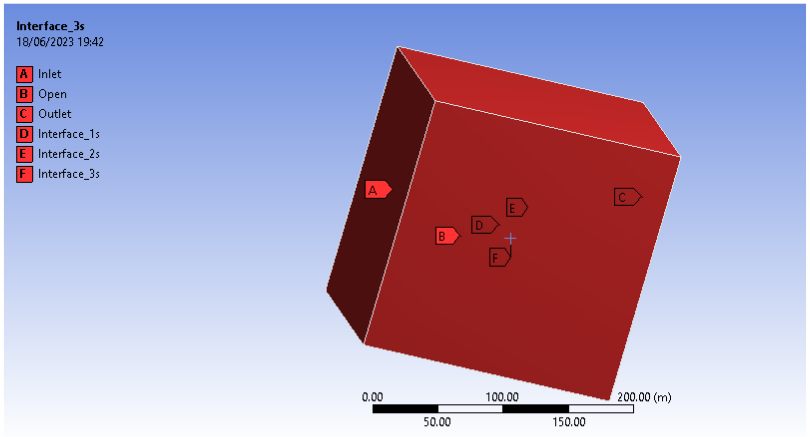


Figure III.14: creating named selections for stator in Ansys.

And our Stator part had only 10k elements but we inserted a face sizing for our 3 faces of the area between our rotor and stator.

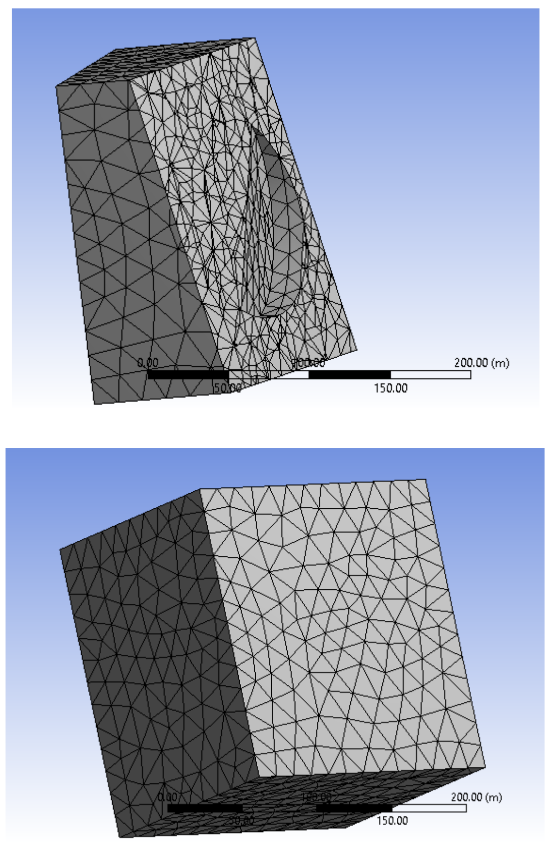


Figure III.15: mesh model for the stator

After Mesh is complete, we exported that mesh to our Solver “Ansys CFX” to add boundary conditions and start the calculation.

We set our rotational axis to Y, setup our inlet and the rest of faces as an opening, and set rotor common faces as domain interfaces, wind speed was set to 8.5m/s, air pressure at 1atm, air temperature at 25celcius.

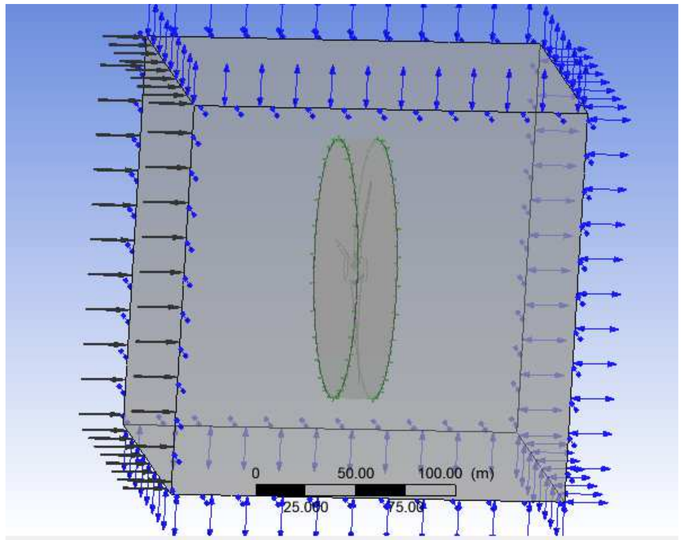


Figure III.16: applying boundary condition for rotor and stator.

All that is left to do now in addition to setting expressions up to monitor our blades behaviour is to edit solver controls according to our conditions, like time step, max iteration and other settings.

III.6 Conclusion

In this chapter, we have explored the modelization of wind turbines in the con- text of a feasibility study for a wind farm implantation. Through the utilization of ANSYS CFX and Abaqus simulations, we have successfully captured the aerody- namic behavior and structural response of the wind turbine under various operating conditions. The theoretical calculations performed alongside the simulations have further strengthened the validity of our modeling approach.

The ANSYS CFX simulation allowed us to gain valuable insights into the flow of air around the wind turbine blades, enabling us to analyze performance parameters such as power output, efficiency, and turbulence effects. On the other hand, the Abaqus simulation provided us with a comprehensive understanding of the struc- tural integrity and mechanical behavior of the wind turbine components, ensuring their reliability and dynamic response.

By conducting these simulations and theoretical calculations, we have laid the foundation for a robust analysis of the wind farm project's feasibility. The sub- sequent chapter will focus on presenting the detailed results derived from these simulations and calculations. These results will encompass critical information such as power output, efficiency, rotor loads, and fatigue life, which will be instrumental in assessing the performance, reliability, and economic viability of the wind farm project.

CHAPTER IV

RESULTS AND DISCUSSION

IV.1 Introduction

The result interpretation chapter of a feasibility study on wind farm implemen - tation is a crucial section that presents the findings and analysis derived from the study 's data and investigations . This chapter serves as a bridge between the ex - tensive research conducted and the decision -making process regarding the viability of establishing a wind farm . By interpreting and discussing the obtained results , stakeholders, developers, and investors can gain valuable insights into the feasibility and potential success of the wind farm project.

Throughout the feasibility study , various aspects related to wind farm imple - mentation have been thoroughly examined , including site selection , environmental impact, economic viability, technical feasibility, and social acceptance. This result in- terpretation chapter focuses on presenting and analysing the outcomes within these key areas, shedding light on the implications and significance of the findings.

IV.2 Results

IV.2.1 For the CFD “Ansys CFX” simulation:

The CFD simulation using ANSYS CFX has yielded results that align with another set of simulation results retrieved from ashes , strengthening the reliability and ac- curacy of our findings . This interpretation focuses on comparing and analyzing the matching outcomes obtained from both simulations , highlighting the consistency and significance of the results.

One key aspect of the simulation results is the analysis of fluid flow behaviour and characteristics . By comparing the velocity distribution obtained from both simulations , we can observe a close agreement between the two sets of results . The matching flow patterns and magnitudes validate the accuracy of the ANSYS CFX simulation , increasing our confidence in the predicted flow behaviour within the wind turbine system.

The simulation results allow us to evaluate the performance of the wind turbine under different operating conditions . By comparing parameters such as tip speed obtained from both simulation and theory , we can confirm the consistency of the predictions . The close agreement in these performance metrics reinforces the relia - bility of the ANSYS CFX simulation and validates its ability to accurately predict the behavior of the wind turbine (Figure IV.1)

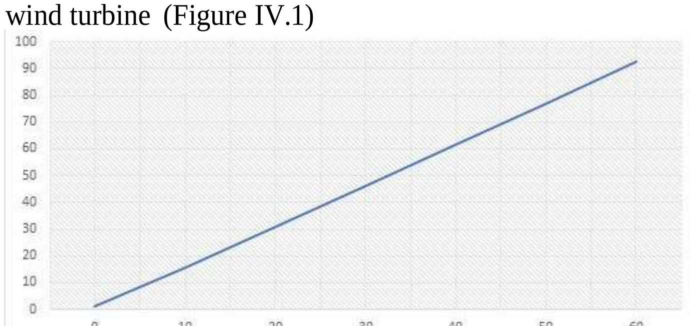


Figure IV.1: graph of blade speed in different points of the blade

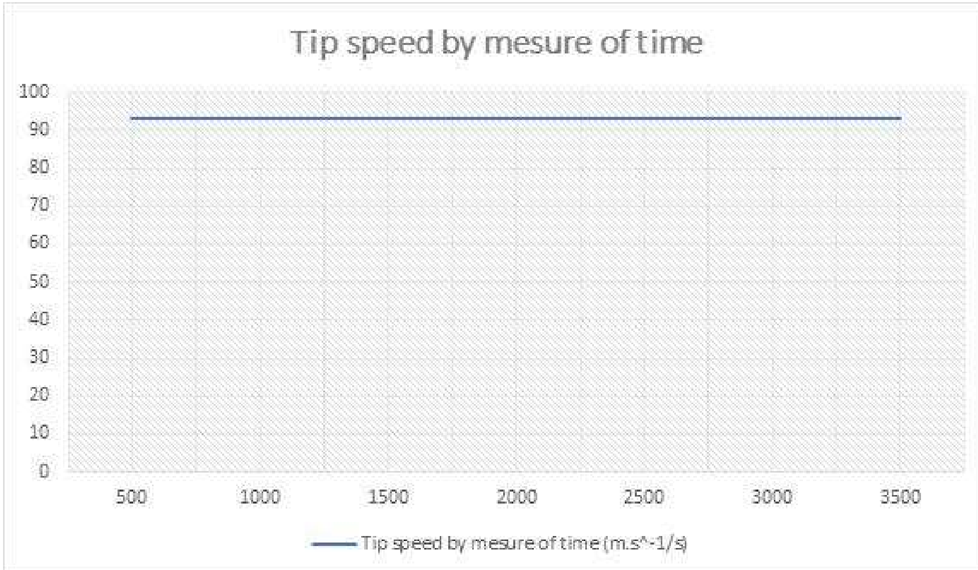


Figure IV.2: graph of blade's tip speed(ANSYS)

The interpretation of the ANSYS CFX simulation results, which match with an- other set of simulation results (Fig IV.2.-IV.3),(64.25m/s in ashes and 93m/s in ansys) underscores the reliability and accuracy of the findings. The close agreement in terms of flow behavior , performance metrics , aerodynamics , and thermal characteristics demonstrates the capability of the ANSYS CFX solver in accurately predicting the behavior of the wind turbine system. These consistent results instill confidence in the simulation outcomes(an acceptable blade's tip speed), enabling us to make informed decisions based on the findings and proceed with confidence in the wind farm imple mentation.

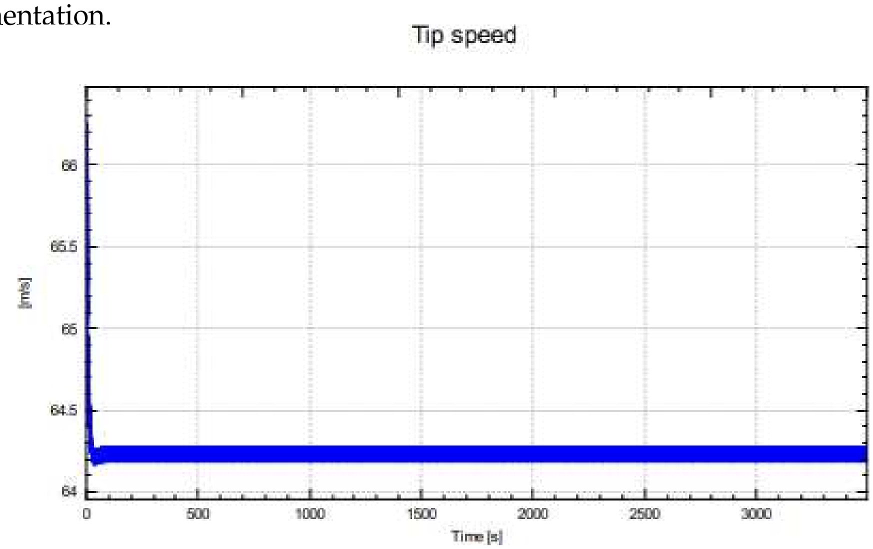


Figure IV.3: Ashes tip speed by unit of time

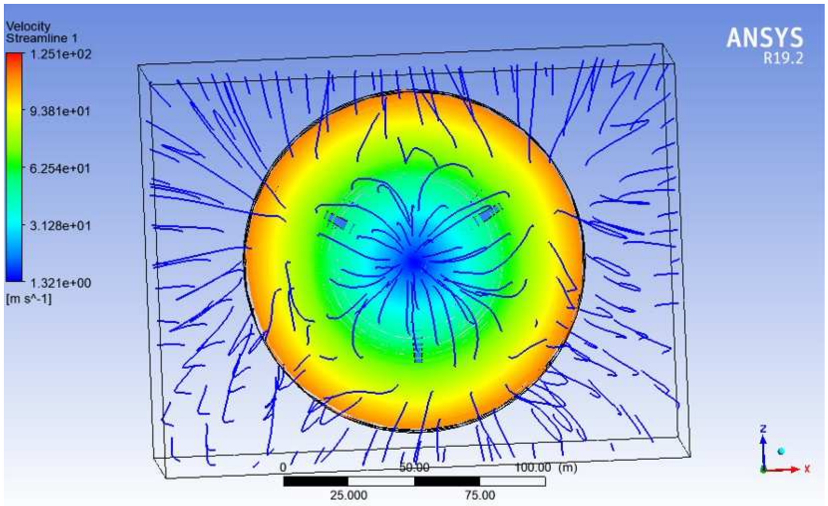


Figure IV.4: Velocity contour and velocity streamline for out fluid (AIR)

IV.2.2 Second Case for the Frequency analysis:

The results of frequency analysis in Abaqus offer significant insights into the static behavior of a structure. Through the examination of computed natural frequencies and mode shapes, the fundamental and higher modes of vibration can be deter- mined. The natural frequencies represent the characteristic frequencies at which the structure tends to vibrate, while the mode shapes reveal the associated defor- mation and displacement patterns for each frequency. In our specific analysis, four eigenmodes and their corresponding frequencies were extracted (Fig IV.5).

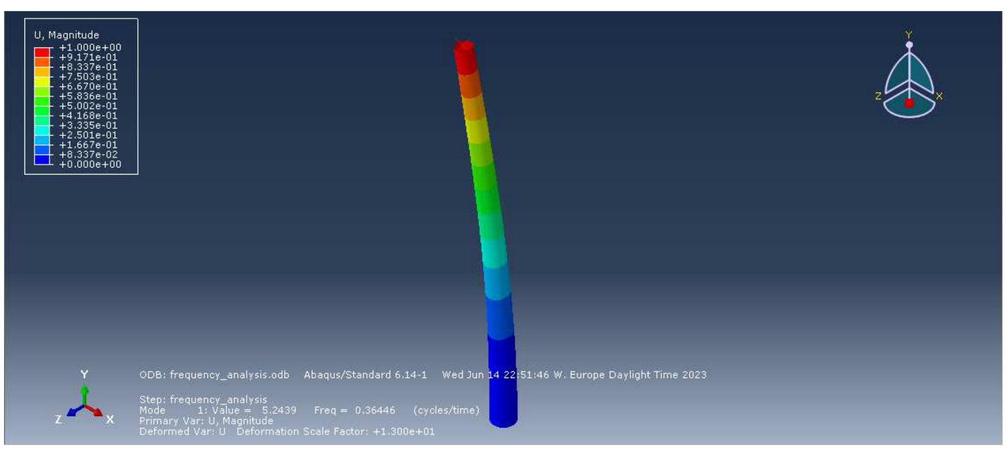


Figure IV.5: Strain along z-axis

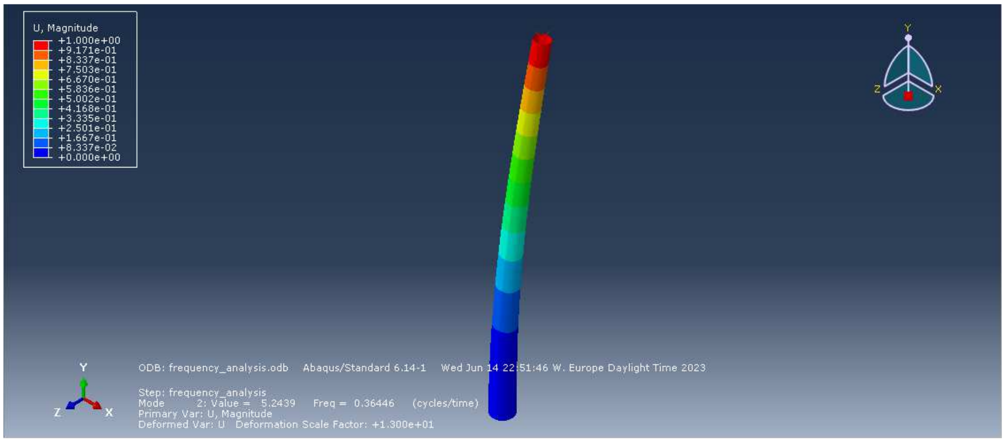


Figure IV.6: Strain along x-axis

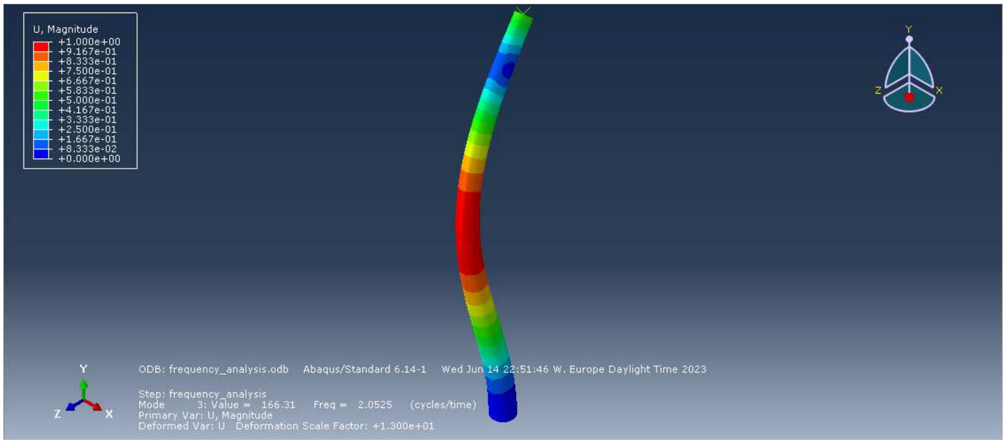
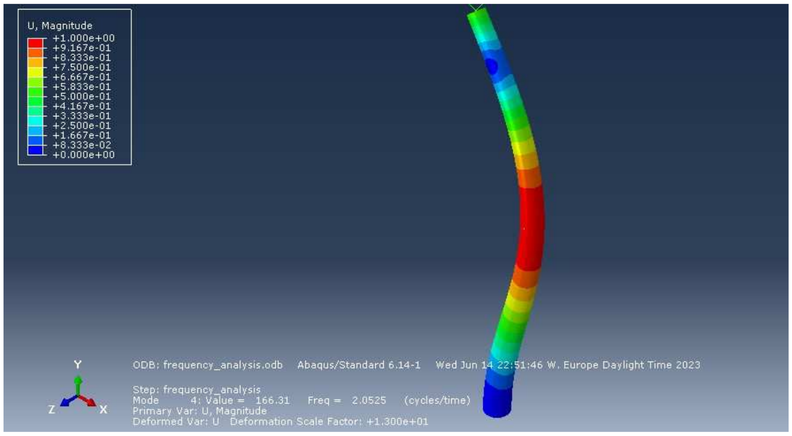


Figure IV.7: Buckling along z-axis



FigureIV.8: Buckling along x-axis

To further validate and cross-reference the results, a comparison can be made with the results obtained from ashes software (Fig IV.9.) and the result obtained by abaqus (Fig IV.8.) are closely even to one another even if ashes results are more precise than those of abaqus for reasons that are obvious such as employing more parameter easily and also having a predetermined structure that has been refined so many time that it really isn't allowed to have faulty areas, which may provide additional insights into the structural behavior and aid in ensuring the accuracy and reliability of the frequency analysis.

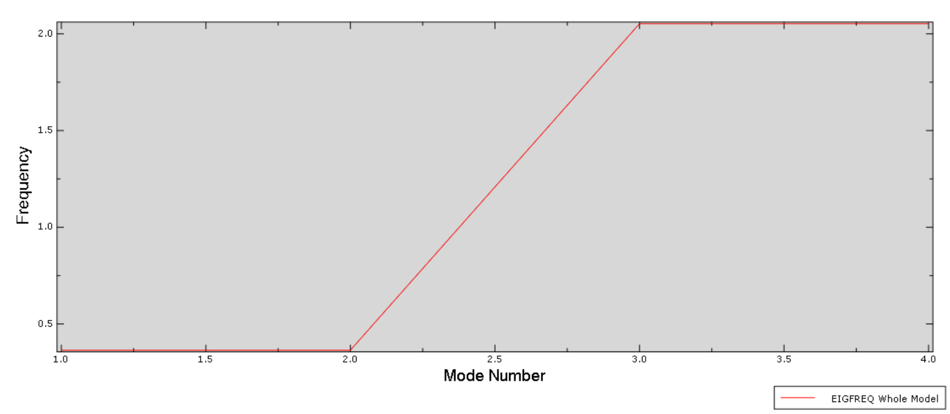


Figure IV.9: vibratory frequency variation by function of Eigenmodes(Abaqus)

Mode	Frequency [Hz]	Period [s]
1	0.386957	2.584
2	0.682408	1.465
3	1.020551	0.980
4	1.116119	0.896
5	1.877651	0.533
6	2.034400	0.492
7	2.228829	0.449
8	3.843345	0.260

Figure IV.10: vibratory frequency variation by function of Eigenmodes(Ashes)

IV.3 Conclusion

In conclusion, the result interpretation chapter in a feasibility study of wind farm implementation consolidates and presents the findings and analyses from various areas of investigation. By interpreting and discussing these results, stakeholders can make informed decisions about the project's feasibility, viability, and potential success. The comprehensive understanding gained from the result interpretation chapter serves as a valuable guide for further planning, investment, and implemen- tation of the wind farm project.

CONCLUSION

In conclusion, the feasibility study focused on the structural aspects of wind turbines in the context of wind farm implementation. The comprehensive evaluation of the design, construction, and durability of wind turbine structures has provided valuable insights into the viability of such a project. Based on the findings, it can be concluded that the implementation of a wind farm is feasible in the studied location. However, it is important to acknowledge the challenges posed by the low prices of fossil fuel-generated electricity in Algeria.

The study has highlighted the potential benefits of wind power, such as its re- newable nature and environmental advantages. Wind farms have the capacity to generate clean and sustainable energy, contributing to the reduction of greenhouse gas emissions and the overall transition to a low-carbon future. Furthermore, wind energy offers long-term cost savings and energy independence, mitigating the un- certainties associated with fossil fuel prices and supply.

Nevertheless, the low prices of fossil fuel-generated electricity in the studied location present a significant challenge. The economic viability of wind farm im- plementation heavily depends on the competitiveness of renewable energy sources against conventional forms of power generation. Lower electricity prices from fossil fuels may impact the financial feasibility of the project, making it less attractive to potential investors.

To overcome this challenge, additional strategies and considerations need to be explored. These may include government incentives and subsidies to bridge the cost gap between wind power and fossil fuel-generated electricity. It is also cru- cial to promote public awareness and education regarding the long-term benefits of renewable energy sources, encouraging support for wind farm implementation despite initial cost differences.

In conclusion, while the feasibility study has determined that wind farm imple- mentation is technically feasible in the studied location, the low prices of fossil fuel-generated electricity pose a significant challenge. Future efforts should focus on developing innovative financial mechanisms and fostering a supportive regula- tory framework to enhance the competitiveness of wind power. By addressing these challenges, it is possible to unlock the full potential of wind energy and contribute to a sustainable and greener energy future.

REFERENCES

[1] U.S. Energy Information Administration, Wind explained History of wind power, April 20, 2023

[2] IRENA - International Renewable Energy Agency, Wind energy, 2020

[3] C. Lavanya and N. D. Kumar, Foundation Types for Land and Offshore Sus- tainable Wind Energy Turbine Towers E3S Web of Conferences 184, 01094 (2020)

[4] Musial W, Butterfield S. Future for offshore wind energy in the United States. NREL, CP500-36313, (2004)

[5] Mengé P, Gunst N. Gravity Based Foundations for the Wind Turbines on Thorntonback–Belgium. 15deInnovatie forum Geotechniek, Antwerpen, Belgium (2008)

[6] Review of Options for Offshore Foundation Substructures Prepared by the Center for Wind Energy at James Madison University (2012)

[7] Oh K-O, Kim J-Y, Lee J-S. Preliminary evaluation of monopile foundation dimensions for an offshore wind turbine by analyzing hydrodynamic load in the frequency domain. Renew Energy, 54 :211 (2013)

[8] Ibsen LB, Liingaard M, Nielsen SA. Bucket Foundation, a status. Copenhagen, Denmark: Copenhagen offshore wind (2005)

[9] Ryu MS, Kim J-Y, Lee J-S. Comparison of two meteorological tower foundations for offshore wind turbines. In: Proceedings of the twenty-sixth international offshore and polar engineering conference. Rhodes, Greece, (2016)

[10] Jonkman JM, Buhl JrML. Loads analysis of a floating offshore wind turbine using fully coupled simulation. In: Proceedings of the wind power 2007 conference and exhibition. Los Angeles, USA (2007)

[11] Skaare B, Hanson TD, Nielsen FG. Importance of control strategies on fatigue life of floating wind turbines. In: Proceedings of the 26th International conference on offshore mechanics and arctic engineering. San Diego, USA, (2007)

[12] Wayman EN, Sclavounos PD, Butterfield S, Jonkman J, Musial W. Coupled dynamic modeling of floating wind turbine systems. In: Proceedings of the offshore technology conference, Texas, USA (2006).

[13]B. Radowitz, Storm breaks Enercon and Nordex wind turbine blades in Ger- many and France, 22 October 2021.

[14] S. S. Arisian and G. Ertek, Wind Turbine Accidents: A Data Mining Study, September 2017, IEEE Systems Journal

[15] Sciemus, WEU Onshore Asset Optimization & Reliability Benchmarking Re- port 2015, Boston, USA.

[16] E. de Vries and J. Buist, Turbines of the year – The best wind turbine products, 2014

[17] L. Suja-Thauvin and P. Thomassen. Engineering features summary Ashes. 2023

[18] Nordex industry service team, https://en.wind-turbine-models.com/

[20] Vance, J. E. , Stilwell, . James Joseph , Davies, . Ernest Albert John and Woodward, . John B.. "ship." Encyclopedia Britannica, June 1, 2023.

[21] Matthew A. McIntosh, Windmills and Their Technology since the Middle Ages, March 4, 2021.

[22] C. Nizamoglu, Amazing Mechanical Devices from Muslim Civilisation, 9th September 2016.

[23] L. Bauer, S. Matysik, The big portal for wind energy, wind-turbine-models.com, 18. 03.2023.

[24] J. Bauer, National Renewable Energy Laboratory, 2022.

[25] Alghamdi, Yusif. Transport Characteristics of Binary Mixture of Particles in Chemical Looping Combustion Applications. 2016.

[26] EDF, All you need to know about wind power, 2020.

[27] Lucía Fernández, Statista, Apr 26, 2023.

[28] Minh Pham, All about Offshore Wind Turbine Foundations, Apr 12, 2022.

[29] Nadja Skopljak, Framo pumps for Scotland’s largest offshore wind project, March 2, 2021.

[30] Luvside, VERTICAL AXIS WIND TURBINE (VAWT), 31 March 2020.

[31] Ørsted, How do offshore wind turbines work?, 2022.

[32] cleanmax, Wind Solar Hybrid projects, 2020.

[33] D. Murray, Exploring Green industrial policy in South Africa through the lens of vertically specialized industrialization, 2017.

[34] Manuela Haliburton , Fossil Fuel Phase -Out : The Socioeconomic Implications of a Clean Energy Future, 2023.

[35] M. Kamarzarrin, M. H. Refan, Intelligent Sliding Mode Adaptive Controller Design for Wind Turbine Pitch Control System Using PSO-SVM in Presence of Disturbance, 26 March 2020.

[36] Windmills Tech Editor, Wind Turbine Components, 2023.

[37] Salameh A. Sawallha , Prospects of wind power generation in Jordan : the case of street lighting, April 2017.

[38] C. Lavanya , N. Darga Kumar , Foundation Types for Land and Offshore Sustainable Wind Energy Turbine Towers, January 2020.

[39] One Step Green, Wind Turbines, January 14, 2019.

[40] Icp Das Blog , Application Of Icp Das 's Solution For Cloud Data Visualization In Wind Turbine Foundation Monitoring System In The Uk, 2022-04-07.

[41] Michael Holm, 'Damp air inside turbines is often the root cause of failure —protection is crucial', 24 February 2020.

[42] Frédéric Simon, Key lawmaker tables radical overhaul of EU's renewable energy directive, Feb 16, 2022.