ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

POTENTIAL WIND FARM DESIGN OF THE CASPIAN SEA SHORES OF AZERBAIJAN

M.Sc. THESIS

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Department of Shipbuilding and Ocean Engineering

Offshore Engineering Programme

JUNE 2022

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İSTANBUL TEKNİK ÜNİVERSİTESİ★LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

AZERBAYCAN'IN HAZAR DENİZİ AÇIKLARINDA POTANSİYEL RÜZGÂR ÇİFTLİĞİ TASARIMI

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To my family,

FOREWORD

First and foremost, I would like to convey my thanks and unending admiration to Prof. Dr. Serdar BEJI, my thesis adviser, who took the time to look after me and guide me. I'd also want to thank him for instilling in me a passion for this area. In addition, I would like to thank my personal friends and family for their support. I could not have done this task without their assistance and support.

June 2022 Tural ISAYEV
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ABBREVIATIONS

AC	: Alternative Current
AEP	: Annuel Energy Production
ASARES	: Azerbaijan State Agency for Renewable Energy Sources
CHP	: Combined Heat and Power
EPR	: European Pressurized water Reactor
GW	: Gigawatt
HAWT	: Horizontal Axis Wind Turbines
HPP	: Hydroelectric Power Plant
IRENA	: International Renewable Energy Agency
KWh	: Kilowatt-hour
LCOE	: Levelized Cost of Energy
MW	: Megawatt
SDPP	: State District Power Plant
TW	: Terawatt
VAT	: Value Added Tax
VAWT	: Vertical Axis Wind Turbines
WEPA	: Wind Energy Potential Atlas
WPP	: Wind Power Plan
WT	: Wint Turbine

SYMBOLS

$\mathbf{SO_2}$	: Sulphur dioxide
m	: Meter
U-235	: Uranium
km	: Kilometer
m/sec	: Metre per second
$	: Dollar
$\mathbf{CO_2}$	: Carbon dioxide
$\mathbf{V_h}$	: Velocity of wind at height h
$\mathbf{V_{href}}$	: Known velocity of wind at height h_{ref}
$\mathbf{z_0}$	: Roughness
h	: Height above ground level for velocity V_h
$\mathbf{h_{ref}}$	: Reference height where V_{href} is known
°C	: Celsius
P	: Wind power
$\boldsymbol{\rho}$	: Density of air
Cp	: Capacity factor
L	: Wave length
H	: Wave height
a	: Wave aplitude
k	: Wave number
$\boldsymbol{\omega}$	: Circular frequency
c	: Wave speed
t	: The time to travel 1 mile
$\mathbf{U_f}$	: The fastest mile wind speed
$\mathbf{U_a}$	: The adjusted wind speed

$\mathbf{U_{3600}}$	**:** The wind speed during 1 hour
$\mathbf{H_s}$	**:** The significant wave height
$\mathbf{T}_s$	**:** The significant wave period
F	**:** Fetch distance
$\mathbf{F_i}$	**:** Inertia force
$\mathbf{F_d}$	**:** Drag force
F	**:** Total force
$\mathbf{C_m}$	**:** Inertia coefficient
$\mathbf{C_d}$	**:** Drag coefficient
M	**:** Maximum moment
$\mathbf{M_i}$	**:** Inertia moment
$\mathbf{M_d}$	**:** Drag moment

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POTENTIAL WIND FARM DESIGN OF THE CASPIAN SEA SHORES OF AZERBAIJAN

SUMMARY

Renewable energy sources include the sun, wind, water, the Earth's heat, and plants, all of which are perpetually renewed by nature. Renewable energy technologies convert these fuels into useable energy, such as electricity, heat, chemicals, or mechanical energy. Fossil fuels are now utilized to heat and power houses, as well as to fuel automobiles. Coal, oil, and natural gas are convenient for providing our energy demands, but there is a finite quantity of these fuels on the planet. We're consuming them at a far faster rate than they're being generated. They'll eventually run out. And, due to safety concerns and waste disposal issues, the US will phase down much of its nuclear power capacity by 2020. Meanwhile, the country's energy demands are predicted to increase by 33% during the next 20 years. Renewable energy may be able to fill the void. Renewable energy is better for the environment even if we had a limitless supply of fossil resources. Renewable energy systems are frequently referred to as "clean" or "green" since they create little, if any, pollutants. Renewable energy will also assist us in achieving energy security and independence. Replacing part of our petroleum with plant-based fuels, for example, may save money while also increasing our energy security. Renewable energy is abundant, and technology is always improving. Renewable energy may be used in a variety of ways. In our daily lives, the majority of us currently utilize renewable energy.

The design of the wind farm has been researched in the fourth chapter. This section focuses on selecting the best site for the wind farm. The situation of the wind blowing around the Absheron area is described in general. The absheron region appears to be typically adequate in terms of wind speed when we look at the wind maps during the studies. In terms of depth, it appears that the region's depth ranges between 20 and 40 meters. On the other hand, the presence of onshore wind farms in the northern half of the Absheron peninsula makes this region more grid-connected. In terms of wind speed, the location in the southern portion of the Absheron peninsula where the wind speed of 7.69 m/sec was found to be the most favorable (A region). However, as previously noted, the sea section in the northern half of the Absheron peninsula is the best location for grid connection. Part B, in one of the zones with the highest wind speed closest to the land, has been judged to be the most suited location. The greatest water depth in this area is 20 meters, and the monopile foundations for the wind turbines to be erected are considered adequate. Furthermore, it has been found that ship traffic is not a barrier for this region, and as is well known, Azerbaijan has oil and natural gas deposits in the Caspian, and there is no pipeline running through this region, despite the threat of underwater pipes. The Vestas117-4.2 MW model was chosen as the wind turbine's model. Because the selected wind turbine's hub height is 91.5 meters, a reference wind speed of 50 meters (8.25 m/sec) was used, and the wind speed at 91.5 meters was found to be 8.7 m/sec. Furthermore, the annual energy production of a wind turbine was calculated based on its data to be 14.7 GWAC/year,

and considering the width of the region, a maximum of 30 wind turbines could be installed in this region, the annual energy production for 30 turbines was calculated to be 441 GWAC/year. This wind farm can also feed 173,000 people each year, according to calculations. In terms of the configuration, the distance between the wind turbines is determined to be 5D (D-rotor diameter), or 585 meters, in order to compensate for wake losses. The layout has been chosen to be square. The wind farm design was successfully finished in the fourth chapter.

The major focus of Chapter 5 is to use the Morrison equation to calculate the maximum force and maximum momentum based on these facts. The following data were obtained from the National Hydrometeorology Department of the Ministry of Ecology and Natural Resources of Azerbaijan: water depth of the selected region, highest wind data of the last 15 years obtained from the National Hydrometeorology Department of the Ministry of Ecology and Natural Resources of Azerbaijan, distance from the region where the wind speed is measured to the location of the wind farm (fetch distance), and diameter of monopile. Using these data, both the wind farm design and the maximum force and momentum calculations were completed successfully.

AZERBAYCAN'IN HAZAR DENİZİ AÇIKLARINDA POTANSİYEL RÜZGÂR ÇİFTLİĞİ TASARIMI

ÖZET

Yenilenebilir enerji kaynakları, tümü doğa tarafından sürekli olarak yenilenen güneş, rüzgar, su, Dünya'nın ısısı ve bitkileri içerir. Yenilenebilir enerji teknolojileri, bu yakıtları elektrik, ısı, kimyasallar veya mekanik enerji gibi kullanılabilir enerjiye dönüştürür. Fosil yakıtlar artık evleri ısıtmak ve elektrik sağlamak için olduğu kadar otomobilleri yakmak için de kullanılıyor. Kömür, petrol ve doğal gaz, enerji taleplerimizi karşılamak için uygundur, ancak gezegende bu yakıtların sınırlı bir miktarı vardır. Onları, üretildiklerinden çok daha hızlı tüketiyoruz. Sonunda tükenecekler. Ve güvenlik endişeleri ve atık imha sorunları nedeniyle ABD, nükleer enerji kapasitesinin çoğunu 2020 yılına kadar azaltacak. Bu arada, ülkenin enerji talebinin önümüzdeki 20 yıl içinde %33 oranında artacağı tahmin ediliyor. Yenilenebilir enerji boşluğu doldurabilir. Sınırsız bir fosil kaynağı kaynağımız olsa bile yenilenebilir enerji çevre için daha iyidir. Yenilenebilir enerji sistemleri, eğer varsa, çok az kirletici oluşturdukları için sıklıkla "temiz" veya "yeşil" olarak adlandırılır. Yenilenebilir enerji, enerji güvenliği ve bağımsızlığına ulaşmamıza da yardımcı olacaktır. Örneğin petrolümüzün bir kısmını bitkisel bazlı yakıtlarla değiştirmek, enerji güvenliğimizi artırırken paradan tasarruf sağlayabilir. Yenilenebilir enerji bol ve teknoloji her zaman gelişiyor. Yenilenebilir enerji çeşitli şekillerde kullanılabilir. Günlük hayatımızda, çoğumuz şu anda yenilenebilir enerji kullanıyoruz. Dördüncü bölümde rüzgar çiftliğinin tasarımı incelenmiştir. Bu bölüm, rüzgar çiftliği için en iyi yerin seçilmesine odaklanmaktadır. Abşeron bölgesi çevresinde esen rüzgarın durumu genel olarak anlatılmaktadır. Çalışmalar sırasında rüzgar haritalarına baktığımızda absheron bölgesi rüzgar hızı açısından tipik olarak yeterli görünmektedir. Derinlik açısından bölgenin derinliğinin 20 ile 40 metre arasında değiştiği görülmektedir. Öte yandan, Abşeron yarımadasının kuzey yarısında karadaki rüzgar çiftliklerinin varlığı bu bölgeyi daha şebeke bağlantılı hale getiriyor. Rüzgar hızı açısından, Abşeron yarımadasının güney kesiminde 7,69 m/sn rüzgar hızının en uygun olduğu yer (A bölgesi) bulundu. Ancak, daha önce belirtildiği gibi, Abşeron yarımadasının kuzey yarısındaki deniz bölümü, şebeke bağlantısı için en iyi konumdur. Karaya en yakın rüzgar hızına sahip bölgelerden birinde yer alan Kısım B, en uygun yer olarak değerlendirilmiştir. Bu alandaki en büyük su derinliği 20 metre olup, kurulacak rüzgar türbinleri için tekil temeller yeterli görülmektedir. Ayrıca, gemi trafiğinin bu bölge için bir engel olmadığı ve bilindiği gibi Azerbaycan'ın Hazar'da petrol ve doğalgaz yataklarına sahip olduğu ve su altı borularının tehdidine rağmen bu bölgeden geçen bir boru hattının bulunmadığı tespit edilmiştir. . Rüzgar türbini modeli olarak Vestas117-4.2 MW modeli seçilmiştir. Seçilen rüzgar türbininin göbek yüksekliği 91,5 metre olduğundan referans rüzgar hızı 50 metre (8,25 m/sn) kullanılmış ve 91,5 metre rüzgar hızı 8,7 m/sn olarak bulunmuştur. Ayrıca, bir rüzgar türbininin yıllık enerji üretimi, verilerine göre 14,7 GWAC/yıl olarak hesaplanmış ve bölgenin genişliği dikkate alınarak, bu bölgeye en fazla 30 rüzgar türbini kurulabilir,

yıllık enerji üretimi 30'dur. türbin sayısı 441 GWAC/yıl olarak hesaplanmıştır. Bu rüzgar çiftliği ayrıca hesaplamalara göre her yıl 173.000 kişiyi besleyebilir. Konfigürasyon açısından, rüzgar türbinleri arasındaki mesafe, iz kayıplarını telafi etmek için 5D (D-rotor çapı) veya 585 metre olarak belirlenmiştir. Düzen kare olarak seçilmiştir. Dördüncü bölümde rüzgar çiftliği tasarımı başarıyla tamamlandı.

Bölüm 5'in ana odak noktası, bu gerçeklere dayalı olarak maksimum kuvveti ve maksimum momentumu hesaplamak için Morrison denklemini kullanmaktır. Azerbaycan Ekoloji ve Tabii Kaynaklar Bakanlığı Ulusal Hidrometeoroloji Dairesi'nden şu veriler elde edilmiştir: Seçilen bölgenin su derinliği, Ekoloji ve Tabii Kaynaklar Bakanlığı Ulusal Hidrometeoroloji Dairesi'nden elde edilen son 15 yılın en yüksek rüzgar verileri Azerbaycan'ın rüzgar hızının ölçüldüğü bölgeden rüzgar çiftliğinin konumuna olan uzaklığı (etkin esme mesafesi) ve kazık çapı. Bu verilerin yardımıyla hem rüzgar santrali tasarımı hem de maksimum kuvvet ve momentum hesaplamaları başarıyla tamamlanmıştır.

1. INTRODUCTION

Countries with clout in the global economy invest heavily in renewable energy sources and make concerted attempts to expand their use. The production, transportation, and use of energy, which has become an indispensible element of our existence, pollutes the environment. Renewable energy is created from sources that can be renewed in a relatively short period of time. Solar, wind, water, biomass, and geothermal energy are all examples of renewable energy sources:

- Green energy, like renewable energy, is a subset of sources with the greatest environmental advantages.
- Renewable energy sources, as well as nuclear power, are examples of clean energy sources that emit little carbon.
- For most of human history, renewable energy sources have been employed to provide heat and power, and more recently, electricity. Renewable energy accounts for 12% of primary energy usage in the United States and 11% globally.
- While there is still a considerable reliance on fossil fuels for heating, power, and transportation, the 1970s oil crisis prompted increased investment in alternative energy sources. Furthermore, as a result of the detrimental impacts of climate change, public demand for non-fossil fuel-based energy has surged, supported by government benefits and standards.

Renewable energy sources are advantageous in satisfying energy demands since they do not contaminate the environment and have a long lifespan. Wind energy is one of the most cost-effective renewable energy sources. Wind is a force of nature that emerges as a result of solar energy reaching the earth. The temperature difference on the earth due to solar energy creates pressure changes. As a result of these changes, wind occurs.

Renewable energy sources are critical for the environment's long-term viability and humanity's future. Following the oil crisis in the late 1900s, the necessity of energy came to be widely appreciated. At the beginning of 2000, studies on renewable energy sources gained momentum and decreased in terms of cost. The concept we call renewable energy is an energy that exists in nature to produce energy and can constantly renew itself if it is used.

The fact that it can renew itself in a natural, continuous way and that this energy source does not disappear are among the most important features that distinguish it from other energy sources. Renewable energy sources occupy an important place for reasons such as being domestic, reducing air pollution, ensuring the independence of the country in the energy sector. Resources such as hydroelectric energy, wind energy, solar energy, geothermal energy, biomass energy, tidal energy are examples of renewable energy sources.

Many developing countries have significant wind energy potential that has yet to be realized. In many places, generating electricity from wind energy is a more cost-effective option than using thermal power plants. It has a reduced environmental and climate effect, decreases reliance on fossil fuel imports, and improves energy supply security.

For many years, developing countries and growing economies have struggled to fulfill increased energy demands for social and economic growth due to outdated energy supply infrastructure. Using fossil fuels such as coal, oil, and gas to overcome supply constraints increases reliance on uncertain markets and depletes important foreign currency reserves. Simultaneously, there is increasing demand on rising newly industrialized nations, in particular, to contribute to the fight against climate change by reducing pollutant emissions.

Wind power is becoming more cost-effective as a result of recent technology advancements that have resulted in more efficient and dependable wind turbines. Regardless of current supply issues, the particular energy prices per year kWh drop with the size of the turbine in general.

Wind energy has become one of the most cost-effective renewable energy technologies in recent years. Wind turbines that generate power nowadays use tried-and-true technology to provide a secure and long-term energy source. Wind energy can already compete with conventional energy generation in suitable, breezy locations. Many countries have vast wind resources that have yet to be used. In the alternative scenario, an increasing number of developing and rising nations are putting their confidence in increased renewable energy consumption and adopting particular expansion objectives for a "green energy mix." Wind power, which has been tested in industrialized nations for years and has reached commercial maturity, has a significant role to play here. Excellent wind conditions in many regions offer low-cost electricity generation when contrasted to expensive imported energy sources like diesel.

A technology with significant benefits is not being exploited to its full potential:

- There are no greenhouse emissions produced by wind energy.
- Wind power facilities have the potential to significantly contribute to regional electricity supply and diversity.
- In comparison to typical power projects, a relatively short planning and construction lead time is required.
- Wind energy projects are adaptable to rising energy demand; single turbines may be added to an existing park with ease.
- Finally, in terms of labor, cash, and materials, wind energy projects may make use of local resources.

The theoretical wind energy potential of Azerbaijan, according to the Wind Energy Potential Atlas (WEPA), is roughly 48,000 MW. The wind energy potential that can be linked to the power system is evaluated at 10,000 MW, based on current electricity grid infrastructure.

By 2020, it is predicted that the installed wind power in Azerbaijan will reach 20,000 MW. The installed wind power in Azerbaijan, which was 20.1 MW in 2005, has increased to 2041.35 MW as of 2012.

1.1 Purpose of Thesis

The researches generally focus on the potential of the wind to be converted into energy in the country, the benefits it can provide, cost analysis, and most importantly, increasing the efficiency of the wind turbine with blade design and material technique.

The reason why we focus on Azerbaijan is the wind potential in Azerbaijan and its usability. In addition, this thesis consists of general information about the situation of wind energy in the world and in Azerbaijan, what should be considered when designing the wind turbine farm, and the calculation of the maximum force and momentum that will be suitable for each wind turbine in the region to be established.

2. WIND ENERGY

Wind energy is the kinetic energy of the air flow that creates the wind. It is considered one of the alternatives (renewable) sources of energy. Some of this energy can be converted into useful mechanical or electrical energy. Wind energy is the most cost-effective, environmentally friendly and inexhaustible form of solar, hydropower, geothermal and biomass energy from other alternative energy sources. Wind power has been used for many years. Sailing ships and windmills can be shown as the first way to take advantage of wind power [1].

Later, wind power was used for grinding grain, pumping water, and cutting wood. It is now used to generate more electricity. It is one of the more efficient technologies for generating electricity. The construction of wind turbines takes less time than the construction of traditional power plants. In addition, wind is, in fact, a constant source of natural energy that any country has. The use of wind energy is one of the fastest growing areas of energy.

The kinetic energy generated by the air flow that creates the wind is known as wind energy. The movement experienced in the wind firstly turns into mechanical energy and then into electrical energy. This is how wind energy is obtained through systems that are specially located at different points. As a clean and endless source of energy, especially with the protection of nature, wind constitutes a very important potential.

Of course, wind energy does not have as high a potential as solar energy. However, it still offers many different advantages as a renewable energy source. By providing energy security, it reduces air pollution to a very minimum level. It is an inexhaustible source of energy [3].

While creating a significant potential against climate change, it also reduces costs. In addition to preventing fuel imports, it is installed very quickly. Moreover, it provides a healthy and safe use that does not emit radiation and does not cause explosions [1].

The sun heats the earth in different ways according to the season, time and topography of the region. As a result, the warm air rises, while the cooled air descends. The descending cold air creates pressure on the earth; this is called high pressure.

The rising air, on the other hand, exerts a lower pressure on the earth; This is called low pressure. Wind is formed when air masses move from a high-pressure area to a low-pressure area. The acceleration, direction and intensity of the resulting wind depend on variables such as pressure gradient force, Coriolis force, centrifugal force and friction force.

Pressure Gradient Force and Formation of Wind Energy: The force that affects the speed and direction of air movement in the pressure change between two specific points is called the pressure gradient force. The effect of the pressure gradient force on the moving air mass is from high pressure to low pressure.

The pressure gradient force causes the wind to be formed by the displacement of the air and become a source of kinetic energy.

Coriolis Force and Formation of Wind Energy: Coriolis force, named after the French scientist Gaspard-Gustave Coriolis, is the deflection of a movement by an oncoming resistance. Since the earth is constantly rotating, it prevents the air movements on the earth to be linear.

As a result of the Coriolis effect, the winds in the northern hemisphere accelerate to the right of the direction of movement, and the winds in the southern hemisphere accelerate to the left of the direction of movement. As a result of the Coriolis force, the wind movements deviate by 10° from the hemisphere they are in.

Centrifugal Force and Formation of Wind Energy: Centrifugal force is the effect of the rotation of the earth on the air movements in the atmosphere. Centrifugal force causes distortion of the linear direction of the wind (2). The place where the centrifugal force is most effective in the world is the Equator line, because the Equator is the place where the Earth's rotation speed is highest. There is no centrifugal force at the North and South poles, where the Earth does not have a rotational speed.

Friction Force and Formation of Wind Energy: The force that causes the wind to decrease in intensity and change its direction as a result of friction with the landforms is called the friction force. While the Coriolis force is effective in large-scale and cyclical air movements, the effect of the friction force on direction and speed change is higher in air movements close to the ground.

Wind energy is produced by converting the kinetic energy of the wind first into mechanical energy and then into electricity. For this, first of all, energy must be controlled. The controlled energy is converted into mechanical energy. Mechanical energy starts the generator and production is completed [2].

The wind turns the blades of the wind turbine. These blades rotate the gears in the gearbox to which they are attached. The spinning wheels drives the generator. The generator transmits the electricity it produces to the transformer. The transformer transmits the electricity it receives to the grid [3].

Wind energy provides many advantages as a renewable energy source:

- Wind energy has no raw material cost.
- Wind power plants do not emit harmful greenhouse gases such as CO_2 to the nature.

Wind power plants take up less space than renewable energy sources such as solar energy. 1 Mega Watthour of electricity produced by a solar energy panel covering an area of 20,000 square meters, one wind turbine alone produces. In this way, it prevents the occupation of agricultural land. Wind energy production is not affected by variables such as season, daylight and precipitation.

Although it is a renewable energy source, wind energy also has some disadvantages:

- In order for a wind turbine to generate electricity, the wind must blow in the optimum speed range. When the wind blows at a speed above or below this range, which varies according to the type of wind turbine, the turbine does not operate and the efficiency of the wind farms decreases.
- The investment cost of wind turbines is higher than solar power plants.
- The circular wind paths on which wind turbines are built are also the migration routes of some bird species. This is why wind turbines cause damage to migratory bird species.
- Wind power plants operate noisily. Therefore, it is not possible to establish them close to settlements.

The most important difference between wind energy and nuclear energy is that wind energy does not have a raw material cost. Nuclear energy, on the other hand, works with rare and hard-to-find materials such as U-235. However, there are other factors that affect the cost of the two types of energy.

EPR (European Pressurized Water Reactor) type nuclear power plant has an electricity generation capacity of 1,600 MW, while the generation capacity of a windmill is approximately 2 MW. While a nuclear reactor can operate with 80% efficiency for 60 years, a wind vane works for about 15 years and 20% efficiency.

In order to produce the electrical energy produced by a nuclear reactor during its lifetime, it is necessary to install approximately 12,600 wind turbines.

While 60 tons of steel and 300 tons of concrete are consumed to produce 1 TeraWatt of electricity with nuclear energy, 2830 tons of steel and 18.900 tons of concrete are consumed to produce 1 TW of electricity with wind energy.

It takes 3.4 square kilometers to produce 1 MW of electricity with nuclear power, while 344 square kilometers is required to produce 1 MW of electricity with wind power. Wind energy has been used throughout history for the purposes of moving objects, transporting and grinding products.

Pumping Water with Wind Energy: The kinetic energy of the wind current is converted into mechanical energy with the shaft on the wind turbine, which is used to pump water in agricultural areas and to draw water from artesian wells.

Mill with Wind Energy: Wind energy, which is converted into mechanical energy through the turbine, enables the two plates to rotate rhythmically and the products between these two plates are grinded.

The formula for calculating wind energy is as follows:

$$P = \frac{1}{2} C \rho A v^3 \tag{2.1}$$

The explanations of the variables in the formula are as follows:

Air Density(ρ): At international standard weather conditions (at sea level, at 15°C and at 1013.25 mb atmospheric pressure), the air density is 1,225 kg/m3.

Wind Speed(v): It is the cube of the average wind speed at the place where the turbine is installed. [7]

Turbine Efficiency(C): It is the efficiency of the wind turbine. The efficiency of a wind turbine is 59.26%; is entered into the formula as 0.5926.

Swept Area(A): It is the circular area swept by the wind turbine blades and is expressed in m^2 unit.

With today's consumption rate, it is predicted that all oil reserves in the world will expire in 48 years, all coal reserves in 216 years, and all-natural gas reserves in 47 years. Therefore, the countries of the world are turning to renewable energy sources. Today, about 6% of the electricity consumed in the world is produced from wind energy. This is approximately 200 times the rate of wind energy production to meet consumption in 2000. At a point where the demand for energy is constantly increasing and the energy supply is constantly decreasing, the destination of energy prices is also clear. Therefore, the use of all kinds of renewable resources should be expanded, and the investment in wind energy, which is one of the most attractive renewable resources, should be increased. It is very important for the future to extract the water by squeezing the stone and to establish wind power plants in every place with potential. Especially in our country, offshore wind investments should be started, and onshore wind power plant investments should be accelerated."

The main differences between wind energy and fossil energy sources are: While wind energy uses the wind, power produced by nature as raw material, fossil energy resources are exhaustible resources.

During the generation of electricity from wind energy, harmful gases such as CO_2 are not released to the nature. Greenhouse gases emitted from fossil energy sources are one of the main causes of global warming. Wind energy production requires the use of very large areas and this affects the use of agricultural land. The area needed for energy production from fossil sources is very limited.

The share of renewable energy sources such as wind energy in energy use is gradually increasing, while the share of fossil energy sources is decreasing.

The advantages and disadvantages of wind energy compared to solar energy are as follows [Figure 2.1]:

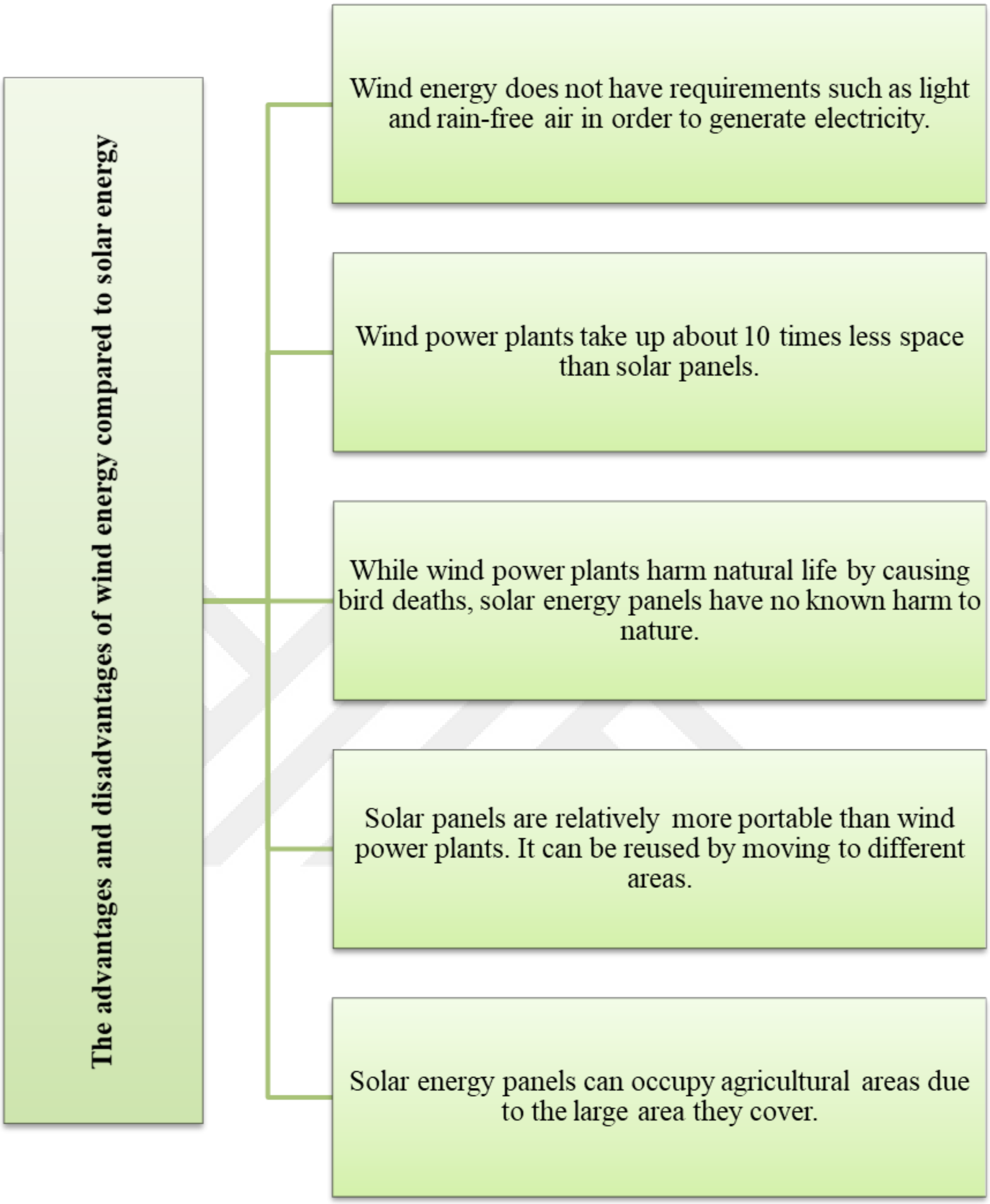

Figure 2.1: The advantages and disadvantages of wind energy compared to solar energy.

Since wind energy is a type of energy that can be produced in almost every region, it reduces energy transmission costs. Facilities that generate electricity from fossil energy sources can only be established in certain parts of the country.

As in many different parts of the world, wind energy is widely used in Azerbaijan. Azerbaijan is among the important countries in terms of wind energy, especially in terms of its geological structure and climatic conditions. In this direction, wind energy is used in different areas for many different purposes through special systems.

a) In houses,
b) In many different businesses,
c) Park and garden and street lighting,
d) Signaling,
e) Caravans with boat and mobile stations,
f) Irrigation systems,
g) All different areas that may need electrical energy.

Wind energy, which provides safe electrical energy with special installation, provides a renewable opportunity at a very low cost. Although it does not have the potential to generate a very high level of electrical energy, it offers the opportunity to protect nature with sufficient energy for certain places.

2.1 Information on Electricity Generation from Wind Energy

Many different wind turbines are installed at different points depending on their intended use. There are many types of wind turbines with different qualities in this regard. There are three different systems, especially depending on the axis of rotation.

a) Horizontal axis wind turbines,
b) Vertical axis wind turbines,
c) Inclined axis wind turbines.

Especially at night, the cold air layer rises up with the warming of the air during the day hence the air expands and begins to rise. On the other hand, the cold air layer in the atmosphere goes down [8].

Thus, wind is formed with the displacement of hot and cold air. When the propellers start to rotate in wind turbines, the kinetic energy is converted into electrical energy by means of a generator. Thus, electrical energy is produced safely, stored and used at different times in different areas.

2.2 Wind Energy in Azerbaijan

The influence of mountains on the climate and wind regime of the Republic is great. For example, the Greater Caucasus Mountains act as a barrier, preventing cold air masses from entering the country from the north and northeast.

Figure 2.2: Wind power plant.

Cold air masses pass around the Greater Caucasus Mountains and enter the territory of the Republic from the Absheron Peninsula. Therefore, the average annual wind speed in Zagatala is 1.2 m/s. In Absheron, it is 8.6 m/s.

The Azerbaijan Scientific Research Energy Institute has divided all weather vane observations collected at the country's meteorological stations into groups and identified the following types of wind speed distribution regimes according to the landscapes of the regions:

Type A regime in Absheron and Kura on the northern borders It is typical for places in the Caspian zone. The average annual wind speed in this zone is greater than 4 m/s. The average annual wind speed in this zone is from 4 m/s to 3 m/s. Type V regime is typical for mountainous regions of the Republic. The average annual wind speed in zone V is less than 3 m/s. Therefore, this zone is considered unsuitable for the use of wind energy. It should be noted that the climatic features of the high mountainous areas, which mainly form the Vzona, have not yet been well studied [4].

According to estimates, the Republic of Azerbaijan has an annual wind energy reserve of about 800 MW due to its geographical location, natural conditions and economic infrastructure. This reserve is estimated at 2.4 billion kWh of electricity per year. This, in turn, saves about 1 million tons of conventional fuel per year, and most importantly, prevents the release of large amounts of waste per year, including ozone-depleting carbon dioxide into the atmosphere.

In 1999, the Japanese company "Tomen" together with the Azerbaijan Research Institute of Energy and Energy Design installed two towers in Absheron with a height of 30 and 40 meters, the average annual wind speed was determined to be v = 7.9-8.1 m / sec. and a feasibility study for the installation of a wind power plant with a total capacity of 30 MW in the Gobustan region [4].

In 2002, an assessment of Azerbaijan's renewable energy resources was conducted and it was found that the Absheron Peninsula has a large potential for wind energy.

The average long-term wind speed is more than 6 m/s, which indicates the availability of favorable technical and economic potential for wind energy. Statistics on wind energy collected from the area where the Northern SDPP is located once again confirmed the presented figures. The indicators presented for the territory of Gobustan region during these studies belong to the 4th class of wind energy potential, which is considered to be high potential.

2.3 Onshore and Offshore Wind Energy Potential in World

At least 3 main goals should be paid to the reasons for the exploitation of renewable energy sources in our country. First of all, electricity is needed to meet people's basic needs and support economic development.

Second, the acquisition, conversion, and use of conventional energy pose significant local (urban air pollution) and global (climate change) problems, causing significant environmental problems.

Third, it took a long time to make fundamental changes in energy production and to get used to it, so it was necessary to take the necessary measures without exacerbating environmental problems.

Due to growing industrial enterprises, technological innovations and rapid population growth, increasing electricity consumption is driving people to search for new and environmentally friendly energy resources.

According to a report by the International Renewable Energy Agency (IRENA) entitled "Future of Wind - The Future of Wind Energy", global wind power capacity could increase 10 times by 2050 to more than 6,000 GW. Of this, 5,000 GW will be onshore and 1,000 GW at sea. According to the report, by 2050, wind energy can meet one third of global electricity needs. Onshore wind power will increase from 542 GW in 2018 to 1787 GW in 2030, and by 2050 to 5044 GW in 2050, and on the high seas to 228 GW in 2030 and 2050 in 2050 [Figure 2.2]. It is targeted to reach 1000 GW [18].

Achieving these goals requires a fourfold increase in onshore wind energy and a 10fold increase in offshore investment. Onshore investment should increase from an average of $67 billion to $211 billion a year, and offshore investment from $19 billion to $100 billion a year. It is also noted that wind energy can save 6.3 gigatons of carbon emissions per year. According to the report, by 2050, Asia will account for 50% of global onshore wind energy investment. Asia will be followed by North America with 23% and Europe with 10%. In offshore wind energy, Asia will account for more than 60% of global investment. After Asia, Europe will be the largest investor with 22% and North America with 16% [4].

Onshore wind power leverage (Levelized Cost of Electricity-LCoE) will continue to decline to $0.02-0.03 by 2050, up from $0.06 per kWh in 2018. Offshore wind power leverage (LCOE) will be reduced from $0.13 per kWh in 2018 to $0.03-0.07 by 2050.

The capacity of onshore wind turbines is expected to increase to 4-5 MW by 2025, and the capacity of offshore wind turbines to 12 MW. It is estimated that the global wind energy industry could be a sector that could employ 3.7 million people by 2030 and 6 million by 2050.

2.4 Wind Energy Potential of Caspian Sea

Renewable energy resources were assessed in the Republic of Azerbaijan in 2019 and 800 MW annual wind energy reserves were identified at a height of 0-30 m. This reserve is equivalent to 2.4 billion kWh of electricity per year.

After the establishment of the ASARES (2009), as a result of a detailed assessment (including wind speed at an altitude of 50 m), the total wind energy potential in the country was determined to be 4500 MW/s. 24.728 billion manats was spent in Azerbaijan in 2018 with an average annual growth of 1-1.5%. kWh of electricity was produced.

With full utilization of wind energy resources, 9.6% of this demand can be obtained only from wind energy. This will bring about 144 million manats to the annual state budget (excluding investments) at retail prices (0.06 manatss for 2015). From the environmental point of view, each MW of CHP in the country saves 14,500 tons of coal and 46,000 barrels of oil over 10 years, as well as 20,000 tons of carbon monoxide (CO_2), 100 tons of sulfur dioxide (SO_2) and 2 tons of nitrogen oxides. prevents.

Carbon dioxide is the main source of greenhouse gases in Azerbaijan, and 97% of its emissions are generated by conventional energy production. 70% of electricity comes from fossil fuels (31% natural gas, 10% oil), which cause environmental pollution and global warming. The Absheron Peninsula and the shores of the Azerbaijani sector of the Caspian Sea are considered suitable areas for wind power generation in our country. The number of windy days in these areas is 245-280 days a year (more than 4 m/s). In the Caspian littoral areas, the average annual wind speed varies from 5.50 to 6 meters per second at an altitude of 40-50 meters per second, and in the Absheron Peninsula at an altitude of 20-30 meters per second [Figure 2.3]. Also, strong windy days with speeds up to 21 m/s (127 in Shubani, 95 in Sumgayit, 40 in Mashtaga, 37 in Pirallahi, 35 in Baku) are often repeated on the peninsula [4].

Partition	Areas	Average annual wind speed m / s
A	Absheron peninsula, Caspian coastal areas and islands (Sumgayit, Mashtaga, Bina, Baku, Puta, Alat, Pirallahi island, etc.).	4-7.8
B	Coastal lowlands (Agstafa, Gazakh, Tovuz, Goychay, Yevlakh, Ganja, Tartar, Sabirabad, Salyan, Shirvan, Bilasuvar, Beylagan, Shamkir, Lankaran, Astara, Julfa, Gadabay, etc.).	2.1-4
C	Mountainous and plain areas (Fuzuli, Agdam, Yardimli, Dashkasan, Khankendi, Lerik, Jabrayil, Kalbajar, Zangilan, Shahbuz, Guba, Khachmaz, Siyazan, Shamakhi, Ismayilli, Gabala, Oguz, Sheki, Zagatala, Balakan, Gakh, etc.).	0.8-2.1

Figure 2.3: Indicators of wind regime in the Republic of Azerbaijan (H-10 m).

The average annual wind speed in Pirallahi, Bina, Baku, Cilov Island and Neft Dashlari fluctuates between 6.2-6.7 m/s. As we move northwest and southwest of the Absheron Peninsula, the average annual wind speed decreases.

These are Golden Nose, Khizi, Gobustan and others. The average annual wind speed in the area decreases to 4-4.6 m/s. It is expedient to build 1,500 MW HPPs in these areas, and 1,500-1,600 kWh on the islands (Pirallahi, Sangi-Mugan, Neft Dashlari, Khara Zira, Chilov). In the coastal part of the Caspian Sea belonging to Azerbaijan, the average annual wind speed in a strip of about 300 km varies between 5.6-7.1 m/s at an altitude of 40-50 m [20].

If we place 15-20 turbines with a capacity of 600 kW/h in 1 km^2 on the Absheron Peninsula, provided that the wind turbines do not overlap at a distance of 1.5 km from the coastline, it is possible to produce 1,800 MW or 4-4.5 bln KW/hr energy.

The average annual wind speed in Nakhchivan AR varies between 3-5 m/s (Table 3). From here (number of windy days 165) it is technically possible to get 70 MW of energy. Thus, the geographical location of the NAR is due to the interaction of two air currents: the cold air flow from the Arctic to the north and the movement of warm air masses from the south to the tropics, creating strong winds in Julfa and Ordubad districts.

Azerbaijan's ability to use wind energy

Azerbaijan has been generating wind power since 2014. In 2013-2014, a total of 732.9 mln. manatss were invested, of which 159.5 mln. manats (22%) was allocated for wind energy and 62.1 MW of electricity was produced.

In 2014, 63.6 mln. manats was invested, of which 34.9 mln. manats (54.8%) falls to the share of wind energy. Thus, the investment in the production and construction of HPPs is repaid for current costs in only 7-8 years. Along with traditional energy sources (24.728 billion kWh in 2014) in our country in 2013, 0.8 mln. kW / h, and in 2014 - 2.3 mln. kWh of wind energy was produced.

A state program consisting of 3 stages in the direction of alternative energy has been developed in Azerbaijan republic. During the period covering 2014-2016, the capacity of HPP will be 150 MW, in 2017-2018 it will be 150 MW, and in 2019-2020 it will be 212.5 MW.

By the end of 2020, the total capacity of wind energy will be 512.5 MW, 28% of alternative and renewable energy sources (1830 MW). The share of ABOEM electricity in Azerbaijan's total annual energy production in the country for 2014 is 12% (95% HPP). This is about 2.5 billion. kWh of electricity. About 89% of electricity generated in Georgia comes from hydropower plants, and 40% in Armenia from nuclear power plants. For example, a wind farm with a capacity of 500 kW prevents the emission of 750-1250 tons of carbon dioxide and 3-6 tons of other harmful substances compared to a coal-fired power plant. Although the cost of energy production at ASARES-built power plants in Azerbaijan is high, the damage caused by fuel-fired power plants to the environment and human health must also be considered [19].

We must also add Azerbaijan's Kyoto commitments (not quantified). Thus, the average cost of wind energy production in the world is $ 2,149 per kWh, and the estimated financial cost in our country is about $ 2,354 per kWh. For example, the financial cost of the project is 47.25 million manatss, adding 2.6% (environment, training, annual operation, maintenance costs, etc.) to the construction costs of the 20 MW HPP to be built in Siyazan region.

Despite the great prospects for the use of wind energy, KEGs are imported for the development of this sector. Even if Azerbaijan is a sustainable alternative energy producer in the absence of KEGs in our country, along with maintaining its external dependence on this area, technological backwardness will always be inevitable. For example, wind turbines in Gobustan and Yeni Yashma are designed for the ocean region. Although there are two types of winds in the Absheron economic region (Khazri and Gilavar), they work unilaterally because they are calculated only for Khazri.

In order to expand the use of alternative energy in the country, along with the financial support of the state, stimulating measures should be taken for individual users. As a result of the efficient use of alternative energy, the state should produce small-capacity PPPs in Azerbaijan and offer them to entrepreneurs without a profit (or with a profit of up to 10%), and get the remaining energy from the state producers. In order to develop alternative energy in the country, entrepreneurs should be given broad rights, economic conditions should be created, import taxes and VAT should be abolished, and the state should promise to receive at least 0.04 manats per 1 kWh of alternative energy from energy producers. This is because, with the funds allocated to this area from the state budget, the power plants will either be built in an inconvenient area or, after some work, will face technical problems, and finally a lot of money will be wasted. Widespread use of ASARES in our country makes it necessary to implement a number of complex measures [19].

1. Support of innovation and scientific research;

2. Expansion of land and tax legislation to ensure greater use of ASARES;

3. Definition of tariff and incentive policies;

4. Application of electricity procurement contracts in the design of newly built or overhauled construction facilities in the economic and social spheres, providing for the use of at least 20% of alternative energy in total consumption;

5. Establishment of technology parks for the application of high technologies in the field of alternative energy, etc.

2.5 Development of Wind Energy in The World

Depending on the advancing technology all over the world, the needs of people for electrical energy are also increasing. Since the existing fossil resources used in electrical energy production are limited, they are decreasing day by day and they will be exhausted one day, on the one hand, electrical energy saving studies are carried out, on the other hand, studies on generating electrical energy using renewable resources continue at a great pace. The importance of the studies for the use of renewable resources in the production of electricity is obvious for the future of the countries, since they reduce the dependence on foreign sources. One of the studies carried out in this context is the generation of electrical energy by using wind potentials, which have shown great development in the world and especially in Europe in recent years.

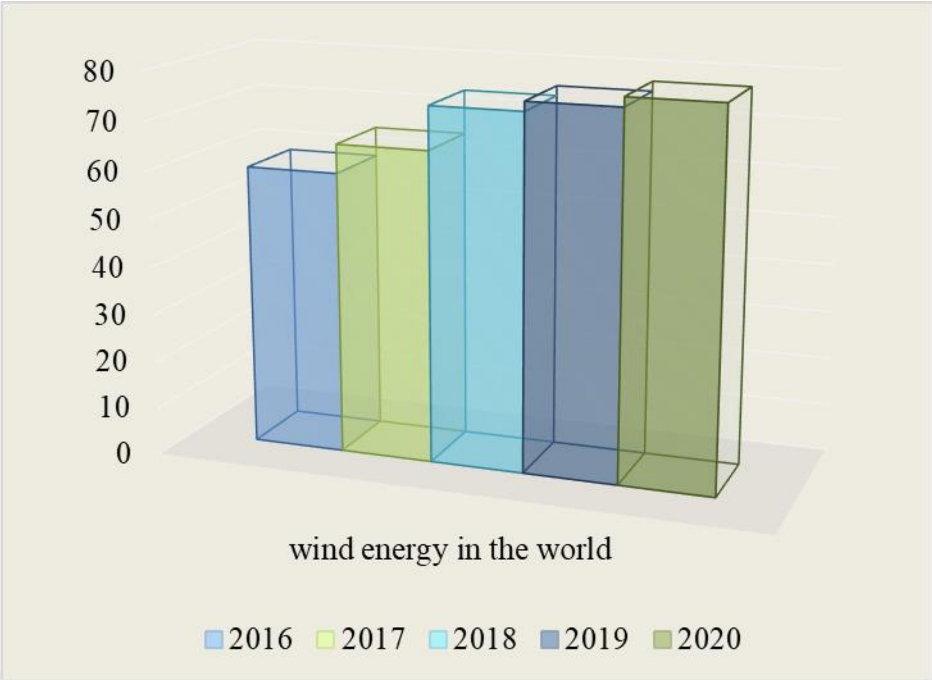

Figure 2.4: Development of wind energy in the world

As of 2019, the total installed wind power in the world is 47 616.4 MW [Figure 2.4]. The change in the installed wind power in the world from 1996 to the present is given below. As can be seen from the figure, the installed power in wind energy continues its increasing trend. During these periods, the average increase rate in wind energy installed power was realized at a very high value of 29%.

As the issues of energy security and climate change begin to be considered, the wind energy sector is also developing day by day. Wind energy production increased by 2,160 MW in 1990, by 43% in 1994 to 3,738 MW, in 1999 by 13,992 MW, and in 2003 by 33,400 MW, thus increasing by an average of 81.6% over the last 10 years.

In 2018-2019, the growth rates reached 9.3% and 12.9%, respectively. While the total capacity of global CHPs in 2015 was 6,070 MW, by the end of 2019, this trend had increased more than 22 times to 365,400 MW. Considering this growth rate, it is possible to give an approximate forecast for the next 5 years. Thus, in 2024, the capacity of HPPs in the world will increase by 54% to 564 MW. In countries where CESs exist, more than 670,000 people work in the sector. In 2030, this figure is projected at 2.6 million. In 2019, Europe alone will receive $ 48.4 billion, Europe $ 35.8 billion, China $ 56.8 billion, India $ 6.1 billion, the Middle East and Africa $ 9 billion, Brazil $ 3.1 billion and Asia (excluding China and India) $ 43.3 billion and the United States $ 13.2 billion [21].

Thus, investment in wind energy production in several countries has approached a competitive level with the cost of conventional electricity generation. Of these, in 2019, Denmark will receive 39.1% (13.08 billion kWh in 2013) and Spain 22.3% of demand (51,439 MWh in 2014) from wind energy. Mineral fuels account for 79% of world energy production, renewable energy sources for 17% and nuclear power plants for 3%. Wind energy is used as an energy source in more than 50 countries around the world. However, wind energy production is highly developed in some countries. In 2019, the total capacity of wind energy operated in the world was 369,553 MW / s. In 2022, the total production capacity will be 1.2 million MW, and in 2030, 20% of the world's electricity needs will be provided by wind energy [21].

3. OFFSHORE WIND TURBINES

Wind is the air movements formed by the effect of the forces that arise as a result of the uneven heating and cooling of the earth. Wind energy, on the other hand, is the motion energy of the air flow that creates the wind.

Wind energy, which has been in use for milleniums, become the main power source for sailing ships in the seas, and windmills and windmills on land. Needs such as wheat, corn milling and water pumping have been solved in this way for years.

Wind energy use began in the Middle East in the third millennium BC. Humanity has experienced a technological process extending from windmills to modern wind power plants in the use of wind energy. With the construction of the steam engine and the uninterrupted production of energy from fuels such as wood and coal, wind energy has begun to lose its importance. Wind energy, which was not given enough attention due to the cheapness of fossil fuels, was remembered again due to the oil crises in the 1970s [17].

With the developments after 1980, wind farms in Europe and the USA have become modern engineering products in terms of economy, environment and energy. With the mass production of Wind Turbines (WTs), investments in this field and developments on turbines have increased day by day and wind power plants have been established. Wind power plants, which were previously built on land, are now built on the seas.

The wind industry has become more widespread and with the help of Risoe National Laboratory, in parallel with the development of the European Wind Atlas, significant decreases have occurred in electricity unit prices.

When the smallest WTs entered the California market in 1982, they had long been in use in Denmark. In California, the state aid program between 1979-1985 showed its effect and the number of small WTs, which was 150 in 1981, reached 16000 by the end of 1985.

Danish manufacturers, which own 75% of all WTs in California, have established an industry for 55kW WTs. Even today, Danish WT manufacturers remain the largest manufacturer in the worldwide market. In 1985, the WT prototype with a wingspan of 25m and a power of 250kW was built in California and launched in a short time.

In Denmark, on the other hand, home type WTs were developed and released to the market in order to keep the market alive. Even today, household type WTs are manufactured in various powers, operating independently between 0.1 and 10kW. Parallel to the development of small WTs, several countries invested in large WTs between 1976 and 1980 upon market demand. Millions of marks have been spent on the development of large WTs in Germany and the world, but support has dwindled as technical problems and negative sentiments arose.

Although the second largest WT production was successful in terms of cost and performance, it did not attract the attention of consumers. Thus, it was not possible to develop large WTs.

Since 1989, WT technology has developed rapidly in Germany. WTs with a rotor diameter of 25m and an output power of 150-250kW were manufactured, followed by turbines with a rotor diameter of 30-35 m and an output power greater than 300 kW. These turbines dominated the market for 2-3 years. In August 1992, the first 500 kW WT made by Tacke-Windtechnik started to work. This was followed by E40 by ENERCON and turbines produced by other European manufacturers. For the development of 500kW WT, rotor production with a blade diameter of 37 m has started [26].

This was followed by WTs with a diameter of 46m and a power of 600 kW designed for use in low wind areas, especially in the interior. Four years after Tacke-Windtechnik's 500 kW WT, towards the end of 1996, ENERCON started to produce 66m diameter WT with 1.5 MW power.

Turbines with a diameter of 66 m and a power of 1.65 MW followed. Nowadays, it is not unusual to see an WT with a rotor diameter of 70 m, 80 m or even 100 m and powers of 2 MW and above for land applications.

Offshore wind turbines and onshore wind turbines have some technological differences. The specific outside protective coating created to shield them from corrosion in offshore systems is the first of these variations. Due to the high humidity and saline climate, a good exterior protection treatment on the wind turbine surface is required since offshore systems are deployed in the sea. Because onshore wind turbines can be placed close to homes, the entire system, particularly the blade design, is engineered to limit noise [5].

In offshore wind turbines, the main purpose of the design is to obtain optimum aerodynamic efficiency rather than noise. For this reason, offshore wind turbines have higher blade speeds than onshore systems. Increasing the blade speeds also brings the following requirements. As a result of the decrease in the rigidity of the wing, the area swept by the wing decreases and thus the wing length is shortened. Reduction of the forces acting on the blade when the wind turbine is not operating as a result of the decrease in the swept area of the blade.

Shrinkage of mechanical parts such as gearbox, main bearing (applicable in case of gear box systems). Periodic maintenance of offshore wind turbines using gear box is also slightly different from onshore systems.

The service time of the lubrication system is longer. Many bearings are automatically lubricated. A special oil filtering system in the gear box ensures that the quality of the oil is maintained for a long time. The most important cost parameters of the offshore WPP are the foundation construction of the turbines and the transmission lines drawn under the sea to the nearest land part [5].

What determines the cost of offshore WPPs is the distance of the facility to land and the depth at which it will be installed. Because these factors are the main factors that determine the basic and transmission connection costs.

The investment cost distribution of offshore WPPs is slightly different from onshore WPPs. For example, in an onshore wind turbine, 68% of the investment cost is wind turbine and 9 percent is foundation construction; In offshore systems, these rates are distributed as 33% and 24%. In addition, the total investment costs of offshore WPP are higher than onshore systems.

The first offshore wind power plant is the Vindeby wind power plant, which has an installed capacity of 5 MW, established near Looland Island in Denmark. In the first stage, offshore wind power plants were established in areas not exceeding 10 kilometers from the coast and 10 meters in depth.

3.1 Structures of Wind Turbines

Wind energy is the type of energy that comes out as a result of the displacement of hot air and cold air. However, depending on the physical differences on earth, the different heating of the atmosphere by the sun is also among the sources of wind energy.

Wind energy created by pressure differences in the atmosphere, in other words, is a different type of solar energy. The process of generating electricity from wind energy is carried out by converting the kinetic energy of the wind into electrical energy [6].

Wind turbines are machines that transform the kinetic energy of the wind into mechanical energy, which is ultimately converted into electricity. Wind turbines are made up of a variety of components. The tower, generator, speed converters, electrical and electronic components, and propellers are all part of this equipment. Direct current generators, synchronous generators, and asynchronous generators are the three types of generators utilized in wind turbines.

Wind turbines are classified according to their axes of rotation, revolutions, power, number of blades, wind effects, gear characteristics and installation positions.

Types of Wind Turbines According to Rotation Axis: Wind turbines are divided into three groups according to their axes of rotation. These groups are as follows: Horizontal axis wind turbines, vertical axis wind turbines, inclined axis wind turbines.

Types of Wind Turbines by Number of Wings: These types of wind turbines can be listed as follows: Single bladed wind turbines, double bladed wind turbines, three bladed wind turbines, multi bladed wind turbines.

Types of Wind Turbines According to the Direction of Wind: According to the wind direction, there are wind turbines that receive the wind from the front and wind turbines that receive the wind from the rear.

Types of Wind Turbines According to Maximum Powers: Types of wind turbines according to their maximum power: Small-powered wind turbines, medium-powered wind turbines, large-powered wind turbines and very large-powered wind turbines.

Types of Wind Turbines According to having a Gear Box or not: Different types of wind turbines stand out, depending on whether they have a gearbox or not. Among these wind turbines, wind turbines with gearbox and wind turbines without gearbox draw attention.

The fact that wind turbines are produced in the most suitable varieties according to their usage and purposes and they have a wide product range provides a great advantage to the users. These wind turbines, which have many types, can be easily accessed today. In this case, quality and reliable manufacturers who can analyze the needs of the day in the best way have an important share.

Wind Turbine Engine and Working Principle: In the working principle of the wind turbine, the air, which is generally fluid, moves towards the turbine and the blades of the turbine start to rotate in this way. With the rotation of the blades, the shaft connected to the junction area of the blades in the hub begins to rotate.

The high-speed shaft transfers kinetic energy to the generator by increasing the rotational speed thanks to the gear boxes. The wind turbine engine is the most basic element in the process of converting wind energy to electrical energy, and the targeted production can be reached in the fastest and most effective way with a high quality and powerful engine system.

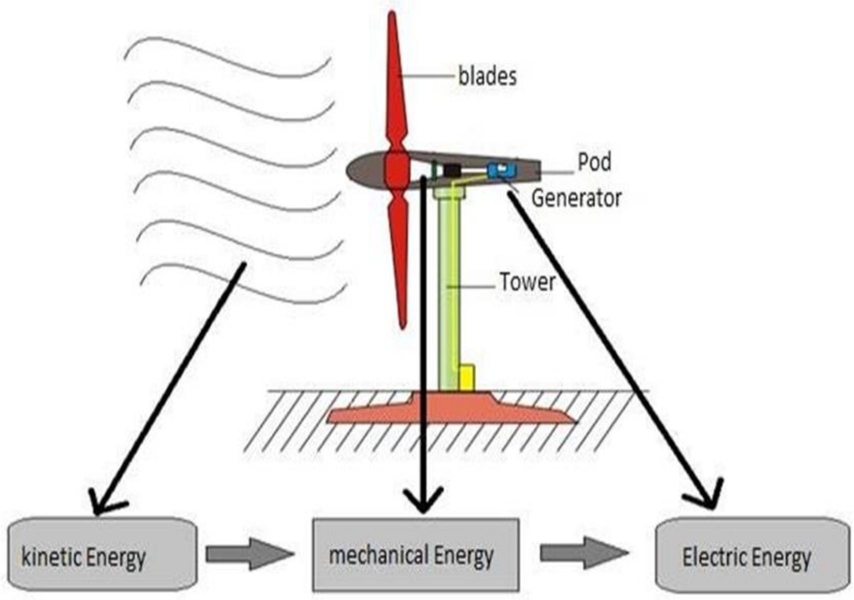

Figure 3.1: Working principle of wind turbine.

In other words, in the working principle of wind turbines, the kinetic energy that occurs as a result of the rotational movement of the propeller is converted into electricity in the machine room section where the other parts of the turbine are located. There are gearbox, generator and other accents in the machine place located in the rear part of the propeller. The rotational movement of the propellers is transmitted to the gearbox by a shaft. Since the shaft does not have sufficient high speed in terms of electricity generation of the generator, high speeds are provided with the gearbox. Electricity is produced according to the generator capacity and the revolution of the shaft.

3.2 Components of Wind Turbines

Since it is invisible it is difficult to imagine that air is a liquid. Unlike denser liquids, air moves faster and covers the entire environment. The process of converting this property of air into kinetic energy is called wind energy.

In the same sense, the use of water compression to generate energy is also called hydroelectric energy, and the center is called the hydro-power station. Wind power plants are also called alternative energy sources.

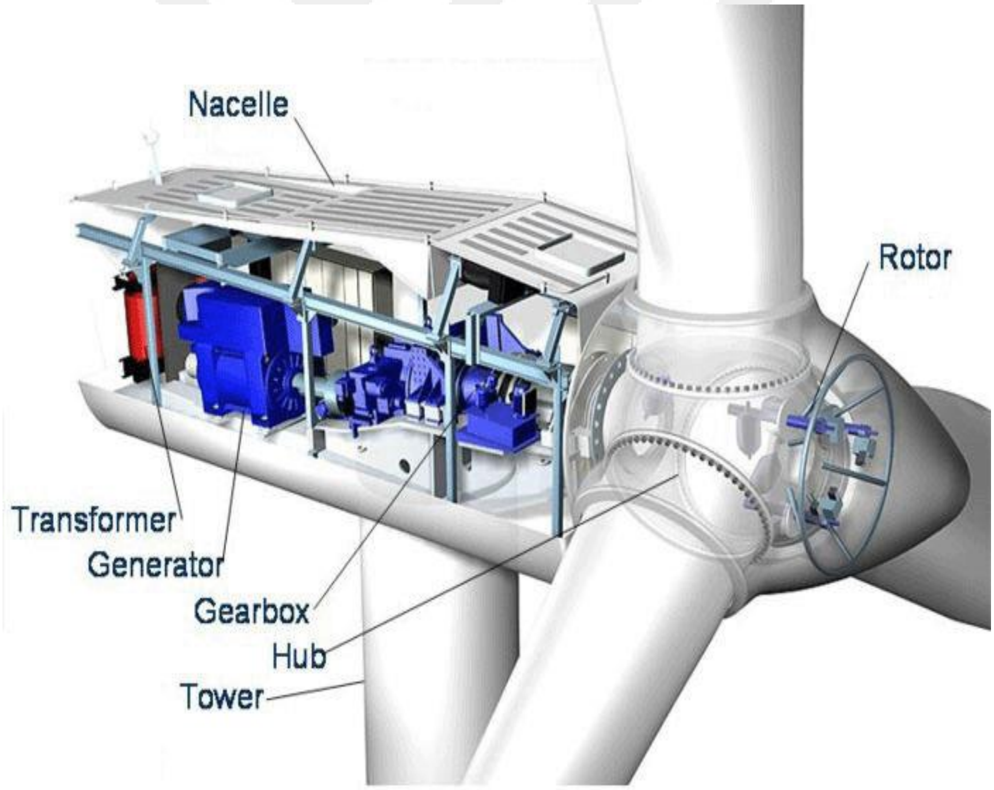

Figure 3.2: Wind turbine.

Once the turbines are installed, the blades rotate the shaft with the movement of the wind. This kinetic energy is converted into electrical energy by a suitable generator.

Wind energy begins at sunrise. It immediately begins to warm up with the sun's rays near the places of the cold air layer. As explained in physics lessons, the warming air expands and rises. At this point, a layer of cold air falls to the ground. The wind changes when hot and cold air escapes.

3.3 Wind Turbine

In the simplest sense, wind turbines produce electricity in three stages:

1. When the wind blows, the blades force the rotor to turn. Thus, the kinetic energy of the wind is transformed into rotational energy.

2. The shaft, which is connected to the rotor also begins to rotate. As the shaft rotates, the motor moves and electricity are produced.

3. Generator has a very simple operation method. Electricity is generated by electromagnetic induction. Similar to an electric motor in small toy cars, there is a magnet inside. In the center of the magnet is a part wrapped with thin wires. When the shaft rotates, this winding zone inside the engine begins to rotate in the middle of the surrounding magnet. The result is an alternating current (AC).

The offshore wind turbines used today are more complex than the use of wind turbines on the land. Wind turbines now come in two different designs. The first is a design that can rotate around a vertical shaft, as can be seen in Fig. 3.3. Vertical Axis Wind Turbines are abbreviated as VAWTs.

These are designed to be perpendicular to the vertical axis hence always adjusted for the wind direction. Generally, an electric motor is needed to provide the first move. The turbine is fixed to the axle with auxiliary wires.

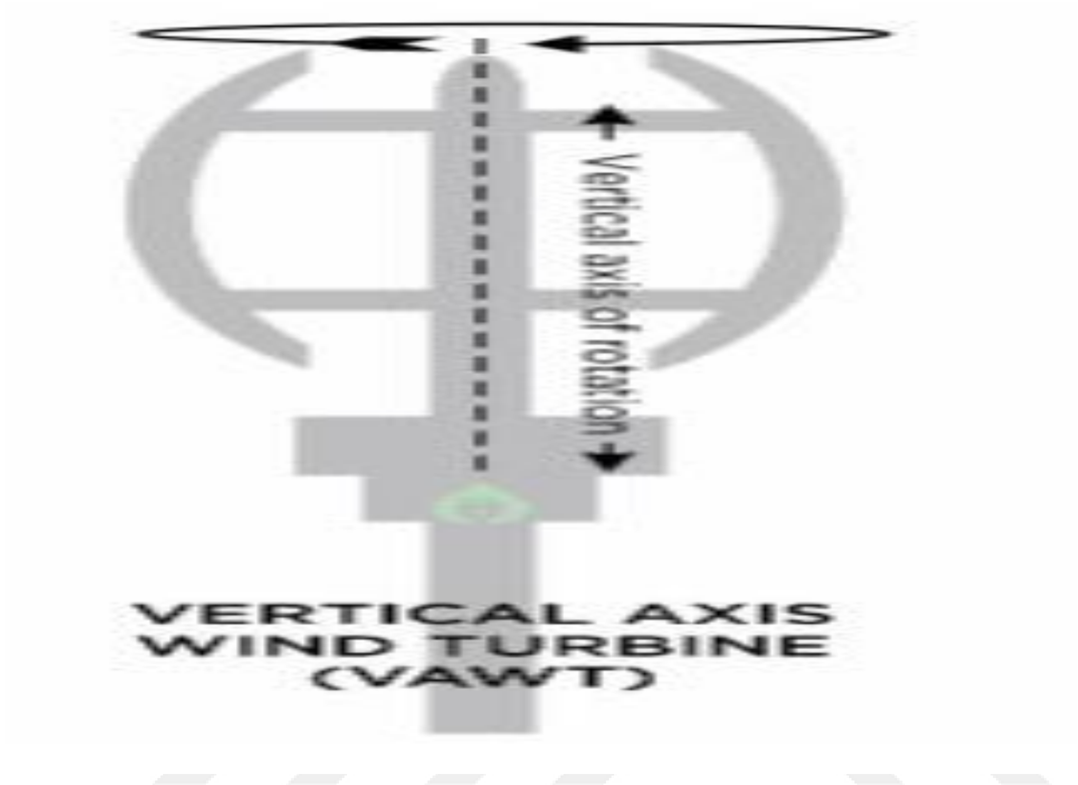

Figure 3.3: VAWT turbine.

The efficiency of the device is low, because it receives less wind near sea level. However, it is advantageous to have all the necessary equipment at ground level, but it has a negative impact on agricultural lands.

Another important design is HAWT called Horizontal Axis Wind Turbine [Figure 3.4]. The axis of rotation is drawn parallel to the ground. With the help of an electric motor, the direction of the propeller can be adjusted according to the direction of the wind. It is not structurally different from an electric motor. It should operate at an altitude of about 80 meters above sea level.

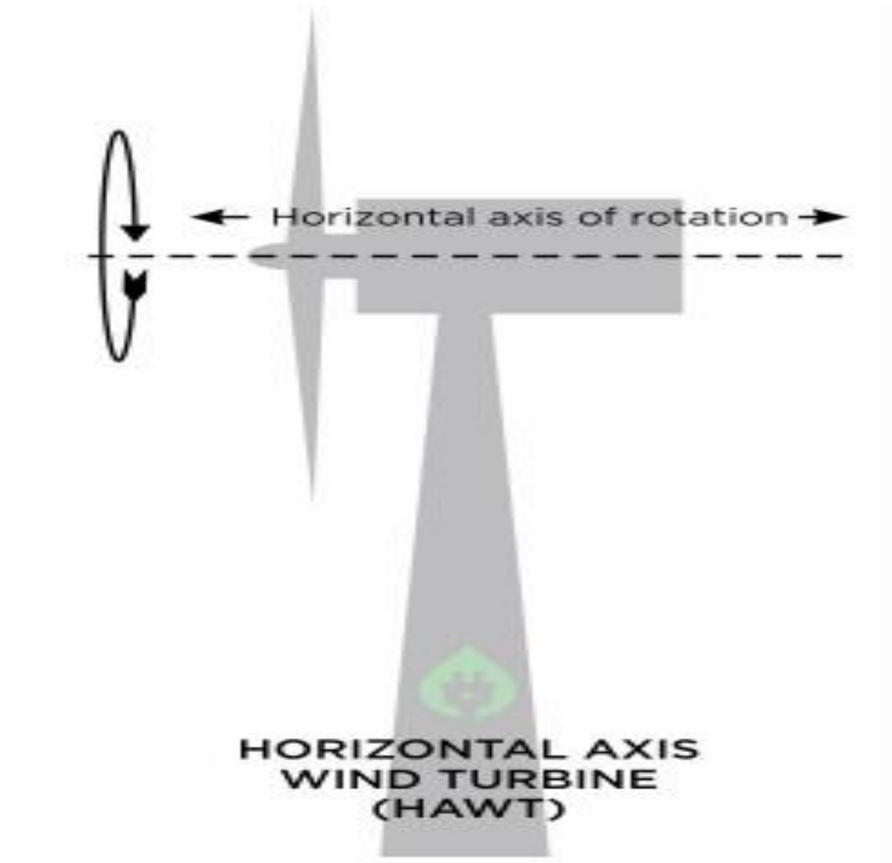

Figure 3.4: HAWT turbine.

Horizontal turbine:

Rotor Blades: Used to convert wind energy into rotation.

Spindle: This transmits rotational motion to the generator.

Gear Box: Increases speed between propeller and shaft to provide faster movement.

Generator: The part that generates electricity from rotational motion.

Breaks: Used to stop the wheel when there is a lot of load and problem.

Tower: Allows the propeller and engine compartment to operate at a safe height from the ground.

Electrical Equipment: Ensures the transmission of generated electricity to the appropriate centers.

3.4 Failure Problems of Turbines

To calculate the energy generated by a wind turbine, it is necessary to know the wind speed and turbine diameter. Basically, large wind turbines rotate at a speed of 15 meters per second. Theoretically, the turbine diameter should be increased to increase the energy produced which in turn requires an increase in the height of the wind turbine. This provides faster wind speeds and a faster rotation.

In general, wind turbines operate at full capacity for find speeds of approximately 9 m/s. The system stops automatically when it reaches 23-25 m/s. If the turbine accelerates too much, several different control mechanisms are available to stop the system. The most common system is the brake system. Failures in wind turbines can be caused by a variety of reasons, including poor quality, poor design and manufacturing standards, construction and assembly deficiencies, local operating conditions, transmission system design and general maintenance. Transmission failures are among the mechanical failures that cause the longest downtimes. During regularly scheduled maintenance, it can be difficult to access the massive rotor blades and evaluate the blade materials and the complex surface areas. New technologies like the use of drones for blade inspections are being used, which aids in the inspection process. However, without proper monitoring and maintenance, it can lead to component failure[30].

Failure rates and downtimes in subsystems during a survey of more than 1500 wind turbines in Germany over a 15-year period show that generator failures represent about 4% of the total number of failures in wind turbines. Failures that may occur in wind turbines have very serious consequences and can make the turbines completely unusable.

The main cause of failure in electrical components of wind turbines is related to bearings and windings. The following components are among the causes of most failures in wind generators using induction generators [Figure 3.5]:

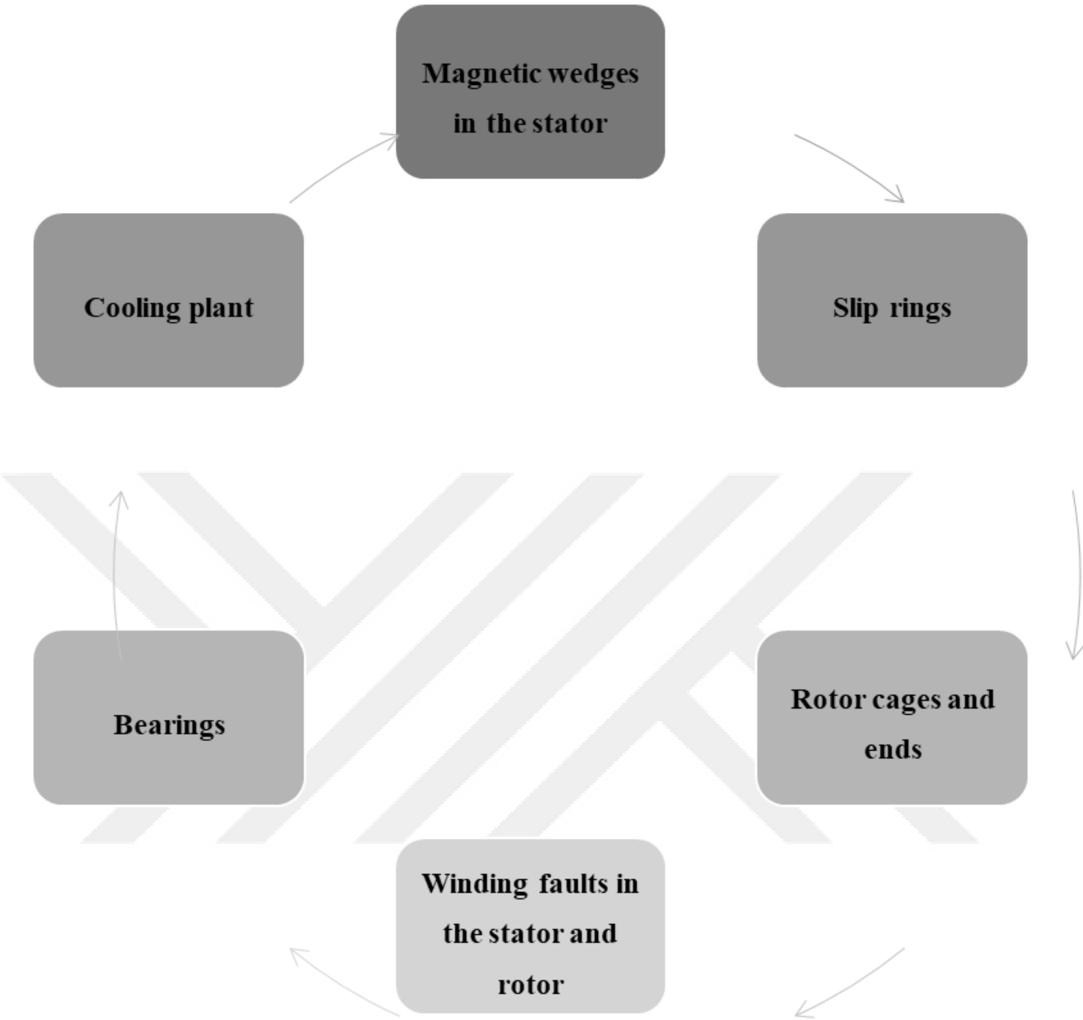

Figure 3.5: Components that cause most failures in wind generators using induction generators.

Studies have shown that most of the failures are caused by electrical equipment (approximately 5.5 failures in every ten machine years) and that the faults in electrical equipment are repaired and reactivated in a very short time (1.5 days on average).

Gearbox failures, on the other hand, are less common (1.5 times per ten years), but repairs are more time consuming (average 6 days). Hydraulic systems are the least problematic, with annual maintenance taking less than half a day.

The average efficiency loss over ten years may be calculated by multiplying the number of failures by the number of days the turbine is not working. Failures in both gearboxes and electrical systems result in only one day of downtime per year on average.

3.5 Advantages of Offshore Wind Turbines

Wind energy, like other renewable energy sources, is an important form of energy. Wind turbines have been developed to take advantage of wind energy [5].

These systems, which convert wind energy into mechanical energy, are installed in areas where the wind will be utilized sufficiently.

These are hills or coastal areas that are usually at a certain elevation on land. For this reason, offshore wind power plants are facilities established on the sea at a certain distance from the shore to benefit from the wind.

Large wind turbines and scavenging areas, improved blade aerodynamics and taller towers are being developed and installed to increase the energy to be produced from wind energy [Figure 3.6].

Depending on the wind turbine manufacturers' development of turbine technology; investment, operation and maintenance costs can be reduced and different designs can be made for different wind conditions.

Figure 3.6: Offshore Wind Turbines.

Offshore (offshore) wind power plants have been established to get maximum efficiency from the wind. The wind does not lose its potential in coastal areas due to absence of any landform. Thus, wind energy with sufficient speed and strength can be used.

As in every system, offshore wind power plants also have some advantages and disadvantages. Wind turbines are machines that transform the kinetic energy of flowing air into mechanical energy and subsequently into electrical energy. They are the most fundamental structural parts of wind power facilities. The wind turbine may be built horizontally or vertically, providing a versatility in terms of operation and energy output in the locations where it is located.

Wind turbines with a horizontal axis are more prevalent. Wind turbines can only start producing energy when the wind speed reaches a specified level. Azerbaijan's wind energy potential is projected to be 48,000 MW. The whole area equal to this potential is approximately 1.30 percent of Azerbaijan's total surface area.

3.6 Advantages of Offshore and Onshore Wind Farms

1. In order to get maximum efficiency from wind power plants, the wind must be regular and at sufficient potential. On land, rugged areas and forests can slow the wind speed. However, in coastal areas, the wind can be used without any impairment.

2. Onshore wind power plants can occupy agricultural lands that are in use. Therefore, both the area where it is installed and its surroundings cannot be used as desired. Since offshore wind power plants are installed in the sea, this problem does not occur.

3. Since wind energy turbines are relatively gigantic structures, they can harm migratory birds. Even if various measures are taken to prevent this situation, it cannot be completely controlled. Offshore power plants do not pose a problem for high-flying birds as they are used at sea level.

4. The installation cost of wind turbines is high. In addition to the cost of the facility, the logistics of huge parts are also a problem. In the installation of offshore wind power plants, the sea route can be used, and the logistics problem can be solved to some extent.

3.7 Disadvantages of Offshore Wind Farms

1. Offshore wind power plants are costlier to install. Because, like any structure built on the sea, there are more parameters to be considered. Therefore, investments may be delayed due to lack of capital.

2. In addition to the installation cost, periodic maintenance costs are also higher in offshore wind power plants.

3. Wind power plants established on land are mostly located away from settlements and in places that will not affect people. On the other hand, the locations around the offshore wind turbines can be used for tourism, fishing, etc. These can create problems for people living in coastal settlements as well.

4. Although it covers a small part of the sea, wind turbines can affect the vitality in the region though they do not to cause pollution or cause major problems.

4. FEASIBILTY STUDY FOR OFFSHORE WIND FARMS

4.1 Possible Wind Farm Location in Caspian Sea

The most important part of feasibility study of a wind farm is to select the most suitable region in terms of the wind speed hence the wind power. Productivity of wind turbines is directly related to the wind speed.

During the cold period of the year, the easterly, north-easterly and northerly winds prevail in the Caspian Sea, and during the warm season, the westerly, north-westerly and in some places south-easterly winds prevail. Depending on the coastline configurations, wind directions that differ from the main direction of the open sea wind are also observed in different parts of the coast. The wind speeds do not differ much during the year. Winds with a speed of 5-7 m/s are often found in the whole sea throughout the year. In some places, the wind speed reaches 25-30 m/s. The wind regime of some parts of the sea is as follows. In the North Caspian Sea, mainly easterly and north-easterly winds (41-43% during the month) prevail in winter. In the spring, easterly, south-easterly, and in the summer, north-westerly and south-westerly winds prevail. In the autumn, the easterly winds prevail again. The fastest winds (storms) are observed in Absheron, Makhachkala and Mangishlag. In the Absheron region, the wind speed called "Baku Nordu" (local name "Khazri") reaches speeds more than 30 m/s, and durationions of more than 10 hours [20]. Considering all these information, it can be said that the most optimal two places on the Azerbaijani coast of the Caspian Sea is the southern and northen coasts of Baku. These areas are indicated as A and B in Fig. 4.1.

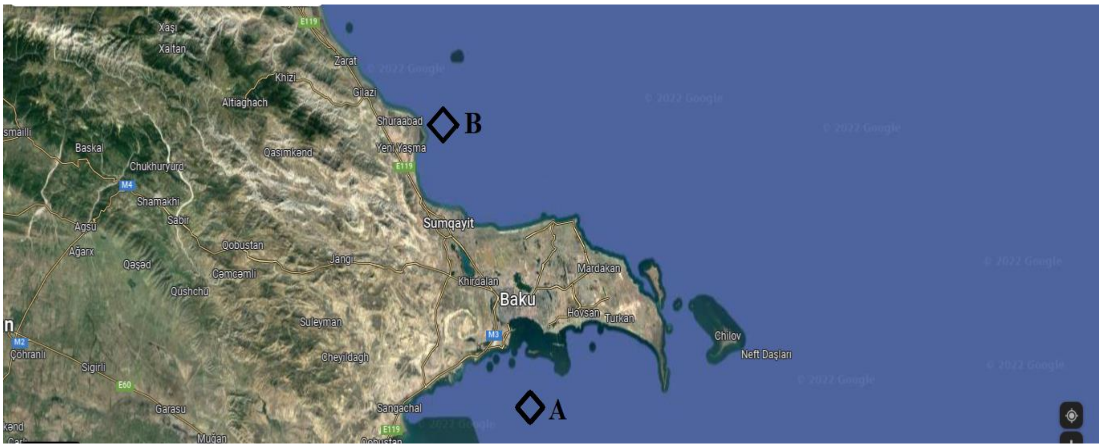

Figure 4.1: Feasible regions A and B.

Potential wind speeds of locations A and B at 50 meter height are given 7.69 m/s and 8.28 m/s, respectively [Figure 4.2] [23]. These wind speeds are sufficient for installing wind farms in these regions [12].

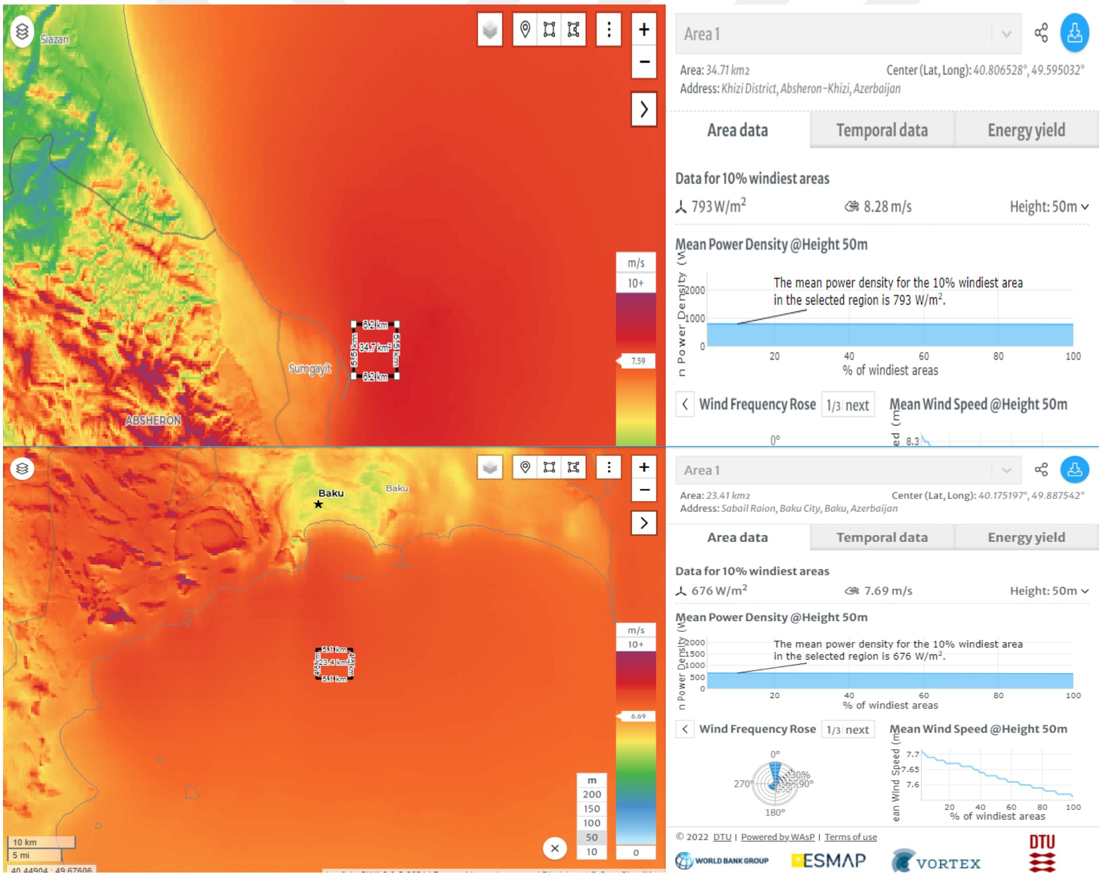

Figure 4.2: Wind speeds of selected areas [12]

Water depth: Formation of seabed and depth of sea are important issues that must be considered seriously. Mainly ofshore wind turbines installation is suitable for depth up to 40 m [13]. For deeper parts construction of turbine becomes complicated and expensive. Floating wind turbine installation technology may be used; however, in these areas installation of floating foundations is not possible. Fig. 4.3 shows the bathymetry of the region [14].

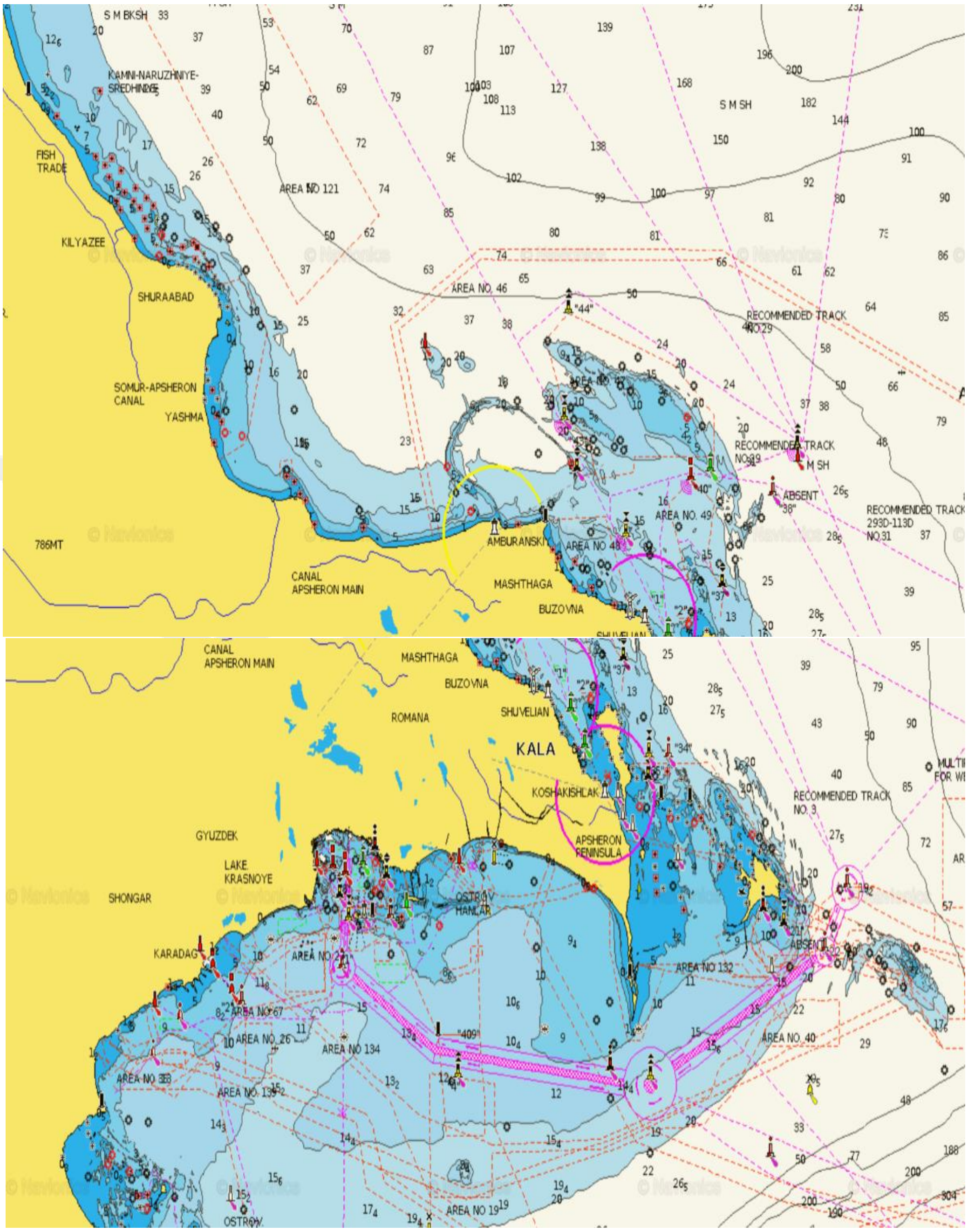

Figure 4.3: Bathmetry map of region [14]

According to the bathymetry map the region A has water depths between 10 m and 40 m. For the region B the water depths range between 15-20 m. Both regions are suitable for wind turbines with fixed type foundations.

Shipping routes: Consideration of shipping lanes is very important for the safety of offshore turbines and the environment. The safety of both daily ship cruises and offshore turbine repairs depends on this factor. In terms of ship movements, Caspian Sea is not a very much busy area. Despite this fact, Baku has one of the most important ports in terms of international trade. This transport corridor stretches from China to Europe, and Baku is right in the middle of this corridor (see Fig. 4.4) [10].

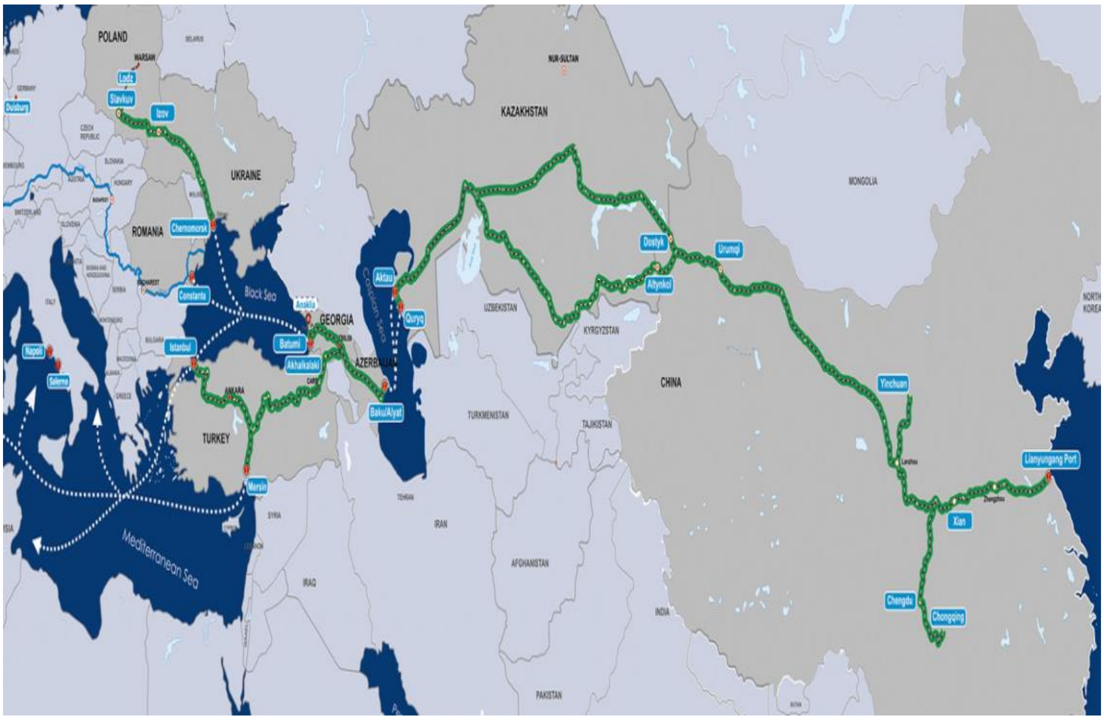

Figure 4.4: Trans-Caspian International Transport Route.

From Kazakhstan and Turkmenistan, there can be very heavy shiping traffic over the Caspian Sea in the future. This will lead to a revival of maritime transport in the waters of Baku [9].

In addition to this, Azerbaijan has oil rigs near the coastal of Baku. All supply and transfer of workers to these oil rigs are carried out mainly by ships. This fact itself increases the movement of ships around Baku. In Fig. 4.5 the instantaneous sea traffic on the Baku shores of the Caspian Sea is depicted. According to the information received for several days, the shipping traffic is mainly observed in this zone throughout the year [11, 15].

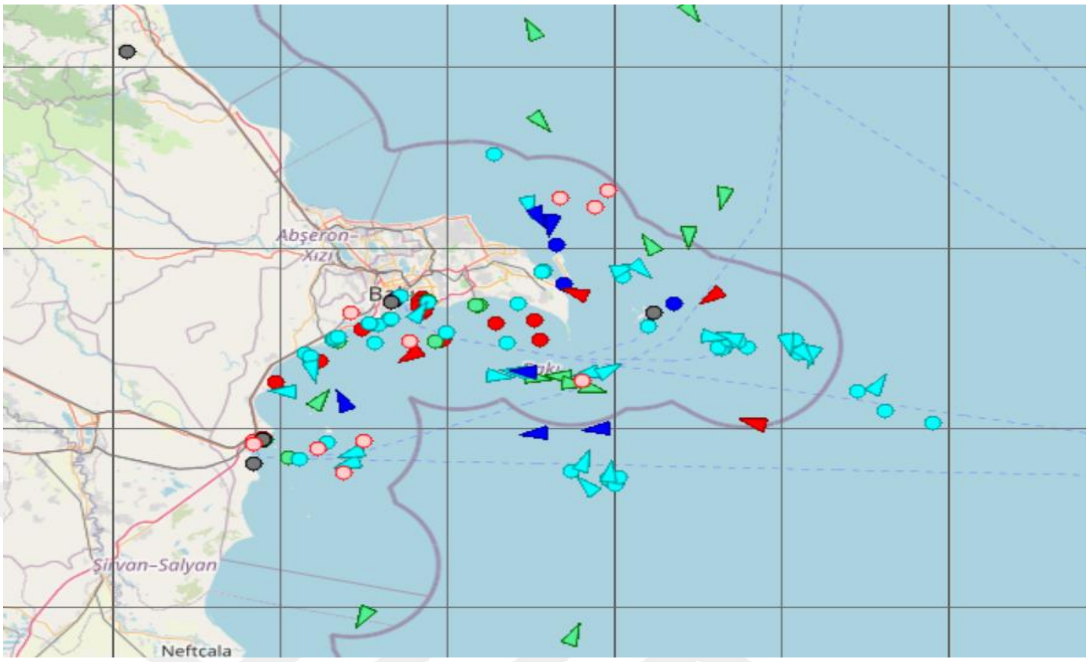

Figure 4.5: Marine traffic near Baku.

As can be seen from Figure 4.5, northern shores of Baku is more suitable to select area to install wind turbine.

Govermental and international laws: Azerbaijan is well-known in the world for its oil fields. In particular, there are rich oil fields on the Absheron Peninsula and its shores. Most of these fields are located in the Caspian Sea. Oil and gas production from these fields is delivered to the land via submarine pipelines [16]. The safety of these pipelines and platforms is important not only for Azerbaijan but also for Europe, Turkey and other western countries. Crude oil and gas from these fields are transported to the Sangachal terminal via pipelines and then to the world market via various pipelines such as SCP, SCPx, BTC, TANAP and TAP.

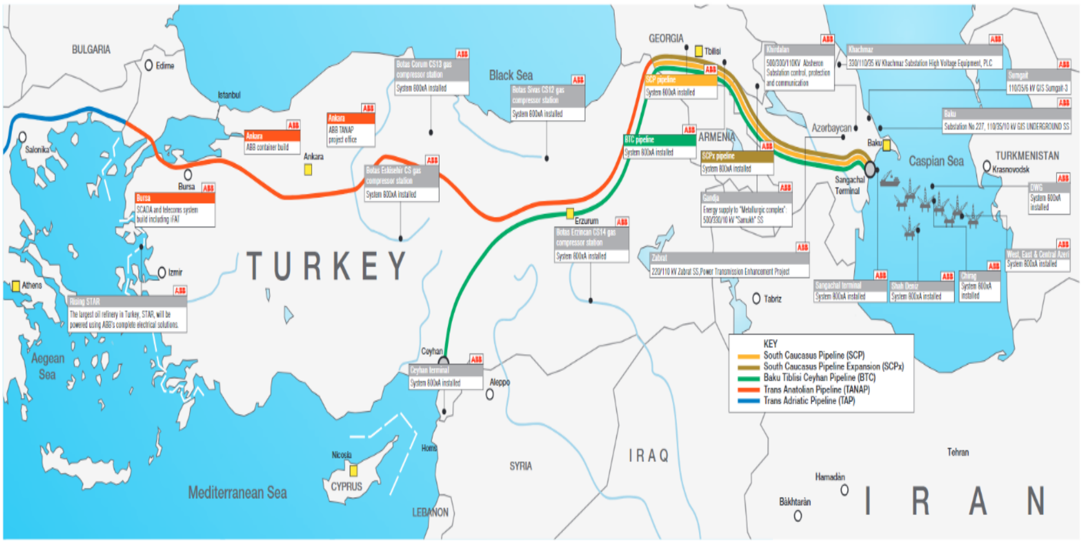

Figure 4.6: Oil rigs and international pipelines

The above mentioned oil rigs, pipelines and Sangachal terminal can be seen from Figure 4.6. [9]. It shows that all oil and gas platforms are located in south-east part of Absheron Peninsula. All these facts make it difficult to build an offshore wind farm in this region. It is not a good idea to choose this region for turbine construction both for turbines and for the country's energy security. On the contrary, the northern part of the peninsula appears to be a completely free area in terms of both oil rigs and underwater pipelines [27].

Grid connection: The purpose of installing wind turbines is to get electricity from them and to realize this, energy from offshore wind turbine must be transferred to land. The point where cables from offshore turbines are connected to the station is called electric grid connection point. Grid connection point must be selected carefully when location is selected for turbines. Because of being complicated and expensive, grid connection must be as much as close to the wind farm.

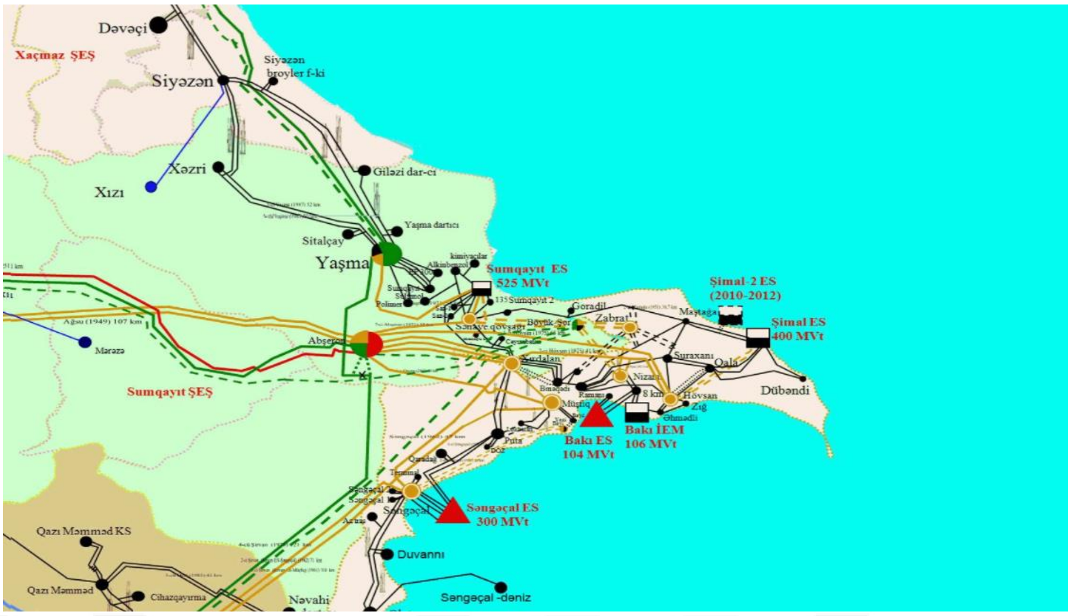

Figure 4.7: Electric stations in Absheron Peninsula.

Figure 4.7 shows that there are some big capacity electric connections on the shores of the Absheron Peninsula. [18]. Two of them are more suitable in terms of their location: Sanggachal electric station (300 MVt) and Sumgait electric station (525 MVt).

Selection of area: Considering all these issues, a search is conducted on two possible regions around the Absheron Peninsula. Both of them are suitable to construct wind farm but one of them is going to be selected. For this, the following topics which mentioned previously are to be considered:

- Wind speed
- Bathmetry
- Ship routes
- Govermental and international laws
- Grid connection

First of all, considering the wind speed, the corresponding speeds for areas A and B for 50 meters are 7.69 and 8.28, as shown in Figure 4.2 [12].

For two areas, depth of water is nearly same and appropriate for turbine installations. The depths are in the range of 10-40 m (Figure 4.3).

There is a significant difference when shipping routes are considered. Area A is both strategic and very dense in terms of shipping. This is due to the proximity of the area to oil wells and commercial ports. On the contrary, area B is quite free and appropriate in this respect.

One of the most serious problem for the selection of area is to get permission from the government for this construction. In this point, area A does not appear suitable for construction as there are strategically important facilities and pipelines in the southern part. There are no state and international facilities in the northern part of the peninsula near the area B.

As a grid connection, both areas have good possibilities to transfer energy economically and potentially. However, the Sumgait power plant and Shuraabad wind power plant, which is close to Area B, appears to be more suitable in terms of energy intake and proximity to residential areas.

Taking into account all these area B is selected for the construction of a wind turbine. After selection, wind speed at different height is going to be calculated for B.

4.2 Wind Turbine Selection

There are some wind turbine companies such as VESTAS, Siemens, GE and etc. But considering the feasibility study and country profile VESTAS turbines has been decided for use in this study. In addition to this, Azerbaijan has some onshore wind farms and most of them are constructed using VESTAS turbines in Absheron [22]. This means VESTAS has major experience installation and maintance of turbines in Absheron Peninsula. In Shurabad and Yeni Yashma projects, VESTAS turbines have been used. As a final desicion, VESTAS V117-4.2 MW turbine has been selected. Technical specifications can be seen below:

- Rated Power – 4000/4200 kW
- Cut-in wind speed – 3m/s
- Cut-out wind speed – 25m/s
- Re cut-in wind speed – 23m/s
- Wind class - IEC IB-T/IEC IIA-T/IEC S-T
- Rotor diameter – 117 m
- Swept area - 10,751 m^2
- Hub height – 84 m and 91.5 m

As seen from turbine specifications, there are two types of hub height choice for this turbine. In this study 91.5 m hub height is going to be used. In B area the wind speed is nearly 8.28 at 50 m height. For 91.5 m, the wind speed is calculated by the use of logarithmic formula.

$$V_h = V_{ref} \frac{\ln\left(\frac{h}{z}\right)}{\ln\left(\frac{h_{ref}}{z}\right)} \tag{4.1}$$

H = 91.5 m

H_{ref} = 50 m

V_{ref} = 8.28

Z = 0.0002 (roughness length for offshore)

$$V_{91.5} = 8.28 * \frac{\ln\left(\frac{91.5}{0.0002}\right)}{\ln\left(\frac{50}{0.0002}\right)} = 8.68\,\frac{m}{s} \tag{4.2}$$

Thus, at 91.5 m height, the wind speed is nearly 8.7 m/s in the area B.

Using this information, Annual Energy Production will be calculated [24].

$$AEP = C_p * P(System\ rated\ power) * 24 * 365 \tag{4.3}$$

C_p is the capacity factor, which is taken as approximately 0.4.

$$AEP = 0{,}4 * 4200 * 24 * 365 = 14.7\ GWh/year$$

which corresponds to the yearly production of a single turbine. The conceptioal project here envisages the construction of 30 turbines. It means that the wind farm capacity is

***30*14.7= 441 GW h/year*.**

It is now possible to determine how many people these wind turbines can serve. The per capita electrical energy consumption of the Azerbaijani people is as follows

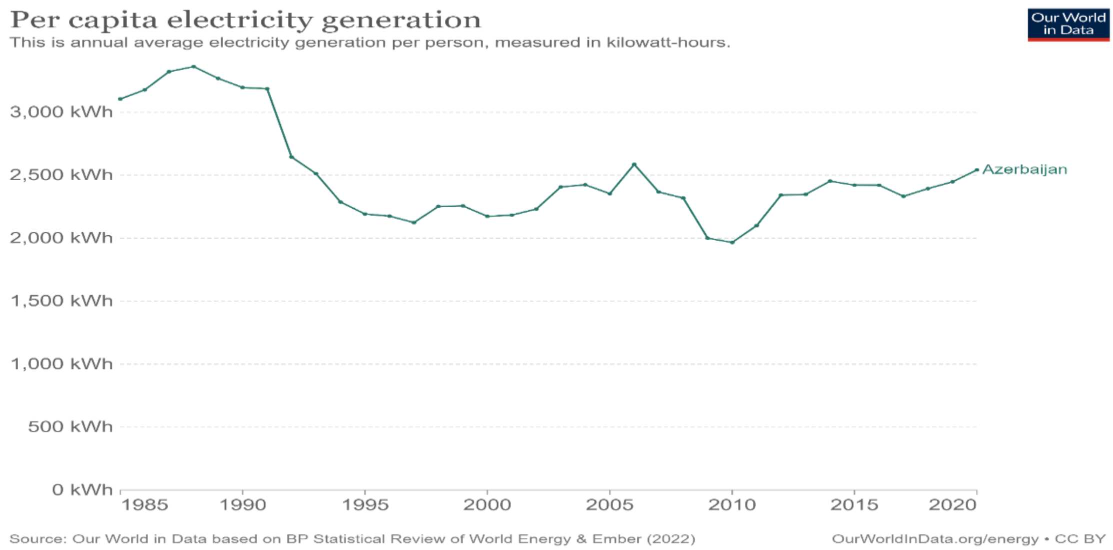

Figure 4.8: Average electricity consumption per capita in Azerbaijan.

According to 2020 data, the energy use of the Azerbaijani people per capita was 2542 kWh. The number of people the wind farm can serve may be calculated by dividing this figure by the yearly average energy usage (2542 kWh/year) mentioned at the above [Figure 4.8].

$$\frac{\mathbf{441\ GWhAC/year}}{2542\ \mathrm{kWh/year}} = 173{,}485\ \text{hposeholds} \tag{4.4}$$

According to the data obtained from the calculation, the wind farm will be able to serve approximately 173000 households.

4.3 Layout

One of the most important things when installing a wind turbine farm is getting its layout right. One of the main reasons for choosing a proper layout is to reduce the wind speed losses due to wake effects. As the wind hits the turbine blades, the air's velocity decreases while its pressure rises. As the wind travels past the turbine rotor, the pressure drops rapidly. Pressure and axial velocity distributions decline unevenly directly below the rotor. When two wind turbines are situated adjacent to each other, the wind speed slows as it approaches the turbine behind the front one, and the turbulence density rises. The wake effect is a phenomenon that causes a decline in the annual power output as well as the life of a wind turbine. The spacing between the turbines should be between 3D and 7D to minimize both the wake effect and energy losses [29]. Accordingly, it is decided that the most suitable sequence for this project would be 5D = 5x117 m = 585 m. This means that the distance between each turbine must be at least 585 m. There are many different types of layout used in wind turbine design, however three of them are utilized far more frequently than the others: Square layout, hexagonal layout, octagonal layout. For this project below layout has chosen [Figure 4.9].

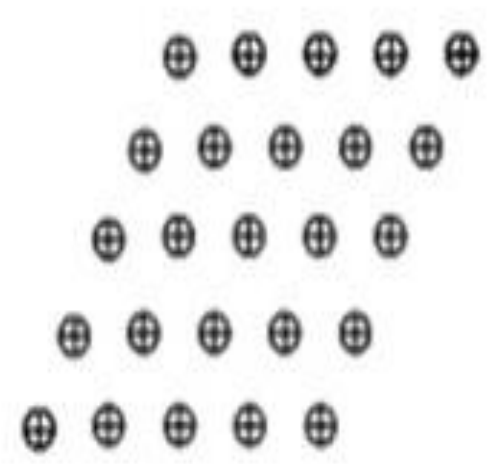

Figure 4.9: Layout for wind farm in selected area.

5. CALCULATION OF THE MAXIMUM TOTAL FORCE AND MOMENTUM

Calculating the total force and moment acting on each turbine piles is an important part of design process. For this, the so-called Morison equation is used. First, some of the main parameters to be used must be defined.

- L= $\frac{gT^2}{2\pi}\tanh(\frac{2\pi d}{L})$ or L= $L_0\tanh(\frac{2\pi h}{L})$ L-wavelength (5.1)
- H = 2a -wave height (5.2)
- $k = \frac{2\pi}{\lambda \; or \; L}$ -wave number (5.3)
- $\omega = \frac{2\pi}{T}$ -circular frequency (5.4)
- c = $\frac{\lambda/\,L}{T} = \frac{\omega}{k}$ -wave speed (5.5)
- $t = \frac{1609}{U_f}$ -time to travel 1 mile, (5.6)
- $\frac{U_f}{U_{3600}} = 1.277 + 0.296 tanh\left[0.9\log(\frac{45}{t})\right]$ (5.7)

U_f -fastest wind speed and U_{3600} -average wind speed during 1 hour

- U_A= $0.71U^{1.23}$, U_A -adjusted wind speed with U=U_{3600} (5.8)
- $\frac{gH_s}{U^2} = 0.283 tanh\left[0.0125\left(\frac{gF}{U_A^2}\right)^{0.42}\right]$ (5.9)
- $\frac{gT_s}{2\pi U} = 1.2 tanh\left[0.077\left(\frac{gF}{U_A^2}\right)^{0.25}\right]$ (5.10)

H_s is the significant wave height, T_s is the significant wave period.

An inertia force proportional to the flow acceleration and a drag force proportional to the square of the instantaneous flow velocity make up the Morison equation. The pile of the turbine may be considered as a cylindrical structure in seabed which is subjected to constant action of waves throughout its life. The amount of wave force acting on the pile is calculated using Morrison's equation. The forces applying on a circular base, as well as their related properties. Morrison's equation is as follows [24],

$$F = F_i + F_d = \rho C_m V \frac{\partial u}{\partial t} + 0.5\,\rho C_d D\, u|u| \quad (5.11)$$

- C_m = 2.0 -inertia coefficient
- C_d = 0.7 -drag coefficient

- $\rho = 1025$ kg/m^3
- D -diameter of cylinder
- d –depth of water

In order to calculate the total inertia and drag forces generated by waves on a vertical cylinder (monopile) the integrated form of the previous formulas are used.

$$F = \int_{-d}^{\zeta} f_i dz + \int_{-d}^{\zeta} f_d dz = -F_i sin\omega t + F_d cos^2 \omega t \quad (5.12)$$

where the inertia and drag force amplitudes are

$$F_i = \frac{\pi}{4}\rho g C_m D^2 H K_i \quad F_d = \frac{1}{2}\rho g C_d D H^2 K_d \quad (5.13)$$

The corresponding moment is calculated as following:

$$M = \int_{-d}^{\zeta}(z+d) f_i dz + \int_{-d}^{\zeta}(z+d) f_d dz = -M_i sin\omega t + M_d cos^2 \omega t \quad (5.14)$$

where the inertia and drag moment amplitudes are

$$M_i = dF_i S_i \quad M_d = dF_d S_d \quad (5.15)$$

The above dimesionless coefficients are defined as

$$S_i = 1 + \frac{(1 - cosh\ kd)}{kd\ sinh\ kd} \quad (5.16)$$

$$S_d = \frac{1}{2} + \frac{1}{8K_d}\left[\frac{1}{2} + \frac{(1 - cosh\ 2kd)}{2kd\ sinh\ 2kd}\right] \quad (5.17)$$

$$K_i = \frac{1}{2} tanh\ kd \quad (5.18)$$

$$K_d = \frac{1}{8}\left(1 + \frac{2kd}{sinh\ 2kd}\right) \quad (5.19)$$

The total force is going to be maximum when $\frac{\partial F}{\partial t} = 0$ hence

$$F_{max} = \left(\frac{F_i^2}{2F_d}\right) + F_d cos^2 \theta_f \quad (5.20)$$

$$\omega t = \theta_f = -\arcsin\left(\frac{F_i}{2F_d}\right) \quad (5.21)$$

For the maximum moment a similar argument gives

$$M_{max} = \left(\frac{M_i^2}{2M_d}\right) + M_d cos^2 \theta_m \quad (5.22)$$

$$\omega t = \theta_M = -\arcsin\left(\frac{M_i}{2M_d}\right) \quad (5.24)$$

Note that when $\frac{F_i}{2F_d} > 1.0$ and $\frac{M_i}{2M_d} > 1.0$ the above solutions are rendered invalid. Then, for this case $(cos\omega t = 0)$ one obtains

$$F_{max} = -F_i \quad and \quad M_{max} = -M_i$$

Because of the depth of the selected region, a monopile turbine foundation is chosen. Considering the water depth (20 m), the diameter of the foundation should be taken at least 8 m in order to make the structure reliable. It is remarked that this is just a first estimate and an iterative approach, coupled with structural strength calculations, must be followed in determining the pile diameter. Calculations will be carried out according to the data received from the National Hydrometeorology Department of the Ministry of Ecology and Natural Resources of Azerbaijan [20]. These calculations will be used to determine the loads acting on the structure. The calculations are based on the fastest wind speeds over the past 15 years (2005-2020) blowing towards the selected region of the wind farm. The greatest wind speed is determined to be 35 m/s during the years indicated since the selected region is located in the NW of Bilgah and based on statistics for the NW. From the region's map it can be noted that the distance between the two regions is approximately 50 kilometers, which is known as the fetch distance [Figure 5.1]. The letter F represents the fetch distance. Fetch is the part of the ocean where the wind blows in the considered direction without any obstacte thus generating waves.

Figure 5.1: Fetch distance for selected region.

U_f = 35 m/s

1) $t = \frac{1609}{U_f} \rightarrow \frac{1609}{35} = \mathbf{45.971\ s}$

2) $\frac{U_f}{U_{3600}} = 1.277 + 0.296tanh\left[0.9\log(\frac{45}{t})\right]$

$\frac{35}{U_{3600}} = 1.277 + 0.296tanh\left[0.9\log(\frac{45}{45.971})\right]$

$\frac{35}{U_{3600}} = 1.277 + 0.296 \cdot (-0.0083440998)$

$\frac{35}{U_{3600}} = 1.2745301465 \rightarrow \boldsymbol{U_{3600} = 27.461\ m/s}$

3) $U_A = 0.71U^{1.23} \rightarrow U_A = 0.71 \cdot 27.461^{1.23} \rightarrow$ $\boldsymbol{U = U_{3600}}$

$U_A = 0.71 \cdot 27.461^{1.23}$

$\boldsymbol{U_A = 41.771\ m/s}$

4) $\frac{gH_s}{U^2} = 0.283tanh\left[0.0125\left(\frac{gF}{U_A^2}\right)^{0.42}\right]$ F=50 km

$$\frac{9.81\ H_s}{27.461^2} = 0.283tanh\left[0.0125\left(\frac{9.81 \cdot 50000}{41.771^2}\right)^{0.42}\right]$$

$\boldsymbol{H_s =}$ **2.887 m** - significant wave height

5) $\frac{gT_s}{2\pi U} = 1.2tanh\left[0.077\left(\frac{gF}{U_A^2}\right)^{0.25}\right]$

$\frac{9.81T_s}{2\pi 27.461} = 1.2tanh\left[0.077\left(\frac{9.81 \cdot 50000}{41.771^2}\right)^{0.25}\right]$

$\boldsymbol{T_s}$**= 6.443 second** – significant wave period

After these calculations, the wave length must be found by using the dispersion relationship

$$L = L_0\tanh(\frac{2\pi h}{L})$$

where h is the water depth of the selected region and also is equal to d and

$$L_0 = \frac{gT^2}{2\pi}$$

6) $L_0 = \frac{gT^2}{2\pi} = \frac{9.81 \cdot 6.443^2}{2\pi} = 64.81$ m

d=h= 20 m

$L = L_0\tanh(\frac{2\pi h}{L}) \rightarrow 64.813\tanh(\frac{2\pi h}{L})$ after these calculations to find L an iterative process must be followed.

$L_1 = 64.813\tanh(\frac{2\pi 20}{64.813}) = 62.184$

$L_2 = 64.813\tanh(\frac{2\pi 20}{62.184}) = 62.575$

$L_3 = 64.813\tanh(\frac{2\pi 20}{62.575}) = 62.519$

$L_4 = 64.813\tanh(\frac{2\pi 20}{62.519}) = 62.527$

$L_5 = 64.813\tanh(\frac{2\pi 20}{62.527})= 62.526$

$L_6 = 64.813\tanh(\frac{2\pi 20}{62.526})= 62.526$

Hence L = 62.526 m.

7) The corresponding wave number and celerity are

$k = \frac{2\pi}{L} = \frac{2\pi}{62.526} = 0.1\ \frac{rad}{m}$ - wave number

$c = \frac{L}{T} = \frac{62.526}{6.443} = 9.704\ m/sec$ – wave celerity

Hydrodynamic coefficients can be taken as approximately Cm ≈ 2 and Cd ≈ 0.7.

$\frac{D}{L} = \frac{8}{62.526} = 0.13$, which is greater than 1/20 and diffraction effect is not negligible but being on the safe side (calculated force and moment are going to be greater) the calculations are done using the Morison formula.

8) Calculation of **d**imensionless coefficients

$K_i = \frac{1}{2} tanh\ kd$ = 0.5 tanh (0.1· 20) = 0.482

$K_d = \frac{1}{8}\left(1 + \frac{2kd}{sinh\ 2kd}\right) = \frac{1}{8}\left(1 + \frac{2\cdot 0.1\cdot 20}{sinh\ (2\cdot 0.1\cdot 20)}\right) = 0.143$

$S_i = 1 + \frac{(1 - cosh\ kd)}{kd\ sinh\ kd} = 1 + \frac{(1 - cosh\ 0.1\cdot 20)}{0.1\cdot 20\ sinh\ 0.1\cdot 20} = 0.619$

$S_d = \frac{1}{2} + \frac{1}{8K_d}\left[\frac{1}{2} + \frac{(1 - cosh\ 2kd)}{2kd\ sinh\ 2kd}\right] = \frac{1}{2} + \frac{1}{8\cdot 0.143}\left[\frac{1}{2} + \frac{(1 - cosh\ 2\cdot 0.1\cdot 20)}{2\cdot 0.1\cdot 20\ sinh\ 2\cdot 0.1\cdot 20}\right] = 0.726$

9) **Calculation of maximum total force**

$F_i = \frac{\pi}{4}\rho g C_m D^2 H K_i = \frac{\pi}{4}\cdot 1025 \cdot 9.81 \cdot 2 \cdot 8^2 \cdot 2.887 \cdot 0.482 = 1{,}406{,}652$ N

$F_d = \frac{1}{2}\rho g C_d D H^2 K_d = 0.5 \cdot 1025 \cdot 9.81 \cdot 0.7 \cdot 8 \cdot 2.887^2 \cdot 0.143 = 33557$ N

It has to be checked whether $\frac{F_i}{2F_d} > 1.0$ is satisfied or not.

$\frac{F_i}{2F_d} = \frac{1{,}406{,}652}{2\cdot 33557} = 20.96 > 1.0$ then $cos\omega t = 0$ and $F_{max} = -F_i sin\omega t + F_d cos^2\omega t$ will be as $F_{max} = -F_i$, namely $\boldsymbol{F_{max} = 1{,}406{,}652\ N}$

10) **Calculation of maximum total moment**

$M_i = dF_iS_i$ = 20· 1,406,652 ·0.619 = 17,414,352 $N \cdot m$

$M_d = dF_dS_d$=20·33557·0.726=487247$N \cdot m$

It has to be checked whether $\frac{M_i}{2M_d} > 1.0$ is satisfied or not.

$\frac{M_i}{2M_d} = \frac{17{,}414{,}352}{2\cdot 487247} = 17.87 > 1.0$ then as for the maximum total force,

Maximum momment will be as: $M_{max} = -M_i$, namely $\boldsymbol{M_{max}}$ **= 17, 414, 352** $\boldsymbol{N \cdot m}$

Calculations for the Second Fetch Distance

As a second case, the distance from Bekdash region of Turkmenistan to the place where the wind turbines will be located will be taken as the fetch distance, and the calculation will be made again within these conditions. Since the peak wind speed data for the initial (Bekdash) region could not be found, it was decided that the highest wind blowing from this direction would be taken as an estimated value of 38 m/s. The reason for a larger wind speed selection is that from the map the average wind speed of the Bekdash region seems to be greater than the wind speed at the beginning of the fetch distance (Bilgah), which is in the first part of the calculation. For this reason, it was decided that the theoretical wind speed would be 38 m/sec. And below figure shows second fetch distance (≈270 km) [Figure 5.2].

Figure 5.2: Second fetch distance for selected region.

U_f= 38 m/sec

1) $t = \frac{1609}{U_f} \rightarrow \frac{1609}{38} = \mathbf{42.316\ s}$

2) $\frac{U_f}{U_{3600}} = 1.277 + 0.296 tanh\left[0.9\log(\frac{45}{t})\right]$

$\frac{38}{U_{3600}} = 1.277 + 0.296 tanh\left[0.9\log(\frac{45}{42.316})\right]$

$\frac{38}{U_{3600}} = 1.277 + 0.296 \cdot (0.0240324864)$

$\frac{38}{U_{3600}} = 1.284113616 \rightarrow \boldsymbol{U_{3600} = 29.592\ m/s}$

3) $U_A = 0.71 U^{1.23} \rightarrow U_A = 0.71 \cdot 29.592^{1.23} \rightarrow \boldsymbol{U = U_{3600}}$

$U_A = 0.71 \cdot\ 29.592^{1.23}$

$\boldsymbol{U_A = 45.793\ m/s}$

4) $\frac{gH_s}{U^2} = 0.283tanh\left[0.0125\left(\frac{gF}{U_A^2}\right)^{0.42}\right]$ F=270 km

$$\frac{9.81\ H_s}{29.592^2} = 0.283tanh\left[0.0125\left(\frac{9.81 \cdot 270000}{45.793^2}\right)^{0.42}\right]$$

$\boldsymbol{H_s}$ **= 6.209 m** - significant wave height

5) $\frac{gT_s}{2\pi U} = 1.2tanh\left[0.077\left(\frac{gF}{U_A^2}\right)^{0.25}\right]$

$$\frac{9.81T_s}{2\pi 29.592} = 1.2tanh\left[0.077\left(\frac{9.81 \cdot 270000}{45.793^2}\right)^{0.25}\right]$$

$\boldsymbol{T_s}$**= 9.764 s** – significant wave period

After these calculations, wave length must be found by using following equation:

$$L = L_0 \tanh(\frac{2\pi h}{L})$$

In here h is the water depth of the selected region and also is equal d and

$$L_0 = \frac{gT^2}{2\pi}$$

6) $L_0 = \frac{gT^2}{2\pi} = \frac{9.81 \cdot 9.764^2}{2\pi}$= 148.849 m

d=h= 20 m

$L = L_0 \tanh(\frac{2\pi h}{L}) \rightarrow 148.849 \tanh(\frac{2\pi h}{L})$ after these calculations, in order to find L some iteration process must be calculated.

$L_1 = 148.849 \tanh(\frac{2\pi 20}{148.849})$=102.415

$L_2 = 148.849 \tanh(\frac{2\pi 20}{102.415})$= 125.287

$L_3 = 148.849 \tanh(\frac{2\pi 20}{125.287})$= 113.550

$L_4 = 148.849 \tanh(\frac{2\pi 20}{113.550})$= 119.509

$L_5 = 148.849 \tanh(\frac{2\pi 20}{119.509})$= 116.458

$L_6 = 148.849 \tanh(\frac{2\pi 20}{116.458})$= 118.014

$L_7 = 148.849 \tanh(\frac{2\pi 20}{118.014})$= 117.219

$L_8 = 148.849 \tanh(\frac{2\pi 20}{117.219})$= 117.624

$L_9 = 148.849 \tanh(\frac{2\pi 20}{117.624})$= 117.417

$L_{10} = 148.849\tanh(\frac{2\pi 20}{117.417})$= 117.524

$L_{11} = 148.849\tanh(\frac{2\pi 20}{117.524})$= 117.469

$L_{12} = 148.849\tanh(\frac{2\pi 20}{117.469})$= 117.497

$L_{13} = 148.849\tanh(\frac{2\pi 20}{117.497})$= 117.483

$L_{14} = 148.849\tanh(\frac{2\pi 20}{117.483})$= 117.490

$L_{15} = 148.849\tanh(\frac{2\pi 20}{117.490})$= 117.486

$L_{16} = 148.849\tanh(\frac{2\pi 20}{117.486})$= 117.488

$L_{17} = 148.849\tanh(\frac{2\pi 20}{117.488})$= 117.487

$L_{18} = 148.849\tanh(\frac{2\pi 20}{117.487})$= 117.488

$L_{19} = 148.849\tanh(\frac{2\pi 20}{117.488})$= 117.487

Thus, L = 117.487 m.

7) The corresponding wave number and celerity are then

$k = \frac{2\pi}{L} = \frac{2\pi}{117.487} = 0.053\ \frac{rad}{m}$ - wave number

$c = \frac{L}{T} = \frac{117.487}{9.764} = 12.033\ m/sec$ – wave celerity

Hydrodynamic coefficients can be taken as approximately Cm ≈ 2 and Cd ≈ 0.7.

$\frac{D}{L} = \frac{8}{117.487} = 0.069$, which is still greater than 1/20 but now much closer to the acceptable value for the neglect of diffraction effects. Hence the use of Morison formula can be justified.

8) Calculation of **d**imensionless coefficients

$K_i = \frac{1}{2} tanh\ kd$ = 0.5 tanh (0.053· 20) = 0.393

$K_d = \frac{1}{8}\left(1 + \frac{2kd}{sinh\ 2kd}\right)$ = $\frac{1}{8}\left(1 + \frac{2\cdot 0.053\cdot 20}{sinh\ (2\cdot 0.053\cdot 20)}\right)$ = 0.190

$S_i = 1 + \frac{(1-cosh\ kd)}{kd\ sinh\ kd} = 1 + \frac{(1-cosh\ 0.053\cdot 20)}{0.053\cdot 20\ sinh\ 0.053\cdot 20}$ = 0.542

S_d=$\frac{1}{2} + \frac{1}{8K_d}\left[\frac{1}{2} + \frac{(1-cosh\ 2kd)}{2kd\ sinh\ 2kd}\right]$ = $\frac{1}{2} + \frac{1}{8\cdot 0.190}\left[\frac{1}{2} + \frac{(1-cosh\ 2\cdot 0.053\cdot 20)}{2\cdot 0.053\cdot 20\ sinh\ 2\cdot 0.053\cdot 20}\right]$ = 0.585

9) **Calculation of maximum total force**

$F_i = \frac{\pi}{4}\rho g C_m D^2 H K_i$ = $\frac{\pi}{4} \cdot 1025 \cdot 9.81 \cdot 2 \cdot 8^2 \cdot 6.209 \cdot 0.393$ = 2,466,646 N

$F_d = \frac{1}{2}\rho g C_d D H^2 K_d = 0.5 \cdot 1025 \cdot 9.81 \cdot 0.7 \cdot 8 \cdot 6.209^2 \cdot 0.190$ = 206,228 N

It has to be checked whether $\frac{F_i}{2F_d}$ > 1.0 is satisfied or not.

$\frac{F_i}{2F_d} = \frac{2{,}466{,}646}{2 \cdot 206{,}228} = 5.98 >$ 1.0 then $cos\omega t = 0$ and $F_{max} = -F_i sin\omega t + F_d cos^2\omega t$

Hence $F_{max} = -F_i$, namely $\boldsymbol{F_{max}} = \mathbf{2{,}466{,}646}$ **N**

10) **Calculation of maximum total moment**

$M_i = dF_iS_i$ = 20· 2,466,646 ·0.542 = 26,738,443 $N \cdot m$

$M_d = dF_dS_d$=20·206,228·0.19=783,666$N \cdot m$

It has to be checked whether $\frac{M_i}{2M_d}$ > 1.0 is satisfied or not.

$\frac{M_i}{2M_d} = \frac{26{,}738{,}443}{2 \cdot 783666}$ = 17.06 > 1.0 then as for the total force,

Maximum total moment is $M_{max} = -M_i$, namely $\boldsymbol{M_{max}} =$ **26, 738, 443** $\boldsymbol{N \cdot m}$

6. CONCLUSIONS

Wind energy is most likely the answer to our energy needs. It is promising and relatively simple to harvest. A single turbine can power over 200 households and has a lifespan of 20 to 25 years. Wind turbines can harness the wind to generate electricity as long as it blows. At present, the wind power accounts for only a small percentage of total electricity generation. Wind turbines, unlike coal, do not emit greenhouse gases and are a 100% renewable energy source. Many individuals believe that wind energy will soon become our primary energy source. Wind turbines may cause some undesirable harms to wildlife and complaints, but all these are relatively minor compared to the wide impact from fossil fuels.

In this thesis, the main focus was to promote offshore wind energy in Azerbaijan which is a country dependent on fossil fuel energy despite its huge wind potential. As mentioned above, there is a great potential for wind energy in the eastern part of Azerbaijan. Areas for possible wind energy industry have been investigated and Gobustan, Sumgayit, Alat which are located in the coastal part of Caspian Sea (Absheron Peninsula) are considered as the most potential regions. It is estimated that this figure is close to 800 MW per year for these areas. The use of this potential will also lead to positive results in the use of Azerbaijan's depleted energy resources.

The area of focus, based on the literature review made for Azerbaijan’s wind energy potential, was selected as the Absheron peninsula. Two potential wind farm locations have been settled in the region for the further analysis. Location A was put in the south of peninsula near the oil rigs because of its easy access from the shore and connection grid advantage. The location B was selected near Sumgayit region because it is free of sheep routes and have comparitive wind capacity. First the locations were compared for their wind speed at 50 m and location B was found to be slightly ahead with 8.28 m/s. The locations were also compared based on its openness in the area, desirably free from ship routes and oil rigs which may create legislative problems for the construction. And because of its busy location, point A was found to be disadvantageous in legalization. Lastly, the grid connection had to be considered to reduce the contruction costs. It was noted that, both locations were suitable for the potential connection to the shore. Based on these comparisons the location B was found the most suitable location for the foundation.

For a suitable foundation type of the farm, the water depth levels at point B were studied, and fixed foundation was selected in final. It was decided that the model of the wind turbine should be Vestas117-4.2 MW. Since the hub height of the selected wind turbine is 91.5 m, the wind speed of 50 meters (8.25 m/sec) was taken as a reference and the wind speed was found to be 8.7 m/sec at 91.5 meters. In addition, based on the data of a wind turbine, its annual energy production was calculated as 14.7 GWAC/year, and considering the width of the region, a maximum of 30 wind turbines could be installed in this region, the annual energy production for 30 turbines was calculated as 441 GWAC/year. It has also been calculated that this wind farm can serve 173,000 people per year. As for the arrangement, it is calculated that the distance between the wind turbines is 5D (D-rotor diameter), ie 585 meters, in order to compensate for the wake losses. The layout is decided to be square type. In the fourth chapter, the design of the wind farm has been completed successfully.

In the last section the maximum force and moment values are computed by using the Morrison equation together with the appropriate data. The data contain water depth of the selected region, the highest wind data of the last 15 years obtained from the National Hydrometeorology Department of the Ministry of Ecology and Natural Resources of Azerbaijan. Two different sets of calculations according to two different fetch distances are done and the results for the maximum total forces and moments are presented.

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