**MARMARA UNIVERSITY**
**FACULTY OF ENGINEERING**

# A Wind Turbine Application 1 MW Capacity For A Real Building

TUĞÇE KURTYİĞİT, ALİCAN İŞLEYEN

**GRADUATION PROJECT REPORT**
Department of Mechanical Engineering

**Supervisor**
Assistant Proffesor Mustafa YILMAZ

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F A C U L T Y O F E N G I N E E R I N G

# A Wind Turbine Application 1 MW Capacity For A Real Building

by

TUĞÇE KURTYİĞİT, ALİCAN İŞLEYEN

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Signature of Author(s) ........................................................................................................
Department of Mechanical Engineering

Certified By ..........................................................................................................................
Project Supervisor, Department of Mechanical Engineering

Accepted By ........................................................................................................................
Head of the Department of Mechanical Engineering

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**June, 2015** Tuğçe Kurtyiğit , Alican İşleyen

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# ÖZET

Rüzgar enerjisi en önemli yenilenebilir enerji kaynaklarından biridir. Rüzgar türbinleri rüzgardan kinetik enerjiyi alarak mekanik enerjiye çevirir. Son zamanlarda yapılan araştırmalarda rüzgar tüneli testleri ve teorik çalışmalar kullanılarak rüzgar türbininin aerodinamik performansı arttırılmaya çalışılmaktadır. Bu çalışmalar, pahalı laboratuar kaynakları ve çok fazla zaman gerektirmektedir. Ancak CFD kullanılarak rüzgar türbini simülasyonu ve aerodinamik kanat analizi problemlerinde ucuz çözümler elde edilmektedir. Bu çalışmada, üç boyutlu aerofoil modelleri ANSYS-FLUENT programında kullanıldı. Bu çalışmanın amacı 1 MW enerji üreten yatay eksenli bir rüzgar türbininin CFD de simülasyonunu elde etmektir. Bu yüzden 1 MW'lık yatay eksenli rüzgar türbininin 3 boyutlu CFD modeli üretildi. Bu 3 boyutlu modeller 1 MW'lık yatay eksenli rüzgar türbininin performansını tahmin etmek için kullanıldı. Ve CFD'de farklı durumlarda kanatlardaki basınç ve hız hesaplandı.

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# ABSTRACT

Wind power is one of the most important sources of renewable energy. Wind-turbines extract kinetic energy from the wind. Currently much research has concentrated on improving the aerodynamic performance of wind turbine through wind tunnel testing and theoretical studies. These efforts are much time consuming and need expensive laboratory resources. However, wind turbine simulation through Computational Fluid Dynamics (CFD) software offers inexpensive solutions to aerodynamic blade analysis problem. In this study, three-dimensional aerofoil CFD models are presented using ANSYS-FLUENT software. Using the CFD, pressure and velocity on the blades were calculated for wind-turbine at different cases . Thus a three-dimensional CFD model of 1MW horizontal axis wind-turbine was produced.These three-dimensional models were used for predicting the performance of a 1MW horizontal axis wind turbine.

# ABBREVIATIONS

**B.C.** **:** Before Christ

**CD** **:** Coefficient of Drag

**CFD** : Computational Fluid Dynamics

**CL** : Coefficient of Lift

**EPA** : Environmental Protection Agency

**EU** : European Union

**GDP** : Gross Domestic Product

**GHG** : Green House Gases

**Gt** : Gigatonnes

**HAWT** : Horizontal Axis Wind Turbine

**Kw** : Kilo Watt

**Kwh** : Kilowatt-hour

**LNG** : Liquefied Natural Gas

**Mtce** : Metric Tons Carbon Equivalent

**MW** : Mega Watt

**OECD** : The Organisation for Economic Co-operation and Development

**OEM** : Original Equipment Manufacturer

**Pa** : Pascal

**PV** : Photo Voltaic

**Twh** : Terawatt-hour

**UN** : United Nations

**VAWT** : Vertical Axis Wind Turbine

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# 1.Introductıon

Energy is a vital commodity and is closely intertwined with climate change and development. Energy is needed for basic human needs: for cooking, heating, lighting, boiling water and for other household-based activities. Energy is also required to sustain and expand economic processes like agriculture, electricity production, industries, services and transport. It is commonly suggested that access to energy is closely linked with development and economic well-being and that alleviating energy poverty is a prerequisite to fulfill the Millennium Development Goals.

Fossil energy resources are limited and fossil energy use is associated with a number of negative environmental effects, therefore energy has become a major geo-political and socioeconomic issue. This development puts pressure on all countries around the world. The pressure on developing countries may be even greater, because they are currently in the process of development which requires higher energy resources for achieving higher living standards. High population levels and high fossil fuel reliance increase this pressure even more. To meet energy security, reduce pressure on fossil energy resources and to ensure a higher environmental quality, the share of low-polluting renewable and clean energy should be enhanced.

Global climate change is already an observed phenomenon today. Strategies for climate change mitigation, as under the Kyoto Protocol, are necessary on a global scale, particularly for high GHG emitters like the industrialised countries, countries in transition and rapidly developing countries. Strategies for climate change adaptation –strategies of how to live with and adapt to climate change- are of an equal global importance. These adaptation strategies are especially needed for the poorest developing countries, which suffer from the impacts of climate change without even significantly contributing to it. Especially developing countries are assumed to be vulnerable to climate change. Unlike industrialised countries, they do often not have the financial and infrastructural resources to adapt to and mitigate climate change. It should be a global priority to promote and support climate change mitigation and adaptation strategies in developing countries.

So to help reduce global warming gases, choose of energy-efficient electrical appliances is necessary. These equipments themselves must be cheap as long as their produced energy, especially in electrical light field.

Energy transitions are usually changes in energy use, energy quantity and energy quality. Bashmakov‘s three laws of energy transitions indicate that energy transitions are often driven by long-term energy costs to income stability (the predominant energy form becomes too expensive), by improving energy quality and by growing energy productivity and decreasing energy intensity.

Sustainable energy transitions can be defined as shifts from a country‘s economic activities based on fossil fuels to an economy based partially on renewable and cleaner lowcarbon energy. This means that substitutions take place from fossil fuel-based technologies to cleaner technologies. Such transitions can take place in every sector of a country‘s or a region‘s economy. Sustainable energy transitions are likely to open up new possibilities for developing countries to achieve higher development and higher living standards while at the same time safeguarding energy resources, the environment and human health.

If we come to Turkey, Turkey has an advantageous geographical position so as to wind energy. Which was held in 2007, Turkey Wind Energy Potential Atlas (REPA) with annual wind speed in Turkey, 8.5 m / s and at least 5,000 MW in the regions above, 7.0 m / s and in the region on at least 48,000 MW in size it was found that wind energy potential exists. Hence this non-negligible potential of solar energy, leads the scientists to work on obtaining the best performance on producing electricity by wind turbines. Although solar energy costs have been decreasing and support mechanisms have increasing.

In this context , with reference of various researches, effects of wind speed and acoustic to be examined in generation of electricity from wind energy. At the same time the factors that affect wind turbine performance and comparison of actual electricity productions in different cases are conducted in this study. Therewithal energy calculations, a brief economic analysis is also presented.

### 1.1. World Energy Outlook

The development of technology and the increasing life quality of human population are closely related to the amount and type of the energy consumed. Moreover world energy consumption differs from the actual world final energy consumption because some energy is lost while transporting the energy from where it is supplied to where it is needed around the world. For example, in 2012, world energy consumption amounted to 155,505 terawatt-hour (TWh), while final consumption was 104,426 TWh or about 32% less than the world energy consumption. In addition, the electricity generated is even smaller then the final energy consumed by humans because much of the electricity that is transported into the grid remains unused.

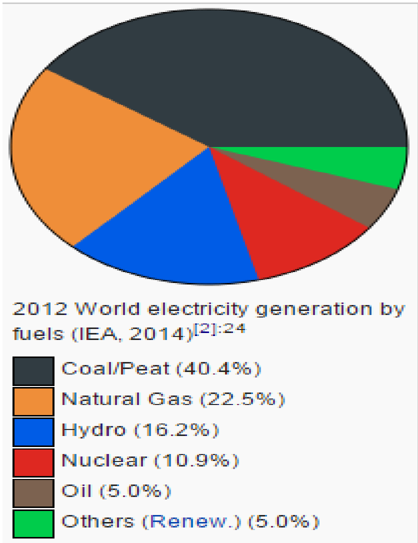


**Figure 1.** World Electricity Energy Generation 2012

In the New Policies Scenario, energy demand grows by 37% to 2040 on planned policies, an average rate of growth of 1.1%. Demand grew faster over the previous decades; the slowdown in demand growth is mainly due to energy efficiency gains and structural changes in the global economy in favour of less energyintensive activities. Natural gas use and the use of low-carbon fuels grow strongest, increasingly replacing coal and oil in the energy mix. By 2040, each fossil fuel accounts for around one-quarter of global energy demand, with the remainder from low-carbon fuels.Energy demand growth shifts decisively away from OECD countries.China dominates energy demand growth until the mid-2020s, but as its population levels off and its economic growth slows around that time, India takes over as the leading engine of energy demand. Despite the strong growth, energy use per capita in 2040 in non-OECD countries is still well below the average of OECD countries in the 1970s at comparable levels of GDP per capita. Technological progress and improved energy efficiency, however, allow a higher level of demand for energy services to be satisfied per unit of energy.The re-ordering of energy trade flows towards Asian markets gathers pace. Rising crude oil-import needs of China and India, from the Middle East and other regions, increase their vulnerability to the implications of a possible shortfall in investment or a disruption to oil supply. The share of natural gas in total inter-regional fossil-fuel trade rises by one-quarter to more than 20% by 2040; concerns about gas security are eased by the increasing availability of LNG. Coal trade grows by 40% to 2040, driven by strong Asian demand.

World oil supply rises by 14 mb/d to 104 mb/d in 2040, but the trend hinges critically on timely investments in the Middle East. Until 2025, non-OPEC supply from the United States, Canada and Brazil contributes to output growth. But by the mid- 2020s, total non-OPEC oil supply starts to fall back, increasing the call on major resource-holding countries in the Middle East. Over the *Outlook* period, the task of bringing production above 100 mb/d rests on a fairly limited number of shoulders.All major regions, except Europe, contribute to the more than 50% rise in natural gas output. Global production of natural gas rises in a near-linear fashion to 5 400 bcm in 2040, with an increasingly important role for unconventional gas which increases its share in output from 17% to 31%. Gas resources are more than sufficient to meet this increase in demand, but the required cumulative investment of more than $11 trillion along the gas supply chain represents a stern challenge, with the way that gas will be priced on domestic and international markets a key uncertainty.Global coal demand grows at a much lower rate than over the last 30 years, at 0.5% per year, to 6 350 Mtce in 2040. Growth of coal demand is constrained by new air pollution and climate policies in the main markets – the United States and China – but also in Europe. Coal use continues to grow briskly in India.China, India, Indonesia and Australia alone account for over 70% of global coal output by 2040, underscoring Asia's importance in global coal trade and pricing.

Energy efficiency slows energy demand growth, diminishes supply-side investment and reduces international energy prices. Without the cumulative impact of energy efficiency measures over theprojection horizon, oil demand in 2040 would be 23 mb/d (or 22%) higher, gas demand 940 bcm (or 17%) and coal demand 920 Mtce (or 15%) higher. Beyond cutting energy use, energy efficiency lowers energy bills, improves trade balances and cuts CO2 emissions. Improved energy efficiency compared with today reduces oil and gas import bills for the five largest energy-importing regions by almost $1 trillion in 2040.Many governments have announced new measures to curb CO2 emissions in the run-up to the UN climate summit in Paris in 2015, but they fall short of reaching the 2 °C target. Emissions rise by 20% to 2040,putting the world on track for a long-term global temperature increase of 3.6 °C. Increasing power sector decarbonisation through 2040 by about 25% is key to achieving climate goals and would take the world halfway towards limiting the temperature increase to 2 °C.In the New Policies Scenario, demand for oil rises by 14 mb/d, to reach 104 mb/d in 2040, despite measures and policies aimed at promoting energy efficiency and fuel switching.

The pace of demand growth decreases markedly, from an annual average of 0.9% to 2020, down to only 0.3% per year in the2030s, moving towards a plateau in global oil consumption. The net growth in demand comes entirely from non-OECD countries: for each barrel of oil eliminated from demand in OECD countries, two additional barrels of oil are consumed in the developing world. China becomes the largest oil-consuming country in the early 2030s.The relative importance of non-OPEC producers increases this decade, but only the large producers of OPEC can meet long-term demand.Output growth in the Americas, led by US tight oil, Canadian oil sands and Brazilian deepwater output, pushes non-OPEC production higher until the mid-2020s. However, a decline in US tight oil after this means that by 2040, non-OPEC supply falls back to 51 mb/d. OPEC production increases by less than 1 mb/d over the remainder of this decade, but then needs to increase substantially in the 2020s (by more than 6 mb/d) and by almost as much again in the 2030s.The refining sector has to adjust to the new geography of oil demand and supply and the changing composition of feedstocks, a process that looks particularly difficult for Europe, which continues to have a large excess of refinery capacity. By 2040, two out of every three barrels of crude oil traded internationally are destined for Asia, up from less than one in two today, drawing to Asia a rising share of the available crude from the Middle East and beyond.Global gas use continues to grow, with demand of 5.4 tcm in 2040 – meaning that gas draws level with coal as the second-largest fuel in the global energy mix, after oil. The main regions pushing global gas demand higher are China, which becomes a larger gas consumer than the European Union around 2030, and the Middle East. Within the OECD, US gas demand grows to 900 bcm by 2040, while in Japan consumption falls back as nuclear reactors are gradually restarted. Gas consumption in Europe returns to 2010 levels only in the early 2030s, with the outlook likewise heavily contingent on policy action, notably on CO2 pricing.Gas production increases in every major region except Europe. Unconventional gas accounts for almost 60% of the growth in global production, helping China to register the fastest gas output growth among the major producers. The United States remains the largest global gas producer, although production tails off in the late 2030s as shale gas output starts to fall back. The way that gas will be priced on domestic and international markets is a key uncertainty, with the challenge of finding a price level and pricing mechanisms acceptable to consumers but nonetheless sufficient to incentivise large new investments in gas supply proving challenging.Coal demand growth is driven by the stringency of carbon policies.

In the New Policies Scenario, demand grows on average by 0.5% per year between 2012 and 2040 (compared to 2.5% over the past 30 years) to over 6 350 million tonnes of coal equivalent. Almost two-thirds of the increase occurs in the next ten years.The outlook for coal varies significantly by region. Demand declines in all major OECD regions, including the United States, where coal use for power plunges by more than one-third between 2012 and 2040. Growth in China's coal use also slows, with demand peaking around 2030. India, where demand continues to rise briskly, overtakes the United States as the world's second-biggest coal consumer after China before 2020.Coal production gradually shifts further to Asia-Pacific. China, India, Indonesia and Australia alone account for over 70% of global coal output by 2040, underscoring Asia's importance in global coal trade and pricing.With increasing trade and rising production costs, the average OECD steam coal import price moves up from current low levels (it averaged $86/tonne in 2013) to over $110/tonne in 2040[7].

In the New Policies Scenario, world electricity demand increases by almost 80% over the period 2012-2040. The power sector represents over half of the increase in global primary energy use, a rise comparable to current North American total energy demand. Non-OECD countries account for the bulk of incremental electricity demand, led by China (33%), India (15%), Southeast Asia (9%) and the Middle East (6%).Fossil fuels continue to dominate the power sector, although their share of generation declines from 68% in 2012 to 55% in 2040. Coal-fired generation is on the decline in the OECD, including the United States where coal-fired power drops by almost one-third to 2040. In China, it grows more than anywhere else, but its share still declines sharply. The share of coal also drops in India, despite strong absolute growth. Oil-fired generation declines by more than half, falling in most regions. By contrast, gas-fired power generation almost doubles over 2012-2040, increasing in most regions. In Europe, gas-fired generation gradually regains favour versus coal on rising CO2 prices, but only gets back to 2010 levels around 2030.The share of renewables in total power generation rises from 21% in 2012 to 33% in 2040, as they supply nearly half of the growth in global electricity generation. Renewable electricity generation, including hydropower, nearly triples over 2012-2040, overtaking gas as the second-largest source of generation in the next couple of years and surpassing coal as the top source after 2035. Rapid expansion of wind and solar PV raises fundamental questions about power market designs: their ability to ensure adequate investment in conventional power plants and long-term reliability of supply. China sees the largest increase in generation from renewables, more than the gains in the EU, US and Japan combined.Global subsidies to renewables reached $121 billion in 2013, up 15% on 2012, and expand to nearly $230 billion in 2030 in the New Policies Scenario, before falling to $205 billion in 2040 due to the end of support commitments for recently deployed capacity.In 2013, almost 70% of subsidies to renewables for power were provided in just five countries: Germany ($22 billion), the US ($15 billion), Italy ($14 billion), Spain ($8 billion) and China ($7 billion). The EU remains the largest financial supporter of renewables to 2040, though the US is a close second after 2035. Solar PV continues to receive the largest portion of subsidies until falling unit costs help to reduce subsidies below those for bioenergy for power just before 2040. The value of solar PV in the system also declines with more deployment, making competitiveness a moving target. Subsidies to onshore wind reach a peak just before 2020 and then decline steadily as it becomes competitive with conventional power plants in many locations.Biofuels use more than triples, rising from 1.3 million barrels of oil equivalent per day (mboe/d) in 2012 to 4.6 mboe/d in 2040, by which time it represents 8% of road-transport fuel demand. Advanced biofuels, which help address sustainability concerns about conventional biofuels, gain market share after 2020, making up almost 20% of biofuels supply in 2040. Reflecting limited cost reductions and increasing use, subsidies to biofuels increase steadily and make up 20% of cumulative renewable energy subsidies over the projectio period.Global investment in the power sector amounts to $21 trillion through to 2040, with over 40% in transmission and distribution networks. Residential electricity prices increase in nearly all regions, in part due to rising fossil fuel prices. However, electricity becomes more affordable over time in most regions, as income levels increase faster than household electricity bills. CO2 emissions from the power sector rise from 13.2 gigatonnes (Gt) in 2012 to 15.4 Gt in 2040, retaining a share of around 40% of global emissions over the period. Increasing penetration of low-carbon technologies and deployment of high-efficiency coal-fired power plants help to slow the growth in CO2 emissions from the power sector. The evolution of the power sector will be critical to meeting climate change goals, due to the sector's rapid growth and because low-carbon alternatives are more readily available.

### 1.2. Renewables Energy

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat [1]. Renewable energy replaces conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services.[2]

The use of renewable fuels dates to Neolithic times, when cave dwellers made fire from wood and other biomass for cooking and heating. For thousands of years thereafter, renewable energy was all humans used. The small amounts of energy accessible to humans through traditional dispersed renewable energy sources meant that for millennia, human lives remained unchanged. Today, many are seeking to use technology made possible by modern, concentrated energy forms to capture and harness dispersed renewable energy potential into concentrated forms. Renewable energy relies upon the natural forces at work upon the earth, including the internal heat represented by geothermal, the pull of lunar gravity as it affects the potential for tidal power, and solar radiation such as that stored through photosynthesis in biomass. Also In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power[1].

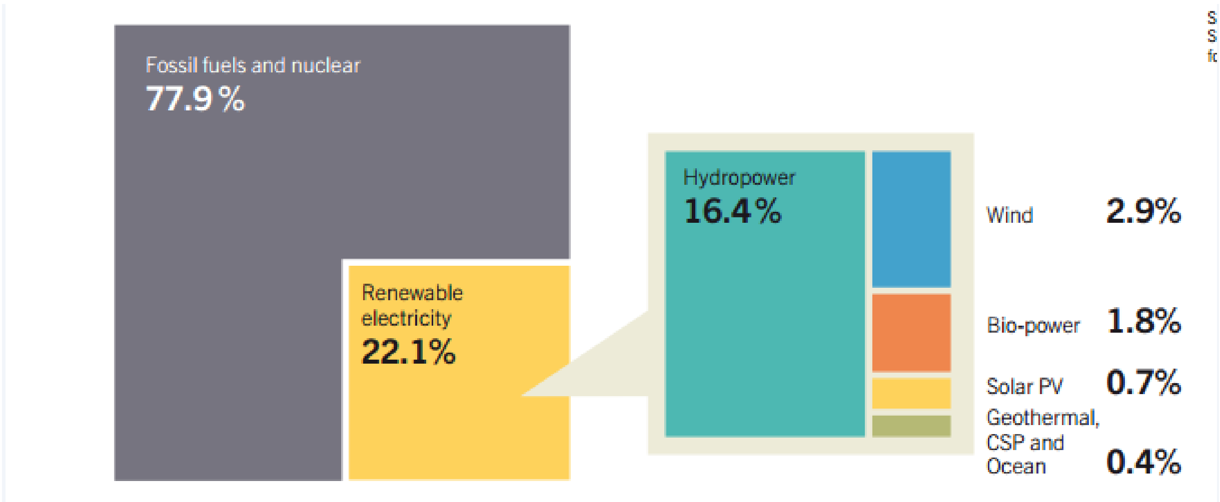


**Figure 2.** Energy Share of Global Electricity Production, End-2013

Renewable energy sources , which will save the world from fossil fuels , are biomass, wind, geotermal, hydropower, solar.

### 1.2.1. Solar energy

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available, and the Turkey has some of the richest solar resources in the world. Modern technology can harness this energy for a variety of uses, including generating electricity, providing light or a comfortable interior environment, and heating water for domestic, commercial, or industrial use.

There are several ways to harness solar energy: photovoltaics (also called solar electric), solar heating & cooling, concentrating solar power (typically built at utility-scale), and passive solar.

Passive solar buildings are designed and oriented to collect, store, and distribute the heat energy from sunlight to maintain the comfort of the occupants without the use of moving parts or electronics.

Solar energy is a flexible energy technology: solar power plants can be built as distributed generation (located at or near the point of use) or as a central-station, utility-scale solar power plant (similar to traditional power plants). Some utility-scale solar plants can store the energy they produce for use after the sun sets.

In addition tosolar energy may be used in a water stabilisation pond to treat waste water without chemicals or electricity. A further environmental advantage is that algae grow in such ponds and consume carbon dioxide in photosynthesis, although algae may produce toxic chemicals that make the water unusable[c].

**Figure 3.** Photovoltaics

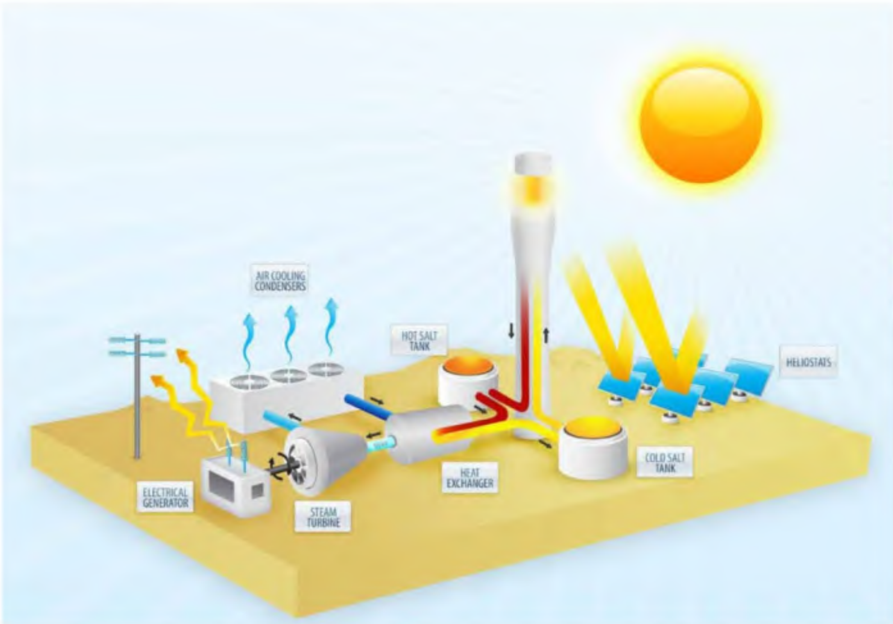


**Figure 4.** Solar Thermal Power

### 1.2.2. Biomass

The term "biomass" refers to organic matter that has stored energy through the process of photosynthesis. It exists in one form as plants and may be transferred through the food chain to animals' bodies and their wastes, all of which can be converted for everyday human use through processes such as combustion, which releases the carbon dioxide stored in the plant material. Many of the biomass fuels used today come in the form of wood products, dried vegetation, crop residues, and aquatic plants. Biomass has become one of the most commonly used renewable sources of energy in the last two decades, second only to hydropower in the generation of electricity. In addition to industrial biomass can be grown from numerous types of plants, including miscanthus, switchgrass, hemp, corn, poplar[d], willow, sorghum, sugarcane, bamboIt is such a widely utilized source of energy, probably due to its low cost and indigenous nature, that it accounts for almost 15% of the world's total energy supply and as much as 35% in developing countries, mostly for cooking and heating.

Biomass is one of the most plentiful and well-utilised sources of renewable energy in the world. Broadly speaking, it is organic material produced by the photosynthesis of light. The chemical material (organic compounds of carbons) are stored and can then be used to generate energy. The most common biomass used for energy is wood from trees. Wood has been used by humans for producing energy for heating and cooking for a very long time.

Biomass has been converted by partial-pyrolisis to charcoal for thousands of years. Charcoal, in turn has been used for forging metals and for light industry for millenia. Both wood and charcoal formed part of the backbone of the early Industrial Revolution (much northern England, Scotland and Ireland were deforested to produce charcoal) prior to the discovery of coal for energy.[3]

Wood is still used extensively for energy in both household situations, and in industry, particularly in the timber, paper and pulp and other forestry-related industries. Woody biomass accounts for over 10% of the primary energy consumed in Austria, and it accounts for much more of the primary energy consumed in most of the developing world, primarily for cooking and space heating.


**Figure 5.** Biomass sources

### 1.2.3. Geotermal

When superhot magma from deep within the earth comes close to the surface, it heats underground water and traps it in cracks and porous rock, creating reservoirs of very hot water and steam. Deep wells can tap the high energy content of this water and steam to drive a myriad of energy services, including electricity, heating, cooling, industrial processes, and even melting snow on roads. Also geothermal power is cost effective, reliable, sustainable, and environmentally friendly[e].

Drilling geothermal wells may involve hydraulic fracturing of underground formations, also known as fracking -- similar to the process used in oil and gas production. Strong protections must be in place to guard underground sources of drinking water from contamination during the fracturing process, which can also use chemical additives in addition to drilling. Hydraulic fracturing operations related to geothermal production are currently exempt from underground injection control regulations under the federal Safe Drinking Water Act.

All drilling and fracturing activities, as well as management of toxic waste, should be conducted with the highest level of environmental protection.

Another way to use geothermal energy on a smaller scale is through a geothermal heat pump, which exploits the temperature difference between the earth's surface and the air. In most places, the temperature at 10 feet below ground level remains between 50 and 60 degrees Fahrenheit year-round. In winter, a geothermal heat pump pulls heat from the relatively warmer ground and pumps it into a building. In summer, the pump cools the same building by pulling the building's warmer air into the relatively cooler ground, where the excess energy can be used in turn to heat water.

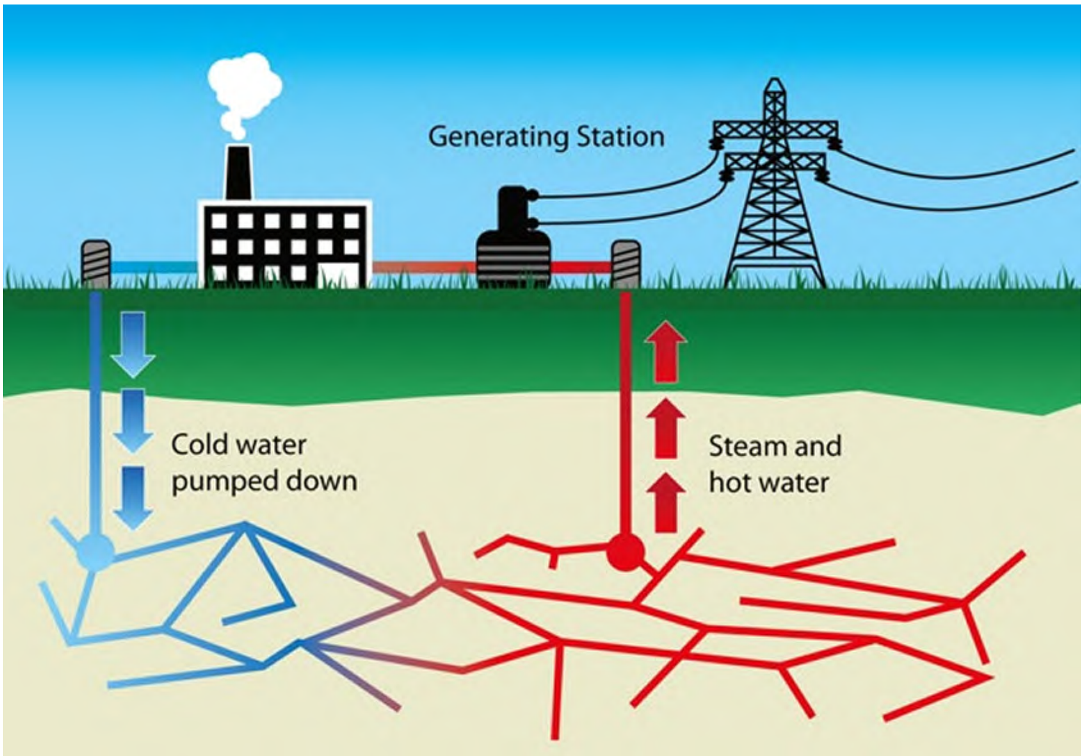


**Figure 6.** Geothermal Energy

### 1.2.4. Hydropower

Most hydroelectric power plants use dams to impound river water in a reservoir, and then release it in a controlled fashion to spin a turbine and generate electricity. Some "run-of-river" facilities operate with just a small dam, but these still divert, or "bypass" a portion of a river. Bypass reaches can be miles long. Other projects simply use water in an existing canal, taking advantage of already available flow.

Over the past century, thousands of important rivers and streams have been dammed to produce hydroelectricity.

While water itself is a renewable resource, the natural ecology of rivers is not. Hydroelectric dams adversely impact aquatic ecosystems by harming plants, fish, and other wildlife in and near rivers. Dam-building peaked in the 1960s in this country, before environmental protection was a consideration. In recent decades, the growth of hydroelectric power has slowed greatly, because most of the "best" sites were already built and environmental laws were enacted.

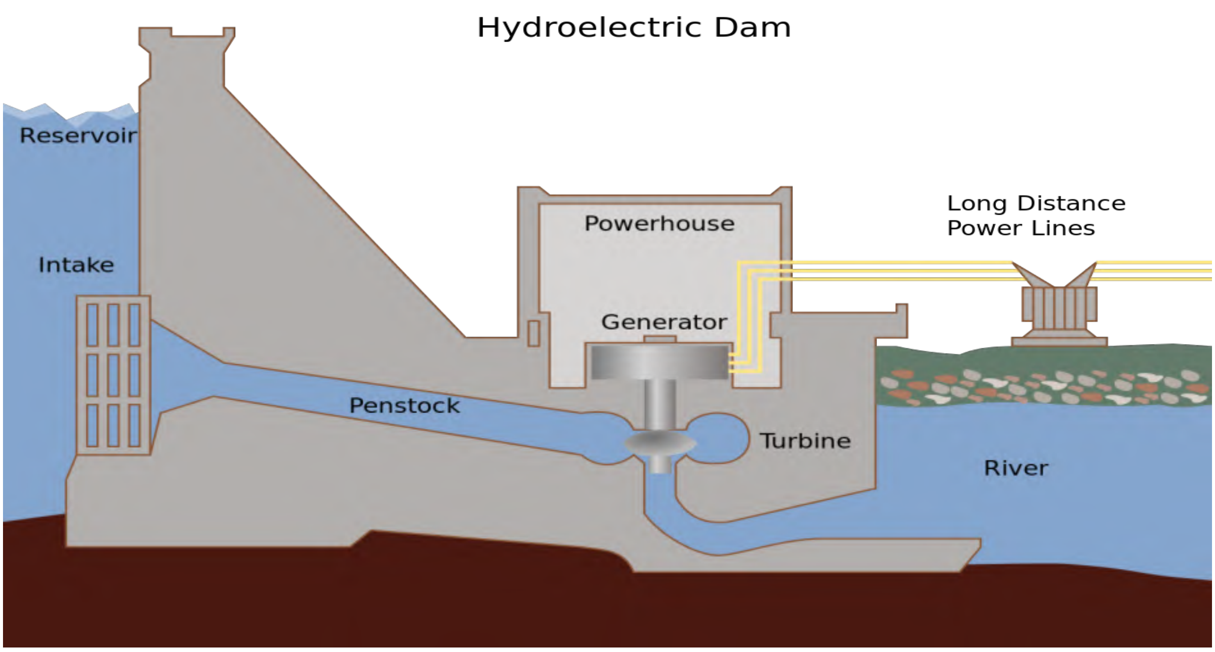


**Figure 7.** Hydropower Dam

### 1.2.5. Wind Energy

The wind is one of the cleanest sources of energy, and because it is a naturally generated resource, it is also the most abundant energy source on the planet today. Wind is an inexpensive source of electricity, competitive with or in many places cheaper than coal, gas or fossil fuel plants[4]. Wind energy is currently supplying as much as 1% of the world's electricity use, however the power of wind energy could potentially supply as much as 20% of global electricity.

Wind energy is created through the use of Wind Turbines, or wind turbine towers. How much energy is produced from one wind turbine depends entirely on how large the turbine is. A large wind turbine will produce several hundred megawatts of electricity which is enough electricity to power several hundred homes. A smaller wind turbine is defined as one that provides 100 kW of electricity or less. These smaller turbines are used for homes or small businesses, or as a resource of backup for electricity. Some people use even smaller turbines to power sailboat batteries or for other uses. In addition to Wind turbines may also benefit from the general trend of increasing use and decreasing cost of carbon fibre materials[g].

Today, wind turbines come in all forms and sizes, but they all function and are built in a very similar manner. Standard components of a wind turbine include:

- Rotor – the blades with surfaces engineered with aerodynamics in mind. As the wind moves over these blades, the rotor will turn, and the generator in the turbine rotates and produces the electricity

- Gearbox – the gearbox will match the speed of the rotor to the speed of the generator. The smallest wind turbines do not use a gearbox.

- Tailvane – this component will align the wind turbine with the wind direction

- Tower – this component is used on horizontal turbines, and is where the turbine is mounted. Vertical turbines do exist, and these are generally built into the ground.

- Battery Station – the larger wind turbines are connected to a battery station which is the system that operates the turbine. Because a generator is used to run the turbine, battery power is necessary to run the generator. The batteries will be turned on and off with the turbine generator switch.

A wind turbine works in the opposite manner that a fan works. Fans use electricity to make wind, whereas turbines use wind to make energy. As wind moves over the aerodynamically engineered rotator blades, a shaft inside of the turbine is spun. This shaft is connected to the generator, which, in turn creates the mechanical energy that we use today.

The height of the tower does play a role in how much wind energy will be produced. The speed of wind will increase with height, and so any increases in the height of a turbine tower will mean larger increases in the amounts of electricity that is generated by the turbine.[4]

Wind energy is the most easily accessed form of energy today, and it is also the cleanest which makes it an affordable and the most feasible option towards making our earth a greener place.

#### 1.2.5.1. Wind Turbine History

Since early recorded history, people have harnessed the energy of the wind. Wind energy propelled boats along the Nile River as early as 5000 B.C. By 200 B.C., simple windmills in China were pumping water, while vertical-axis windmills with woven reed sails were grinding grain in Persia and the Middle East.

New ways of using the energy of the wind eventually spread around the world. By the 11thcentury, people in the Middle East used windmills extensively for food production. Returning merchants and crusaders carried this idea back to Europe. The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches and later to generate electricity for homes and industry.

American colonists used windmills to grind wheat and corn, to pump water and to cut wood at sawmills. With the development of electric power, wind power found new applications in lighting buildings remotely from centrally generated power. Throughout the 20th century, small wind plants, suitable for farms and residences, and larger utility-scale wind farms that could be connected to electricity grids were developed.

During World War II, the largest wind turbine known in the 1940s, a 1.25-megawatt turbine that sat on a Vermont hilltop known as Grandpa's Knob, fed electric power to the local utility network. Wind electric turbines persisted in Denmark into the 1950s but were ultimately sidelined due to the availability of cheap oil and low energy prices.

The oil shortages of the 1970s changed the energy picture for the U.S. and the world. It created an interest in alternative energy sources, paving the way for the re-entry of the wind turbine to generate electricity.[5]

### 1.2.5.2. Anatomy Of A Wind Turbıne

A wind turbine is a collection of operating systems that converts the kinetic energy of the wind into electric energy that ultimately will be used in homes, communities, and businesses. The main operating systems include: tower, blade, rotor, drivetrain, gearbox, generator, electrical systems, nacelle, yaw & pitch, and controls.

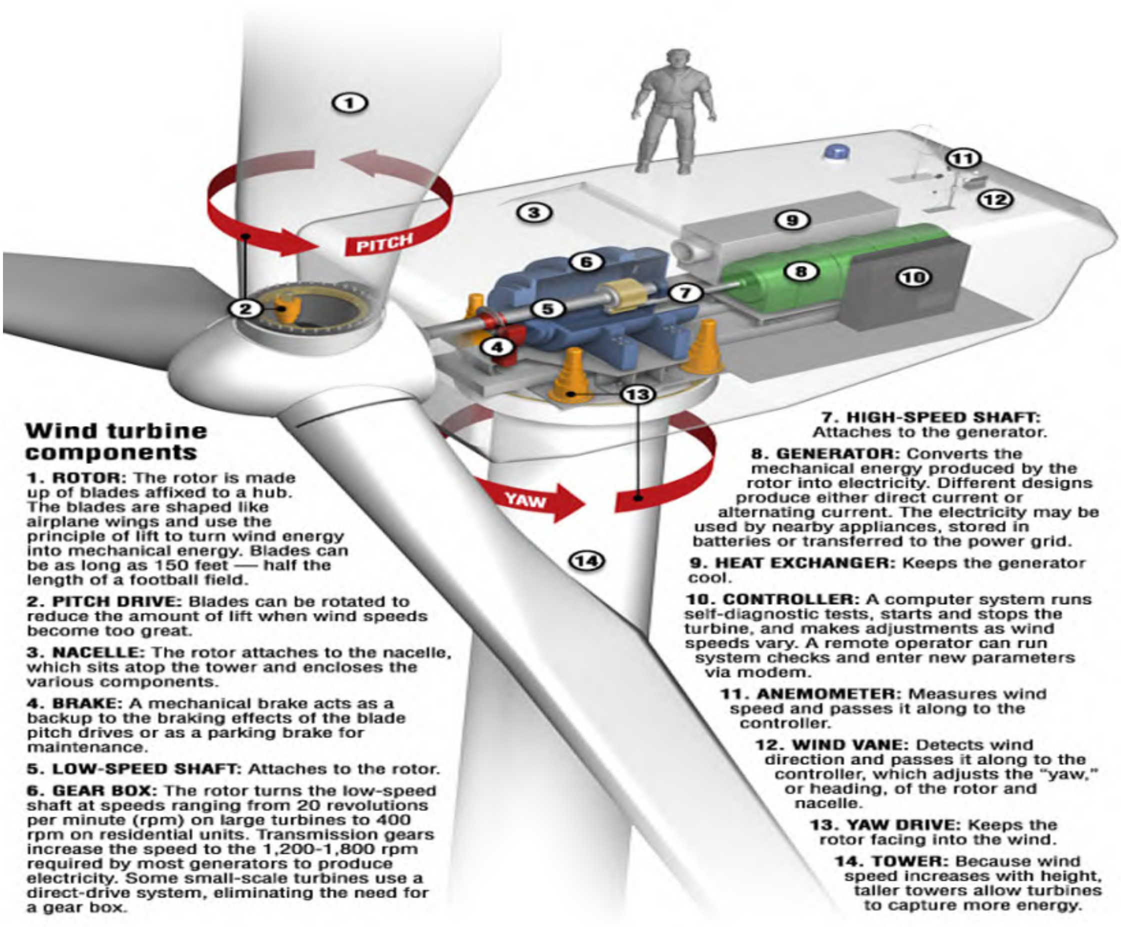


**Figure 8.** Wind Turbine Components

Current utility-scale wind turbines installed in the US range from 100 kW generator platforms to a 3.6-MW generator with a 116-meter rotor diameter on an 82-meter tower. The average capacity of all wind turbines installed in the U.S. in 2012 was 1.95 MW, consistent with installations in 2011. Many manufacturers are developing larger turbine models capable of being deployed in areas with lower wind speeds and in offshore applications.

In 2012 alone, the U.S. wind industry installed over 6,700 turbines. To install that number of turbines, the U.S. industry required 20,100 blades and the same number of tower sections, approximately 3.2 million bolts, 36,000 miles of rebar, and 1.7 million cubic yards of concrete (enough for more than 7,630 miles of 4 foot-wide sidewalk). There are over 8,000 components in each turbine assembly.

### 1.2.5.2.1. Rotor

The rotor for a typical utility-scale wind turbine includes three high-tech blades, a hub, and a spinner. The blades are one of the most critical aspects for a wind turbine and are considered a strategic component by wind turbine OEMs. Most manufacturers create multiple blade types for a single wind turbine in order to enhance performance in different wind conditions. The blades range in size from about 34 to 55 meters and are made of laminated materials – such as composites, balsa wood, carbon fiber, and fiberglass – that have high strength-to-weight ratios. These materials are molded into airfoils to generate lift, which causes the rotor to turn. The blades also often include material to protect against lightning strikes. They are bolted onto the hub, with a pitch mechanism interposed to allow the blade to rotate about its axis to take advantage of varying wind speeds.

**Figure 9.** Rotor

The hub – usually made of ductile cast iron – is one of a wind turbine's heaviest components, weighing 8 to 10 tons for a 2-MW turbine. The hub is designed to be rigid yet able to absorb a high level of vibration. also, the resistance of the rotor blades, in terms of their tensile strengths, exhibits a natural variability[f].

### 1.2.5.2.2. Nacelle

The nacelle of a wind turbine is the box-like component that sits atop the tower and is connected to the rotor. The nacelle contains the majority of the approximately 8,000 components of the wind turbine, such as the gearbox, generator, main frame, etc. The nacelle housing is made of fiberglass and protects the internal components from the environment. The nacelle cover is fastened to the main frame, which also supports all the other components inside the nacelle. The main frames are large metal structures that must be able to withstand large fatigue loads.

#### 1.2.5.2.3. Drive Train

The heart of the wind turbine is its electricity generating system. Inside the nacelle of a typical wind turbine, the rotor drives a large shaft into a gearbox, which steps up the revolutions per minute to a speed suitable for the electrical generator. A wind turbine gearbox must be robust enough to handle the frequent changes in torque caused by changes in the wind speed. The gearbox requires a lubrication system to minimize wear. Wind turbines being sold in the U.S. have either induction or permanent-magnet generators, depending on the model being sold. Induction generators are more common and require a gearbox as described.

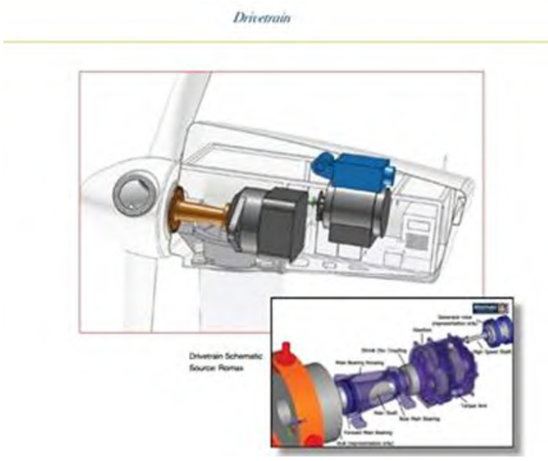


**Figure 10.** Drivetrain

Some wind turbines avoid the gearbox completely and use a direct drive system. A direct drive system connects the rotor directly to a permanent-magnet generator. These turbines avoid the mechanical problems associated with a gearbox, but require extremely heavy and expensive generators that can produce electricity capable of supplying the grid.

#### 1.2.5.2.4. Yaw

All turbines have a yaw drive system to keep the rotor facing into the wind and to unwind the cables that travel down to the base of the tower. The yaw drive system usually consists of an electric or hydraulic motor mounted on the nacelle which drives a pinion mounted on a vertical shaft through a reducing gearbox. The yaw drive system also has a brake in order to be able to stop a turbine from turning and stabilize it during normal operation.

#### 1.2.5.2.5. Control System

To control the functioning of the wind turbine, it is fitted with a number of sensors to read the speed and direction of the wind, the levels of electrical power generation, the rotor speed, the blades' pitch angle, vibration levels, the temperature of the lubricants and other variables. A computer processes the inputs to carry out the normal operation of the turbine, with a safety system which can override the controller in an emergency. The control system protects the turbine from operating in dangerous conditions and ensures that the power generated has the proper frequency, voltage, and current levels to be supplied to the grid.

#### 1.2.5.2.6. Tower

The nacelle and generator are mounted on top of a tall tower to allow the blades to take advantage of the best winds. The power available to a wind turbine is proportional to the cube of the wind speed. Therefore, a 10% increase in wind speed would result in a 33% increase in available power.  Towers are typically made of three or four tubular steel sections coated with paints and sealants and joined by flanges and bolts. Today's wind turbine tower is usually about 80-100 meters tall. Most towers come with load lifting systems with load-bearing capacity of more than 400 pounds.

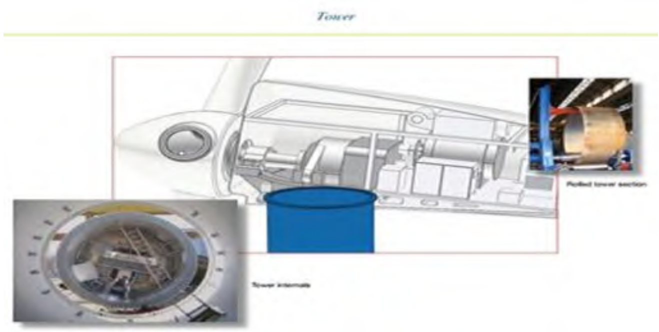


**Figure 11.** Tower

#### 1.2.5.2.7. Transportation

Transportation of turbine components often involves road, rail, and water. Given the increasing size, weight, and length of components, innovative transportation, manufacturing and logistics solutions are necessary. With respect to trucking, only a fraction of the industry is capable of managing the heavy-load long-haul requirements of the wind turbine industry. One turbine can require up to eight hauls (one nacelle, three blades and four tower sections). A truck carrying a tower section must be able to support a load with a propensity to roll that is over 30 meters long and weighs over 150,000 pounds. Due to tunnel and overpass restrictions, rail transport can be even more dimensionally limited than over-the-road transportation, though innovations in rail transit have helped to increase the use of rail.

#### 1.2.5.2.8. Construction

Once the nacelle, blades, and tower sections are delivered to the wind farm site, construction of the wind farm can begin. The tower is normally fitted with a base flange, which can be attached to the foundation by screwed rods cast into concrete or bolted to an embedded tower stub. For the foundation, a variety of slab, multi-pile and mono-pile solutions have been used for tubular towers, depending on the condition of the ground where the turbine is being installed. Also the aerodynamic design of the blades, the design of a complete wind power system must also address the design of the installation's rotor hub, nacelle, tower structure, generator, controls, and foundation [b].

In addition to the erection of each turbine, there is additional construction work needed to connect each turbine to the power grid, such as access road construction, laying electrical cable, and installation of an electrical substation.

**Figure 12.** Construction

#### 1.2.5.3. Advantages Of Wind Energy

Excessive heating of earth due to burning of fossil fuels have forced people across the globe to generate power through wind. It is being used extensively in areas like USA, Denmark, Spain, India and Germany. Like any other source of power generation, wind energy has its own advantages and disadvantages.

1. Renewable Energy : Wind energy in itself is a source of renewable energy which means it can be produced again and again since it is available in plenty. It is cleanest form of renewable energy and is currently used many leading developed and developing nations to fulfill their demand for electricity.

2. Reduces Fossil Fuels Consumption : Dependence on the fossil fuels could be reduced to much extent if it is adopted on the much wider scale by all the countries across the globe. It could be answer to the ever increasing demand for petroleum and gas products. Apart from this, it can also help to curb harmful gas emissions which are the major source of global warming.

3. Less Air and Water Pollution : Wind energy doesn't pollute at all. It is that form of energy that will exist till the time sun exists. It does not destroy the environment or release toxic gases. Wind turbines are mostly found in coastal areas, open plain and gaps in mountains where the wind is reliable, strong and steady. An ideal location would have a near constant flow of non-turbulent wind throughout the year, with a minimum likelihood of sudden powerful bursts of wind.

4. Initial Cost : The cost of producing wind energy has come down steadily over the last few years. The main cost is the installation of wind turbines. Moreover the land used to install wind turbines can also be used for agriculture purpose. Also, when combine with solar power, it provides cheap, reliable, steady and great source of energy for the for developed and developing countries.

5. Create Many Jobs : Wind energy on the other hand has created many jobs for the local people. From installation of wind turbines to maintenance of the area where turbines are located, it has created wide range of opportunities for the people. Since most of the wind turbines are based in coastal and hilly areas, people living there are often seen in maintenance of wind turbines.

Despite these advantages there few disadvantages too which makes wind turbines not suitable for some locations.

### 1.2.5.4. Disadvantages Of Wind Energy

Wind turbines provide clean an effective way of producing power for home or business. Wind turbines are built in the form of vertical axis and horizontal axis. The more common type of wind turbines built across the world is the horizontal wind turbine. Wind turbines have its own impact on wildlife and surrounding environment which contribute towards disadvantages of wind turbines.

Here's are some of the major disadvantages of wind turbines.

1. Noise Disturbances : Though wind energy is non-polluting, the turbines may create a lot of noise. This alone is the reason that wind farms are not built near residential areas. People who live near-by often complaint of huge noise that comes from wind turbines.

2. Threat to Wildlife : Due to large scale construction of wind turbines on remote location, it could be a threat to wild life near by. Few studies have been done by wind turbines to determine the effect of wind turbines on birds and animals and the evidence is clear that animals see wind turbines as a threat to their life. Also, wind turbines require them to be dig deep into the earth which could have negative effect on the underground habitats.

3. Wind Can Never Be Predicted : The main disadvantage of wind energy is that wind can never be predicted. In areas where large amount of wind is needed or winds strength is too low to support wind turbine, there solar or geothermal energy could prove to be great alternatives. That is one of the reasons that most of the companies determine wind turbine layout, power curve, thrust curve, long term wind speed before deploying wind turbines.

4. Suited To Particular Region : Wind turbines are suited to the coastal regions which receive wind throughout the year to generate power. So, countries that do not have any coastal or hilly areas may not be able to take any advantage of wind power. The location of a wind power system is crucial, and one should determine the best possible location for wind turbine in order to capture as much wind as possible.

5. Visual Impact : Though many people believe that wind turbines actually look nice but majority of them disagree. People consider wind turbines to have an undesirable experience. Petitions usually comes in court before any proposed wind farm development but few people think otherwise and feel they should be kept in tact for everyone to enjoy its beauty.

Although these disadvantages make it look that wind energy may not suitable for every country but its advantages make it a great source of energy.

### 1.2.5.5. Types of Wind Turbines

Wind turbines can be separated into two basic types determined by which way the turbine spins. Wind turbines that rotate around a horizontal axis are more common (like a wind mill), while vertical axis wind turbines are less frequently used (Savonius and Darrieus are the most common in the group).

#### 1.2.5.5.1.Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of when we think of a wind turbine. A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis.

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.

Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.

Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind. Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines.

HAWT advantages:

1) The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%.

2) High efficiency, since the blades always move perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.

HAWT disadvantages:

1) Massive tower construction is required to support the heavy blades, gearbox, and generator.

2) Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position.

3) Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.

4) Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower).

5) HAWTs require an additional yaw control mechanism to turn the blades toward the wind.

6) HAWTs generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself.

Cyclic stresses and vibration:When the turbine turns to face the wind, the rotating blades act like a gyroscope. As it pivots, gyroscopic precession tries to twist the turbine into a forward or backward somersault. For each blade on a wind generator's turbine, force is at a minimum when the blade is horizontal and at a maximum when the blade is vertical. This cyclic twisting can quickly fatigue and crack the blade roots, hub and axle of the turbines.

**1.2.5.5.2.Vertical Axis Wind Turbines (VAWT)**

Vertical axis wind turbines, as shortened to VAWTs, have the main rotor shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on sites where the wind direction is highly variable or has turbulent winds.

With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT generally create drag when rotating into the wind.

It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence. In addition to recent research suggests that vertical wind turbines may be placed much more closely together so long as an alternating pattern of rotation is created allowing blades of neighbouring turbines to move in the same direction as they approach one another[j].

#### 1.2.5.5.2.1.VAWT subtypes

Darrieus wind turbine:

Darrieus wind turbines are commonly called "Eggbeater" turbines, because they look like a giant eggbeater. They have good efficiency, but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Also, they generally require some external power source, or an additional Savonius rotor, to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in a higher solidity for the rotor. Solidity is measured by blade area over the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing.

Savonius wind turbine:

A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers. Because they are a drag type turbine they are less efficient than the common HAWT. Savonius are excellent in areas of turbulent wind and self starting.

VAWT advantages:

1) No yaw mechanisms is needed.

2) A VAWT can be located nearer the ground, making it easier to maintain the moving parts.

3) VAWTs have lower wind startup speeds than the typical the HAWTs.

4) VAWTs may be built at locations where taller structures are prohibited.

5) VAWTs situated close to the ground can take advantage of locations where rooftops, mesas, hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

**VAWT disadvantages:**

1) Most VAWTs have a average decreased efficiency from a common HAWT, mainly because of the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.

2) Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.

### 1.2.5.6. WİND SPEED MEASUREMENT

**Anemometer**

An anemometer is a device that is used for measuring wind speed, and is one instrument used in a weather station. The term is derived from the Greek word anemos, meaning wind. The first anemometer was invented by Leonardo da Vinci. Leonardo actually designed two different types of instruments for measuring wind speed. You can see the drawings for both on the left. The first one (see right above) is called a "lamellae" or "pennello" anemomenter because feathers were once used to gauge wind speed. It was a graduated stick with a thin plate which moved according to the force of the wind. The other one (right below) is made from cone shaped tubes and was design to check that the wind pressure turning the wheels was proportional to the opening in the cones through which the air passes, given the same wind speed.

#### 1.2.5.6.1. Four Cup Anemometer

A simple type of anemometer is the cup anemometer, invented in 1846 by Dr. John Thomas Romney Robinson. (see right) It included four cups which were mounted on one end of four horizontal arms, which were attached at 90 degree angles to each other on a vertical shaft. Wind blowing horizontally would turn the cups at a speed that was proportional to the wind speed. If you counted the turns ofthe cups over a specific period of time, you could determine the average wind speed for that location. When Robinson first designed his anemometer, he incorrectly stated that no matter how big the cups were or how long the arms were, the cups always moved at one-third of the speed of the wind. It was later discovered that the actual relationship between the speed of the wind and that of the cups, called the"anemometer factor," actually depended on the dimensions of the cups and arms, and may have a value between two and a little over three.

#### 1.2.5.6.2.Three Cup Anemometer

Four cups anemometers were found to experience delays in accuracy when wind speeds changed quickly. So, the three cup anemometer was engineered to improve accuracy and especially in environments where wind might change quickly or unexpectedly. The three cup anemometer was first developed by the Canadian John Patterson in 1926. As is true of many engineered products, they are improved or "re-engineered" over time to enhance performance, reduce costs, or boost safety. In 1935, the three cup anemometer was enhanced by Brevoort & Joiner of the United States. Their work led to a cup-wheel design which was more accurate with an error rate of less than 3% at speeds up to 60 miles per hour (mph). In 1991, the design was changed by the Australian Derek Weston to be able to measure both wind direction and wind speed. Weston added a tag to one cup, which caused the speed to increase and decrease as the tag moved alternately with and against the wind. Three cup anemometers are currently used as the industry standard for wind energy assessment studies.

#### 1.2.5.6.3. Sonic Anemometers

Sonic anemometers were first developed in the 1970s and use ultrasonic sound waves to measure wind speed and direction. They measure wind velocity based on the time of flight of sonic pulses between pairs of transducers. The lack of moving parts makes them appropriate for long term use in exposed automated weather stations and weather buoys where the accuracy and reliability of traditional cup-and-vane anemometers is adversely affected by salty air or large amounts of dust.

### 1.2.5.7.Green Buildings

Green Building, also known as green construction or sustainable building, is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort.

Although new technologies are constantly being developed to complement current practices in creating greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation

A similar concept is natural building, which is usually on a smaller scale and tends to focus on the use of natural materials that are available locally.Other related topics include sustainable design and green architecture. Reducing environmental impact:

Green building practices aim to reduce the environmental impact of buildings. Buildings account for a large amount of land use, energy and water consumption, and air and atmosphere alteration. In addition to passive solar building design is often implemented in low-energy homes. Designers orient windows and walls and place awnings, porches, and trees[h]. The environmental impact of buildings is often underestimated, while the perceived costs of green buildings are overestimated. A recent survey by the World Business Council for Sustainable Development finds that green costs are overestimated by 300 percent, as key players in real estate and construction estimate the additional cost at 17 percent above conventional construction, more than triple the true average cost difference of about 5 percent..Goals of green building is:

The concept of sustainable development can be traced to the energy (especially fossil oil) crisis and the environment pollution concern in the 1970s.The green building movement in the U.S. originated from the need and desire for more energy efficient and environmentally friendly construction practices. There are a number of motives to building green, including environmental, economic, and social benefits. However, modern sustainability initiatives call for an integrated and synergistic design to both new construction and in the retrofitting of an existing structure. Also known as sustainable design, this approach integrates the building life-cycle with each green practice employed with a design-purpose to create a synergy amongst the practices used.

Green building brings together a vast array of practices and techniques to reduce and ultimately eliminate the impacts of buildings on the environment and human health. It often emphasizes taking advantage of renewable resources, e.g., using sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, rain gardens, and for reduction of rainwater run-off. Many other techniques, such as using packed gravel or permeable concrete instead of conventional concrete or asphalt to enhance replenishment of ground water, are used as well.

While the practices, or technologies, employed in green building are constantly evolving and may differ from region to region, there are fundamental principles that persist from which the method is derived: Siting and Structure Design Efficiency, Energy Efficiency, Water Efficiency, Materials Efficiency, Indoor Environmental Quality Enhancement, Operations and Maintenance Optimization, and Waste and Toxics Reduction.The essence of green building is an optimization of one or more of these principles. Also, with the proper synergistic design, individual green building technologies may work together to produce a greater cumulative effect.

On the aesthetic side of green architecture or sustainable design is the philosophy of designing a building that is in harmony with the natural features and resources surrounding the site. There are several key steps in designing sustainable buildings: specify 'green' building materials from local sources, reduce loads, optimize systems, and generate on-site renewable energy.

### 1.2.5.8. EFFICIENCY OF WIND TURBINES

Wind turbines start operating at wind speeds of 4 to 5 metres per second and reach maximum power output at around 15 metres/second. At very high wind speeds, i.e. gale force winds, (25 metres/second) wind turbines shut down. A modern wind turbine produces electricity 70-85% of the time, but it generates different outputs depending on the wind speed.

Over the course of a year, it will typically generate about 30% of the theoretical maximum output (higher offshore). This is known as its capacity factor. The capacity factor of conventional power stations is on average 50%. Because of stoppages for maintenance or breakdowns, no power plant generates power for 100% of the time.

### 1.2.5.9. Situation of Wind Energy in the World

Wind energy is the most advanced and widespread renewable energy source being the most convenient in commercial terms. Being a clean energy source, wind energy is environment friendly having no possibility of extinction as long as the sun exists. It is an ever growing energy source despite being continuous and despite the fact that it is not exactly known whether available amount will be at hand when required. For instance, As of the end of 2014, worldwide, total cumulative installed capacity from wind power amounts to 369,553 MW and increased by 16% compared to the previous year (318,106 MW).

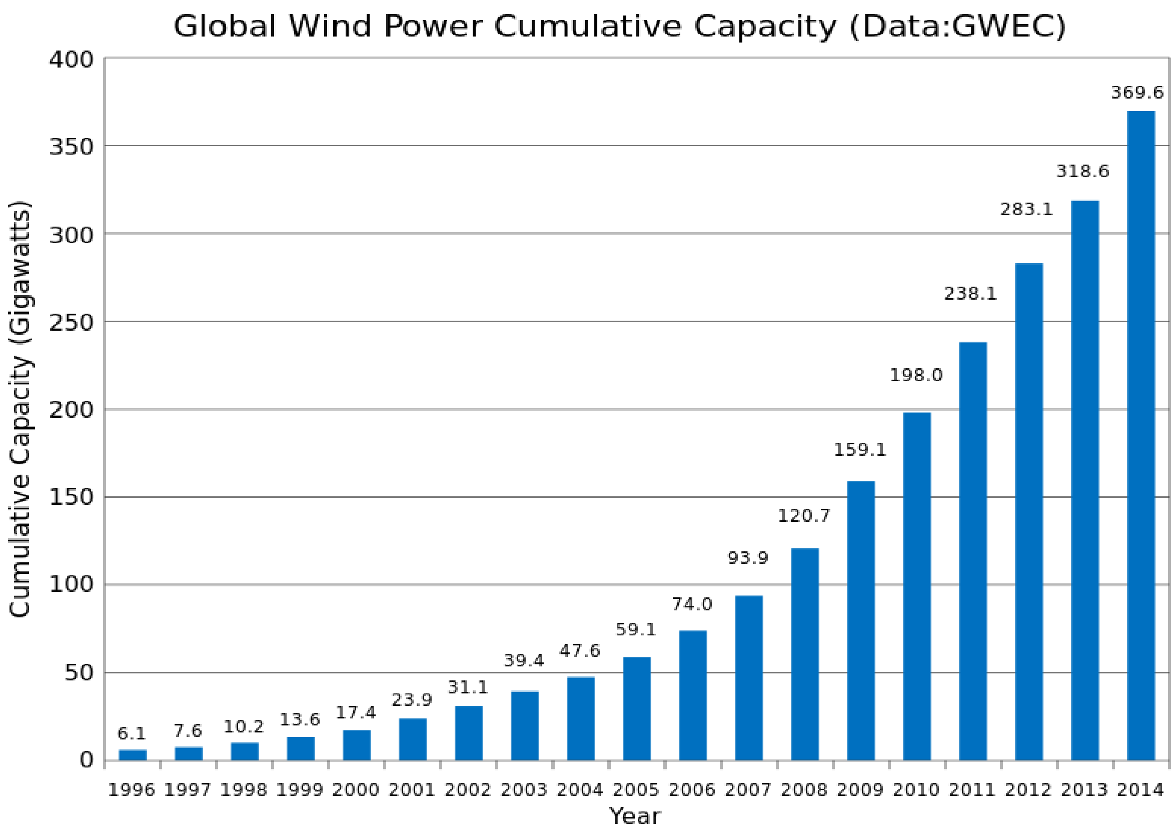


**Figure 13.** Global Wind Turbine Cumulative Capacity

### 1.2.5.10.The Current Situation of Wind Energy in Turkey

A wind atlas of Turkey published by the Turkish Energy Market Regulatory Agency (EPDK) in May 2002 indicates that the regions with the highest potential for wind speeds at height of 50 m are the Aegean, Marmara, and Eastern Mediterranean regions of Turkey, as well as some mountainous regions of central Anatolia [6]. Figure 5 shows scattering of average wind speed in 50 m high in Turkey. In addition to this, meteorological data by the USA space studies have shown that Turkey has high wind capacity.

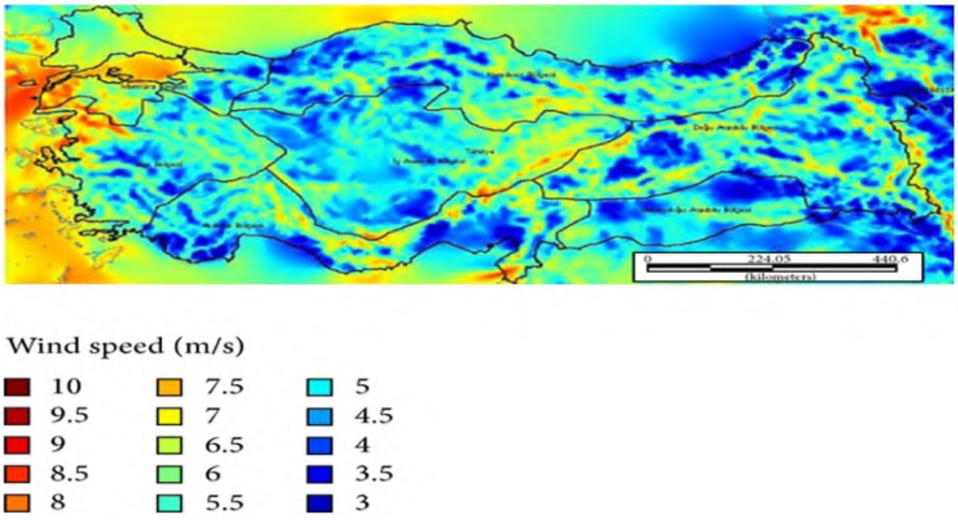


**Figure 14.** Scattering of average wind speed at 50 m high in Turkey

Power intensity in 50 m of elevation above ground, which is significant to establishturbines, in places with 4-5 m/s of average annual wind speed at 50 m of elevation above ground mostly exceed annual average of 500 w/m$^2$. Estimated figures resulting from the researcher conducted in the field, technical wind energy potential of Turkey, established power, and average efficiencies are available in Table 1[6]. In this table, the land of Turkey has been classified by means of wind energy resource degree. It can be seen from this table that approximately 37% of the land of Turkey has capacity above medium.

| Wind source degree | Wind class | Wind power at 50 m. (W/m$^2$) | Wind speed at 50 m. (m/s) | Overall area (km$^2$) | Windy land (%) | Potential capacity (MW) |
|---|---|---|---|---|---|---|
| Medium | 3 | 300–400 | 6.8–7.5 | 16781.39 | 2.27 | 83906.96 |
| Good | 4 | 400–500 | 7.5–8.1 | 5851.87 | 0.79 | 29259.36 |
| Perfect | 5 | 500–600 | 8.1–8.6 | 2598.86 | 0.35 | 12994.32 |
| Perfect | 6 | 600–800 | 8.6–9.5 | 1079.98 | 0.15 | 5399.92 |
| Perfect | 7 | >800 | >9.5 | 39.17 | 0.01 | 195.84 |
| Total | | | | 26351.28 | 3.57 | 131756.40 |

**Table 1.** Areal distribution of wind speed, power and potential energy amount in Turkey

## 2. Material And Method

Wind turbine is a practical application of Sir Isaac Newton's third law of motion which states that, 'for every force acting on a body there is an opposite and equal reaction'.

### 2.1. MODELING USING SOLIDWORKS

First of all we draw all parts of our combustion house in Solidworks 2013. It consists of one air inlet and four exit occurs in our solid part.

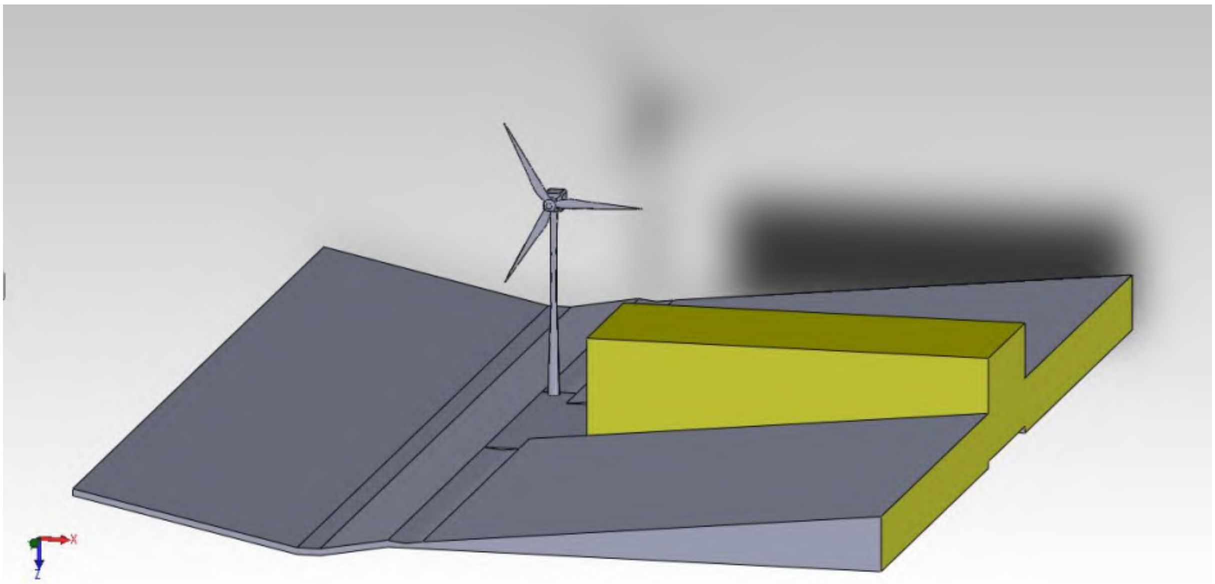

**Figure 15.** Modeling using Solidworks

#### 2.1.1.Aerofoil

We all do know how a bird flies; it maintains the pressure of the air around for its body to float. Similarly when a wing moves through the air, it splits and moves above and below the wing. The air passing above the wing gets spread out or expanded and hence the pressure decreases, while the air passing below the wing moves straight enough to maintain its speed and pressure. To maintain equilibrium higher air pressure usually moves towards a region which has lower air pressure. The air above the wing has lower air pressure as compared to air below the wing. Thus the air below is pushed upwards which in turn lifts the wing, sandwiched in between. This lift is due to the angle of attack and shape. When the air hits the wings it results in an opposite force to the direction of deflection. Its components are called as lift (perpendicular) and drag (parallel.) As the speed of the plane increases, more the lift and eventually when the force of motion (lift) is greater than the gravitational pull, the plane starts flying.

There are different types of airfoils,

- **Semi-symmetrical Airfoil:** Most of the full size planes have this type installed. Its thinner than the symmetrical airfoil and has lesser drag. It has a fully curved top and a half curved bottom.

- **Symmetrical Airfoil**: They are curved on both sides, equally. Generate high lifts with change in speed and power. They are generally thick and hence are very strong. The plane maintains its altitude with change in speed.
- **Flat Bottom Airfoil**: Flat bottoms are usually seen in trainer flights. They look extremely thin. Its bottom is flat and top is curved. Flat bottom's are speed sensitive. They are similar to symmetrical airfoils. When power and speed is added it produces great lift
- **Supersonic Airfoil**: A supersonic airfoil is used to generate lift at supersonic speeds. Its need arises when an aircraft is operated consistently in supersonic range.
- **Supercritical Airfoil**: A supercritical is designed to delay the drag in the transonic speed rangeare a few to name. A supercritical is designed to delay the drag in the transonic speed range. They have a flat upper surface, a highly cambered aft and a greater leading edge radius.

We decided to use NACA 4415 in our project.

Our data files:

**Table 2.** NACA 4415 Data Files

| | |
|---|---|
| 100.000 | 0.00000 |
| 0.99893 | 0.00039 |
| 0.99572 | 0.00156 |
| 0.99039 | 0.00349 |
| 0.98296 | 0.00610 |
| 0.97347 | 0.00932 |
| 0.96194 | 0.01303 |
| 0.94844 | 0.01716 |
| 0.93301 | 0.02166 |
| 0.91573 | 0.02652 |
| 0.89668 | 0.03171 |
| 0.87592 | 0.03717 |

| | |
|---|---|
| 0.8535 | 0.04283 |
| 0.82967 | 0.04863 |
| 0.80438 | 0.05453 |
| 0.77779 | 0.06048 |
| 0.75000 | 0.06642 |
| 0.72114 | 0.07227 |
| 0.69134 | 0.07795 |
| 0.66072 | 0.08341 |
| 0.62941 | 0.08858 |
| 0.59755 | 0.09341 |
| 0.56526 | 0.09785 |
| 0.53270 | 0.10185 |
| 0.50000 | 0.10538 |
| 0.46730 | 0.10837 |
| 0.43474 | 0.11076 |
| 0.40245 | 0.11248 |
| 0.37059 | 0.11345 |
| 0.33928 | 0.11361 |
| 0.30866 | 0.11294 |
| 0.27886 | 0.11141 |
| 0.25000 | 0.10903 |
| 0.22221 | 0.10584 |
| 0.19562 | 0.10190 |
| 0.17033 | 0.09726 |
| 0.14645 | 0.09195 |
| 0.12408 | 0.08607 |
| 0.10332 | 0.07970 |
| 0.08427 | 0.07283 |
| 0.06699 | 0.06541 |
| 0.05156 | 0.05753 |
| 0.03806 | 0.04937 |
| 0.02653 | 0.04118 |
| 0.01704 | 0.03303 |
| 0.00961 | 0.02489 |
| 0.00428 | 0.01654 |
| 0.00107 | 0.00825 |
| 0.00000 | 0.00075 |
| 0.00107 | -0.00566 |
| 0.00428 | -0.01102 |
| 0.00961 | -0.01590 |

| | |
|---|---|
| 0.01704 | -0.02061 |
| 0.02653 | -0.02502 |
| 0.03806 | -0.02915 |
| 0.05156 | -0.03281 |
| 0.06699 | -0.03582 |
| 0.08427 | -0.03817 |
| 0.10332 | -0.03991 |
| 0.12408 | -0.04106 |
| 0.14645 | -0.04166 |
| 0.17033 | -0.04177 |
| 0.19562 | -0.04147 |
| 0.22221 | -0.04078 |
| 0.25000 | -0.03974 |
| 0.27886 | -0.03845 |
| 0.30866 | -0.03700 |
| 0.33928 | -0.03547 |
| 0.37059 | -0.03390 |
| 0.40245 | -0.03229 |
| 0.43474 | -0.03063 |
| 0.46730 | -0.02891 |

| | |
|---|---|
| 0.50000 | -0.02713 |
| 0.53270 | -0.02529 |
| 0.56526 | -0.02340 |
| 0.59755 | -0.02149 |
| 0.62941 | -0.01958 |
| 0.66072 | -0.01772 |
| 0.69134 | -0.01596 |
| 0.72114 | -0.01430 |
| 0.75000 | -0.01277 |
| 0.77779 | -0.01136 |
| 0.80438 | -0.01006 |
| 0.82967 | -0.00886 |
| 0.85355 | -0.00775 |
| 0.87592 | -0.00674 |
| 0.89668 | -0.00583 |
| 0.91573 | -0.00502 |
| 0.93301 | -0.00431 |
| 0.94844 | -0.00364 |
| 0.96194 | -0.00297 |
| 0.97347 | -0.00227 |
| 0.98296 | -0.00156 |

| | |
|---|---|
| 0.99039 | -0.00092 |
| 0.99572 | -0.00042 |
| 0.99893 | -0.00011 |
| 100.000 | 0.00000 |

## 2.2.MESH MODELS

**Cut cell Cartesian meshing:**

1. This mesh method generates a high percentage of hexahedral cells in a Cartesian layout in the far field, to deliver accurate fluid flow results.

2. Local to the surface, mixed element types are used that allow the mesh to conform to sharp features.

3. The surface cells can be inflated to generate hexahedral and prismatic layers to capture near-wall physics effects.

4. Rapid mesh generation of hexahedral cells with minimal user setup make this mesh method ideal for complex geometry for computational fluid dynamics (CFD) simulation.

**Automated sweep meshing:**

1. Sweepable bodies are automatically detected and meshed with hex mesh when possible..

2. Edge increment assignment and side matching/mapping are done automatically.

3. Sweep paths are found automatically for all regions/bodies in a multibody part.

4. Defined inflation is swept through connected swept bodies.

5. Sizing controls and mapped controls can be added, and source faces selected to modify and take control of the automated sweeping.

6. Adding/modifying geometry slices/decomposition to the model greatly aids in the automation to obtain a pure hex mesh.

**Thin solid sweep meshing:**

1. This mesh method quickly generates a hex mesh for thin solid parts that have multiple faces as source and target.

2. This method can be used in conjunction with other mesh methods.

3. Sizing controls and mapped controls can be added, and source faces selected to modify and take control of the automated sweeping.

**Multi Zone sweep meshing:**

1. This advanced sweeping approach uses automated topology decomposition behind the scenes to attempt to automatically create a pure hex or mostly hex mesh on complicated geometries.

2. Decomposed topology is meshed with a mapped mesh or a swept mesh if possible. The option to allow for free mesh in sub-topologies that can't be mapped or swept is available.

3. This method supports multiple source/target selection.

4. Defined inflation is swept through connected swept bodies.

5. Sizing controls and mapped controls can be added, and source faces selected to modify and take control of the automated sweeping.

**Hex-dominant meshing:**

1. This mesh method uses an unstructured meshing approach to generate a quad-dominant surface mesh and then fill it with a hex-dominant mesh.

2. This approach generally gives nice hex elements on the boundary of a chunky part with a hybrid hex, prism, pyramid, tet-mesh used internally.

Mesh generation is one of the most critical aspects of engineering simulation. Too many cell may result in long solver runs, and too few may lead to inaccurate results. ANSYS Meshing technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible. ANSYS Meshing technology has been built on the strengths of stand-alone, class-leading meshing tools. The strongest aspects of these separate tools have been brought together in a single environment to produce some of the most powerful meshing available[8].

Mesh parameter changes

The highly automated meshing environment makes it simple to generate the following mesh types:

- Tetrahedral
- Hexahedral
- Prismatic inflation layer
- Hexahedral inflation layer
- Hexahedral core
- Body fitted Cartesian
- Cut cell Cartesian

Consistent user controls make switching methods very straight forward and multiple methods can be used within the same model. Mesh connectivity is maintained automatically. Different physics requires different meshing approaches. Fluid dynamics simulations require very high-quality meshes in both element shape and smoothness of sizes changes. Structural mechanics simulations need to use the mesh efficiently as run times can be impaired with high element counts. ANSYS Meshing has a physics preference setting ensuring the right mesh for each simulation.

The first step of analysis period is having a better mesh to obtain better results from analysis of the flow regions. It is limited into some standards in meshing process. Mesh processing was made tetrahedron mesh cells. Node number is **281803**. Mesh Element Number is **1587608**. Skewness number is **0.232**.

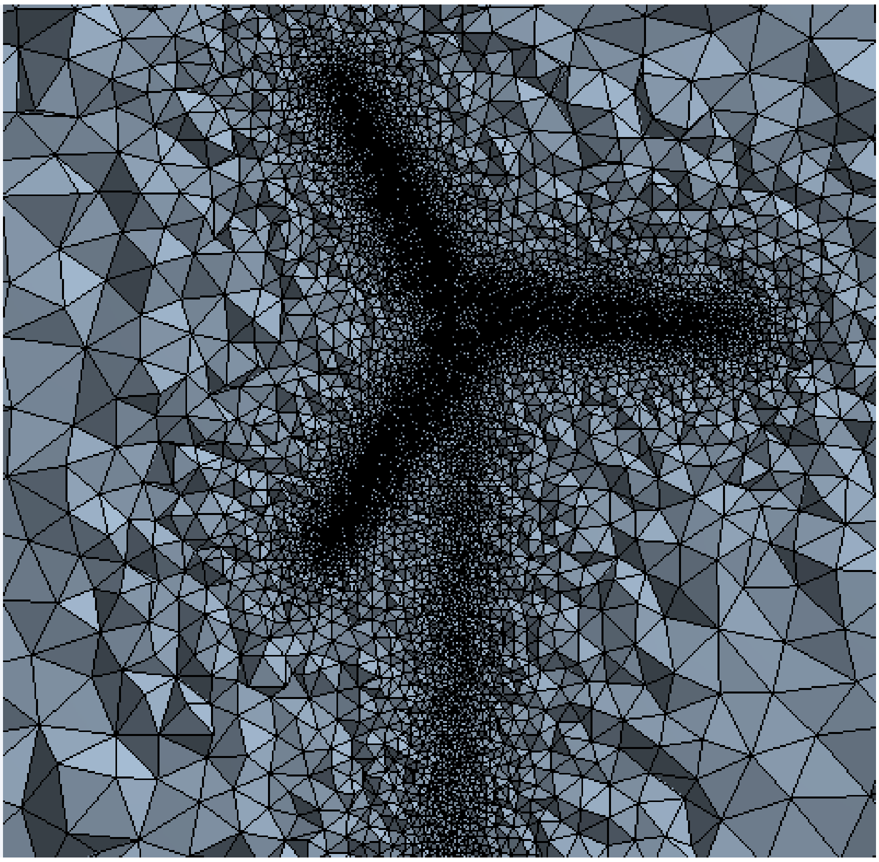

**Figure 16.** Meshing Model

## 2.3.The Principles Of Conversion

There are two forces in play: Lift and Drag. The Lift Force is perpendicular to the wind direction. It is caused by a pressure difference between the air on either side of the blade. The Drag Force is in the same direction as the wind. The ratio between lift and drag largely depends on the shape of the blade and the angle of the main line of the blade (chord line) and the main wind direction - the angle of attack. The lift force is largest for streamlined.

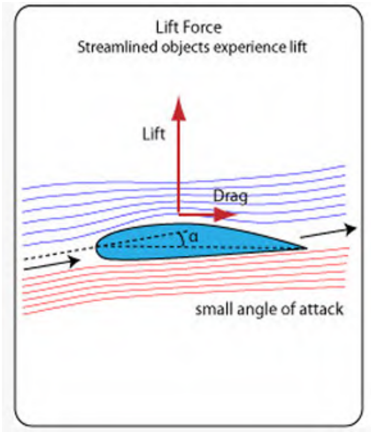


**Figure17.** Lift Force

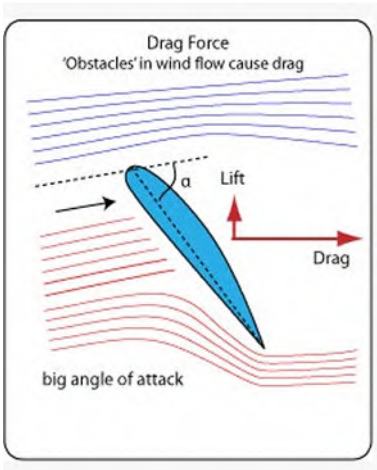


**Figure 18.** Draft Force

## 2.4. Wind Characteristics

As the wind power is proportional to the cubic wind speed, it is crucial to have detailed knowledge of the site-specific wind characteristics. Even small errors in estimation of wind speed can have large effects on the energy yield, but also lead to poor choices for turbine and site. An average wind speed is not sufficient. Site-specific wind characteristics pertinent to wind turbines include:

- Mean wind speed: Only interesting as a headline figure, but does not tell how often high

wind speeds ocur

- Wind speed distribution : diurnal, seasonal, annual patterns
- Turbulence: short-term fluctuations
- Long-term fluctuations
- Distribution of wind direction
- Wind shear (profile)

We are providing information on those dimensions and tools for basic yield calculations. However, due to the sensitivities, no calculation can replace on-site wind measuring campaigns

### 2.4.1.Wind Speed Patterns

Wind speed patterns can be depicted as a wind speed spectrum. A high value indicates a significant change in wind speed over the corresponding time period. Although this graph is obviously site-specific, there are distinctive similarities. A typical graph is shown on the right.

The peaks in the wind speed spectrum account for annual, seasonal and daily patterns as well as short-term turbulences. A striking phenomenon is the spectral gap between time periods of 10 minutes to 2 hours.

These patterns are important not only for yield estimations, but also for forecasting of wind power output.

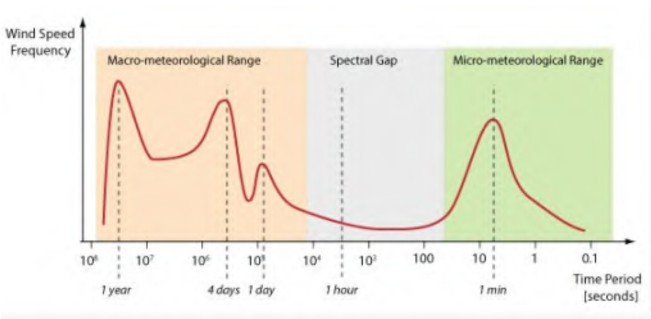


**Figure 19.** Wind Speed Frequency

#### 2.4.1.1. Micro-meteorological Range: Turbulence:

One of the main characteristics of wind its high temporal variations. Wind speeds can double or triple within seconds, meaning power increased 8 or 27 times! Turbulence intensity increases with obstacles such as buildings, tress or steep mountain tops. Sites with high average wind speeds tend to suffer less from turbulence.

## 2.5. Computational fluid dynamics (CFD)

There are many commercial CFD softwares used in engineering, such as PHOENICS (it is the first commercial CFD software), STAR-CD, ANSYS FLUENT/CFX and so on. All CFD softwares have three main structures which are Pre-Processer, Solver and Post Processor.

### 2.5.1. The principle theories relevant to CFD modelling

No matter what kind of CFD software is, the main processes of simulation are the same. Setting up governing equations is the precondition of CFD modelling; mass, momentum and energy conservation equation are the three basis governing equations. After that, Boundary conditions are decided as different flow conditions and a mesh is created. The purpose of meshing model is discretized equations and boundary conditions into a single grid. A cell is the basic element in structured and unstructured grid. The basic elements of two-dimensional unstructured grid are triangular and quadrilateral cell. Meanwhile, the rectangular cell is commonly used in structured grid. In three-dimensional simulation, tetrahedra and pentahedra cells are commonly used unstructured grid and hexahedra cell is used in structured grids. The mesh quality is a prerequisite for obtaining the reasonably physical solutions and it is a function of the skill of the simulation engineer. The more nodes resident in the mesh, the greater the computational time to solve the aerodynamic problem concerned, therefore creating an efficient mesh is indispensable. Three numerical methods can be used to discretize equations which are Finite Different Method (FDM), Finite Element Method (FEM) and Finite Volume Method (FVM). FVM is widely used in CFD software such as Fluent, CFX, PHOENICS and STAR-CD, to name just a few. Compared with FDM, the advantages of the FVM and FEM are that they are easily formulated to allow for unstructured meshes and have a great flexibility so that can apply to a variety of geometries.

### 2.5.2.Solutions methods

- Standard $k-\varepsilon$ model: it has a nice stability and precision for high Reynolds number turbulent flow but it is not suitable for some simulation with rotational effect.

- RNG k−ε model: it can used for low Reynolds number flow, as considering the rotational effect, the simulated accuracy will be enhanced in rapidly strain flow.

- Realizable k−ε model: it is more accurate for predicting the speeding rate of both planar and round jets but it will produces non-physical turbulent viscosities when the simulated model includes both rotating and stationary fluid zone (Fluent 6.3 User‟s Guide 12.4, 2006).

- Standard k-ω model: it contains the low-Reynolds-number effects, compressibility and shear flow spreading. It has a good agreement with measurements with problems of far wake, mixing layers and plane, round, and radial jets.

- Shear-stress transport (SST) k-ω model: because it absorbs both the property of good accuracy in the near-wall region of standard k-ω model and nice precision in the far field region of k−ε model (Fluent 6.3 User‟s Guide 12.5, 2006)

# 3. Cases

We have 2 cases ; Case 1 & Case 2. Case 1 is consist of building and wind turbine. Case 2 is consist of only wind turbine.

## 3.1. Case 1

Case 1 includes wind turbine and building. So 3 plane is used for calculating pressure and velocity. In the analysis of this case the operating conditions of them are:

- Operating pressure: 101325 Pa = 1atm
- Velocity inlet: 16 m/s

**Boundary conditions:**

- Top : OUTLET
- Bottom: WALL
- İnlet: VELOCITY_INLET
- Outlet: PRESSURE_OUTLET
- Blades: WALL
- Building: WALL

**Continuum conditions:**

- Airflow: FLUID

### 3.1.1. Plane 1

We put into plane 1 at the middle of hub.

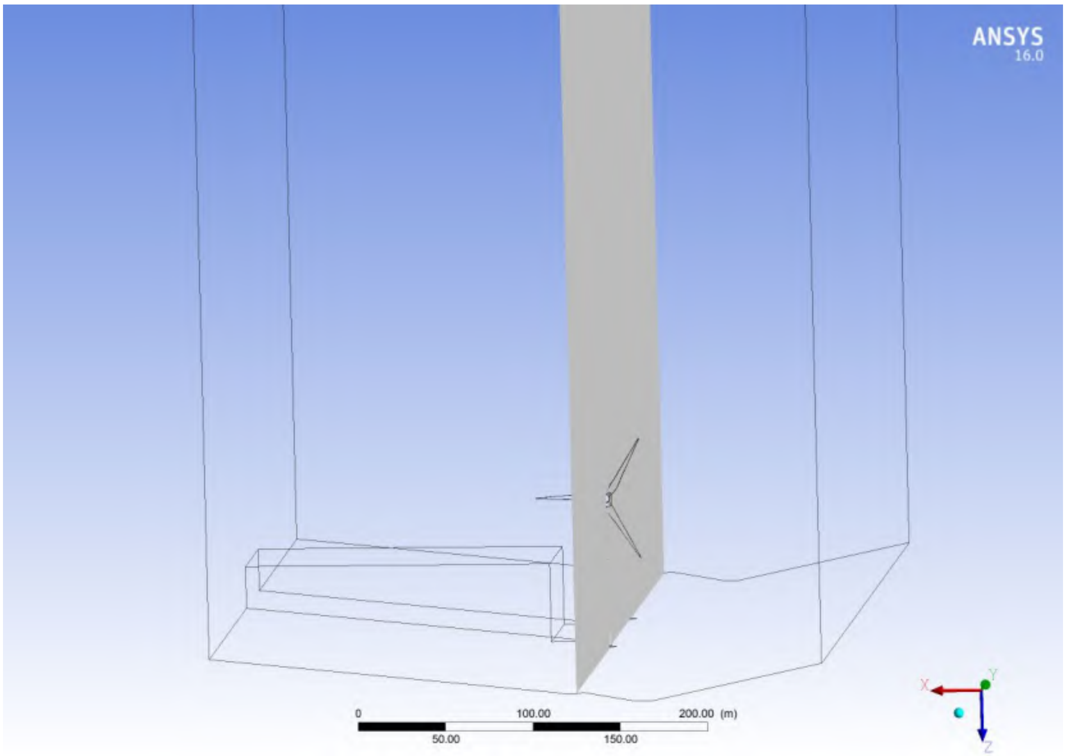


**Figure 20.** Case-1 Plane 1

#### 3.1.1.1. Plane 1's Results

Pressure and velocity are calculated by using CFD programme.

**Pressure**

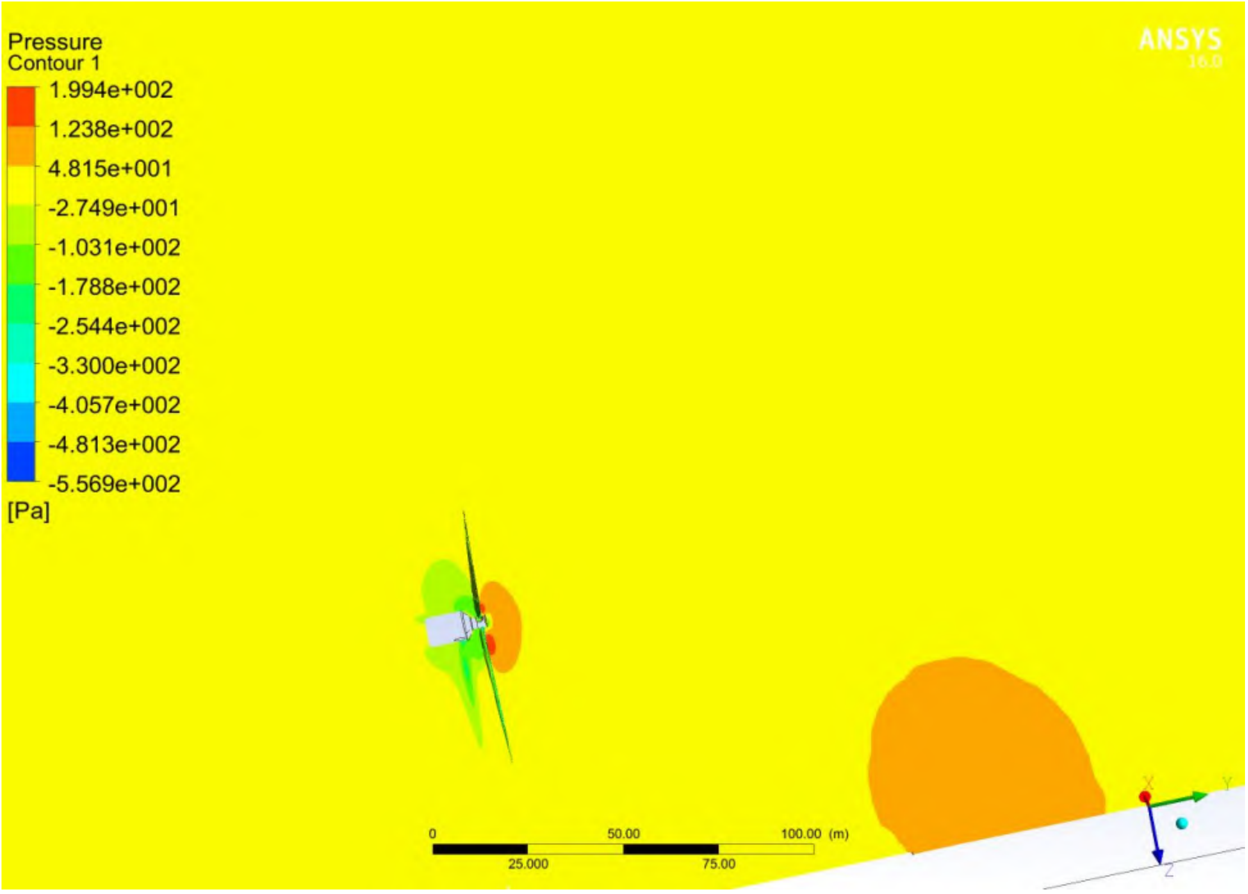


**Figure 21.** Case-1 Plane 1 Pressure

We measured at pressure of plane 1 by affecting to wind turbine. Moreover the pressure are the greatest values on red regions of wind turbine. The red regions are stagnation regions.

A point in the field a flow about a body where the fluid particles have zero velocity with respect to the body. In fluid mechanics a stagnation point is a point in a flow field where the local velocity of the fluid is zero. Stagnation points exist at the surface of objects in the flow field, where the fluid is brought to rest by the object. The Bernoulli's equation shows that the static pressure is highest when the velocity is zero and hence static pressure is at its maximum value at stagnation points. This static pressure is called the stagnation pressure. And maximum pressure 199.4 Pa.

**Velocity**

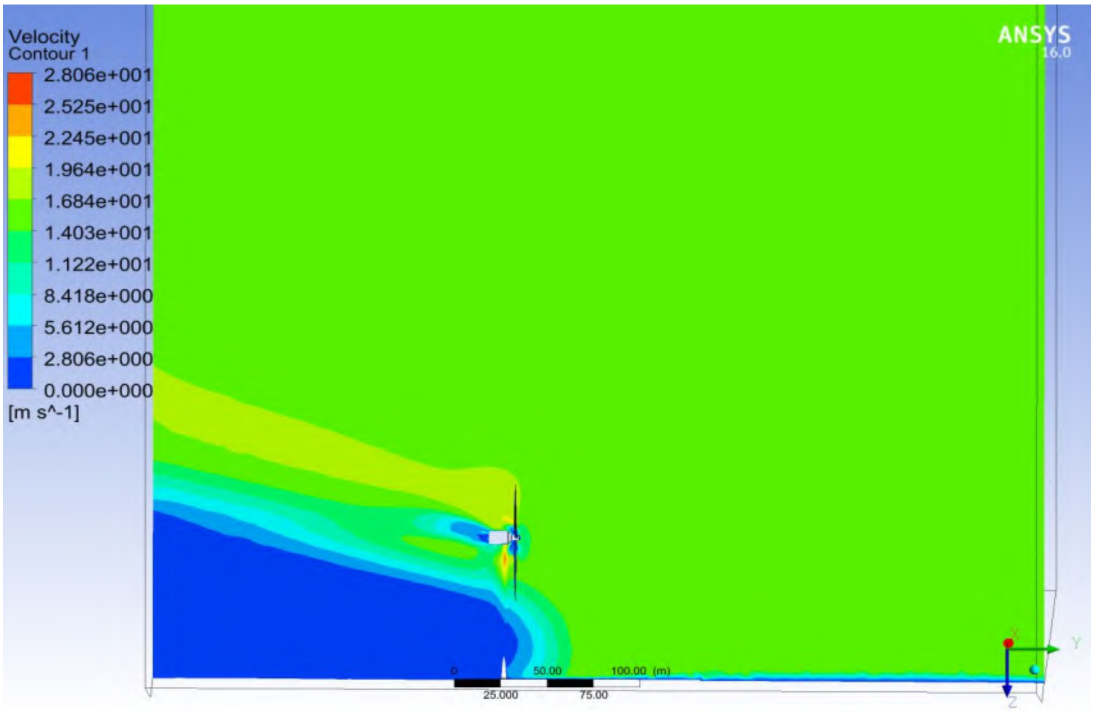


**Figure 22. Case-1 Plane 1 Velocity**

Velocity is zero in blue regions because of boundary layer. A boundary layer is a layer of viscous fluid closed to the solid surface of a wall in a contact moving air in which the flow velocity varies form zero at the wall up to a boundary, which approximately corresponds to the free air velocity. And average velocity is 16.8 m/s(green regions).

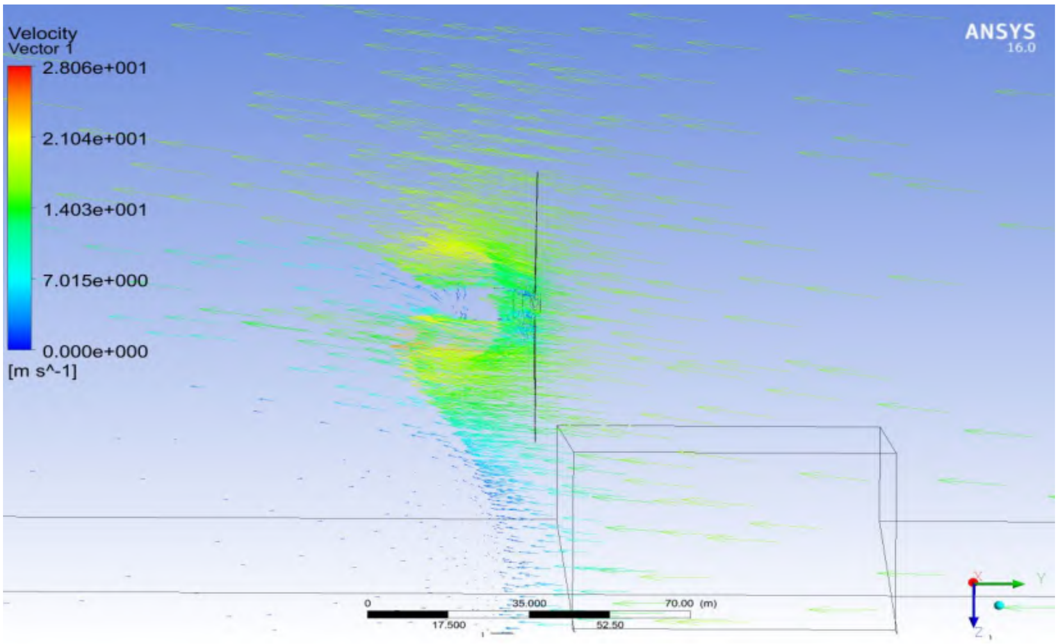


**Figure 23.** Case-1 Plane 1 Velocity Vector

The figure 25 shows the velocity distribution. Also the wake effect occurs behind the hub. This effect occurs between convercial upwind and downwind turbines. Upwind turbines create wind waker that impact the natural wind flow to adjacent downwind turbines, causing the downwind turbines to experience diminished energyproduction and, in some cases, increased mechanical loads. For wind turbines, wake effect relates to the wind speed deficit and diminished energy content wind possesses after leaving a particular utility-scale wind turbine.

### 3.1.2. Plane 2

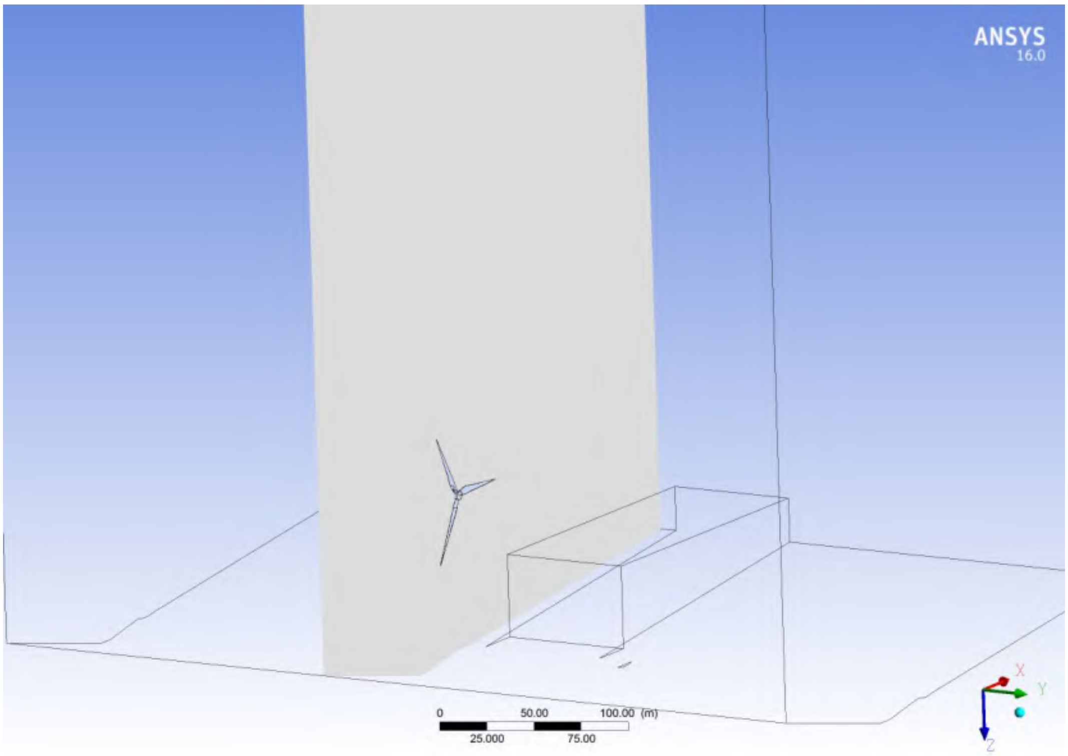


**Figure 24.** Case-1 Plane 2

We put into plane 2 at the middle of blades.

#### 3.1.2.1. Plane 2's Results

Pressure and velocity are calculated by using CFD programme.

**Pressure**

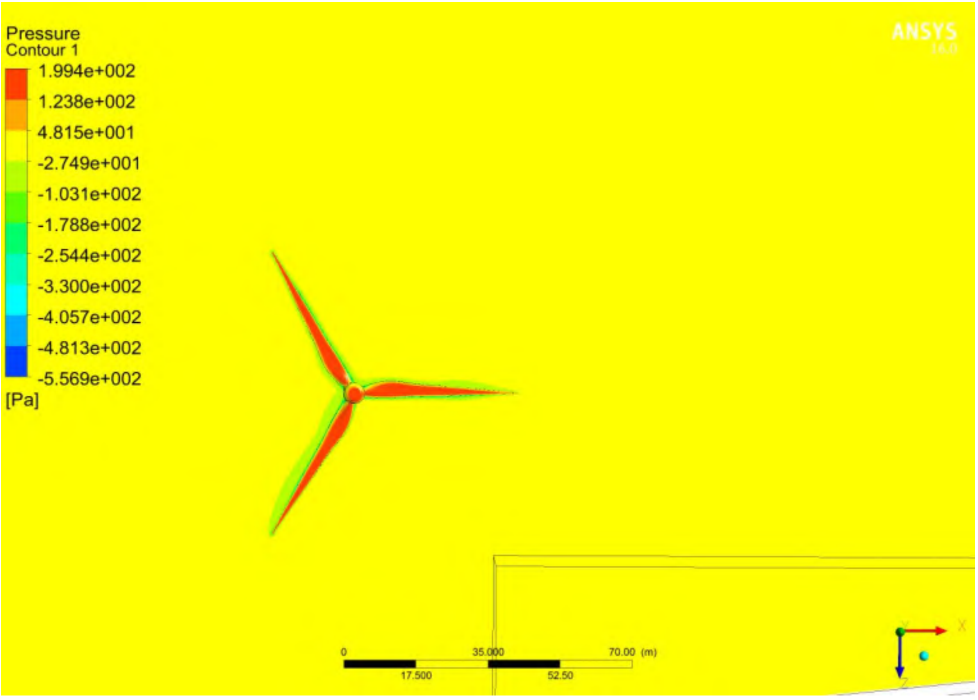


**Figure 25.** Case-1 Plane 2 Pressure

We measured at pressure of plane 2 by affecting to wind turbine. Moreover the pressure are the greatest values on red regions of wind turbine. Red regions show the stagnation pressure because of stagnation point. Stagnation pressure is 199.4 Pa on blades and hub.

## Velocity

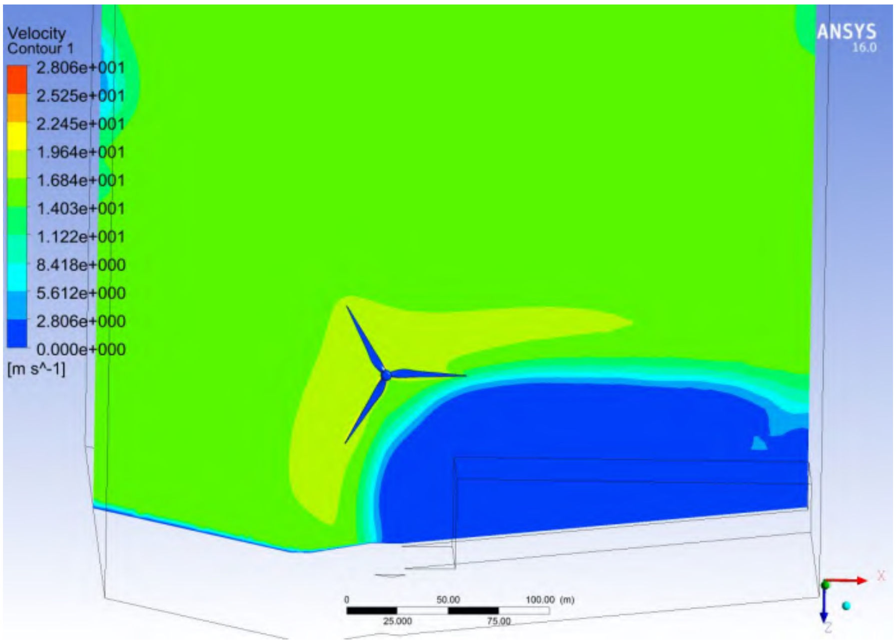


**Figure 26.** Case-1 Plane 2 Velocity

The velocity on the building is zero in the blue areas because of boundary layer.The velocity on the turbine is also zero because of the stagnation areas.

### 3.1.3. Plane 3

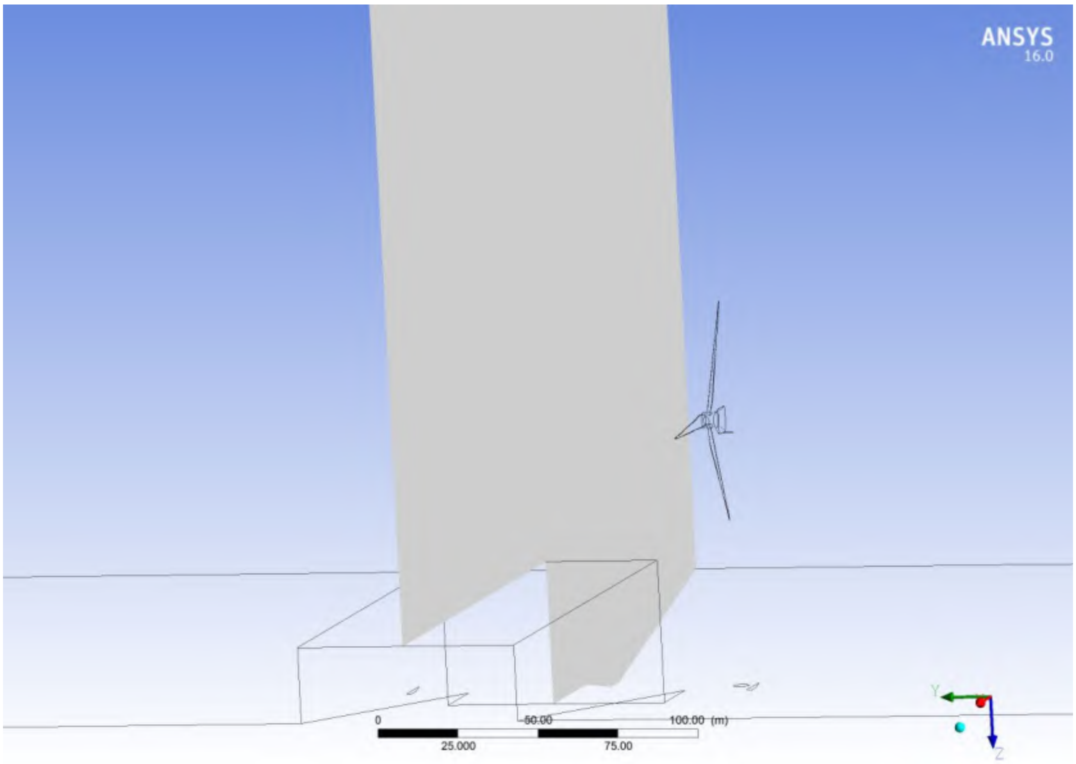


**Figure 27.** Case-1 Plane 3

We put into plane 3 at the middle of factory.

#### 3.1.3.1. Plane 3's Results

Pressure and velocity are calculated by using CFD programme.

**Presssure**

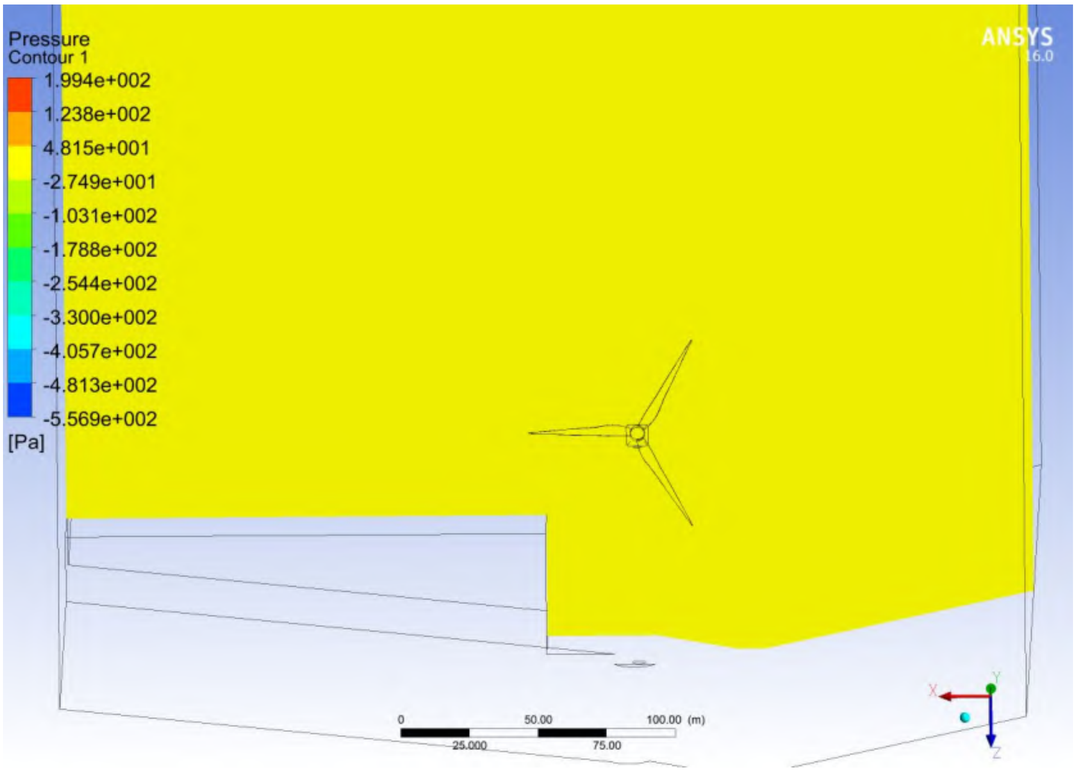


**Figure 28.** Case-1 Plane 3 Pressure

We measured at pressure of plane 3 by affecting to wind turbine.Plane 3 is in front of the wind turbine. Therefore pressure is same all areas and pressure is equal to atmospheric pressure.

## Velocity

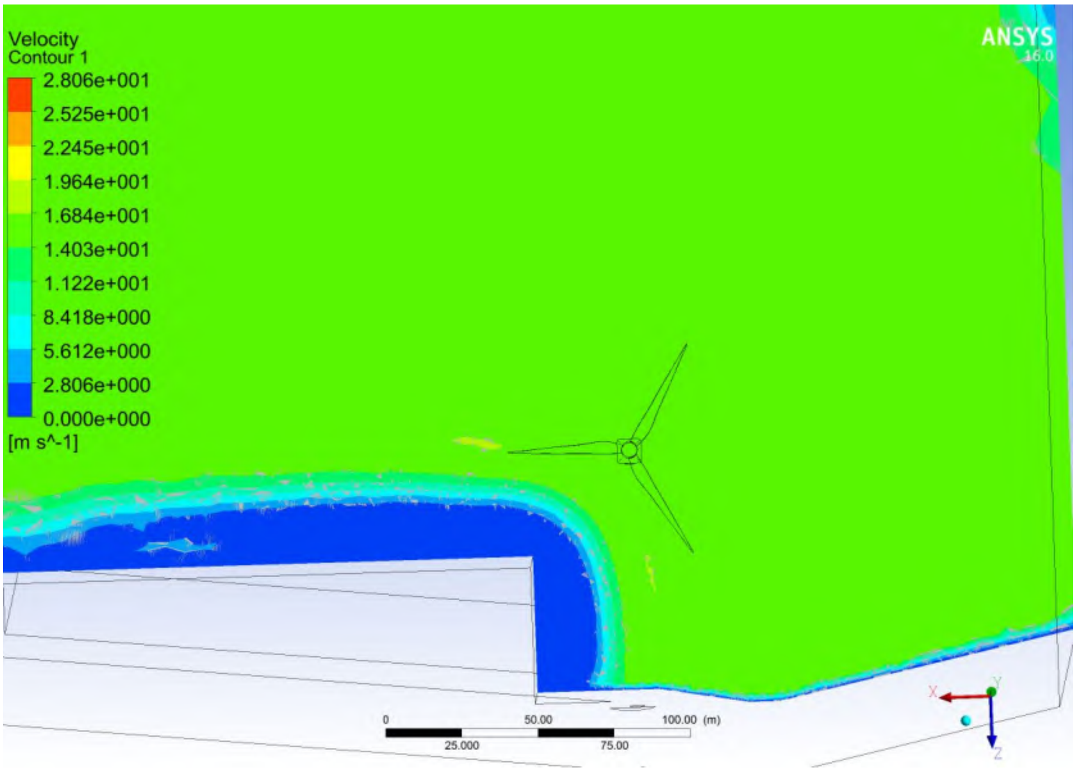


**Figure 29.** Case-1 Plane 3 Velocity

The velocity is zero in the blue areas because of boundary layer. Also no-slip condition is exist on the building surface. Additionally in fluid dynamics, the no-slip condition for viscous fluids states that at a solid boundary, the fluid will have zero velocity relative to the boundary.

**Streamline**

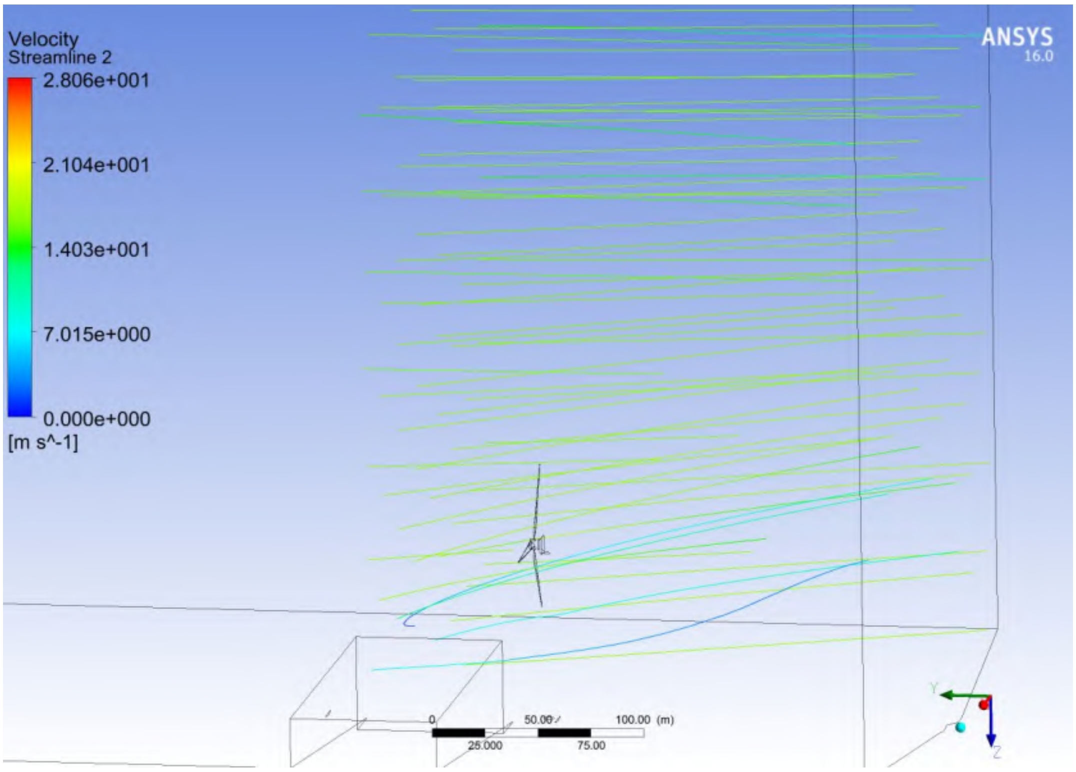


**Figure 30.** Case-1 Plane 3 Streamline

The streamlines in this plot group show the instantaneous fluid velocity as wind flows toward, through, and away from the factory and wind turbine.

**Drag & Lift Coefficients of Case 1**

The results of the drag&lift coefficients of Case 1 obtained iterating in Fluent are the pictures shown below:

**CD**

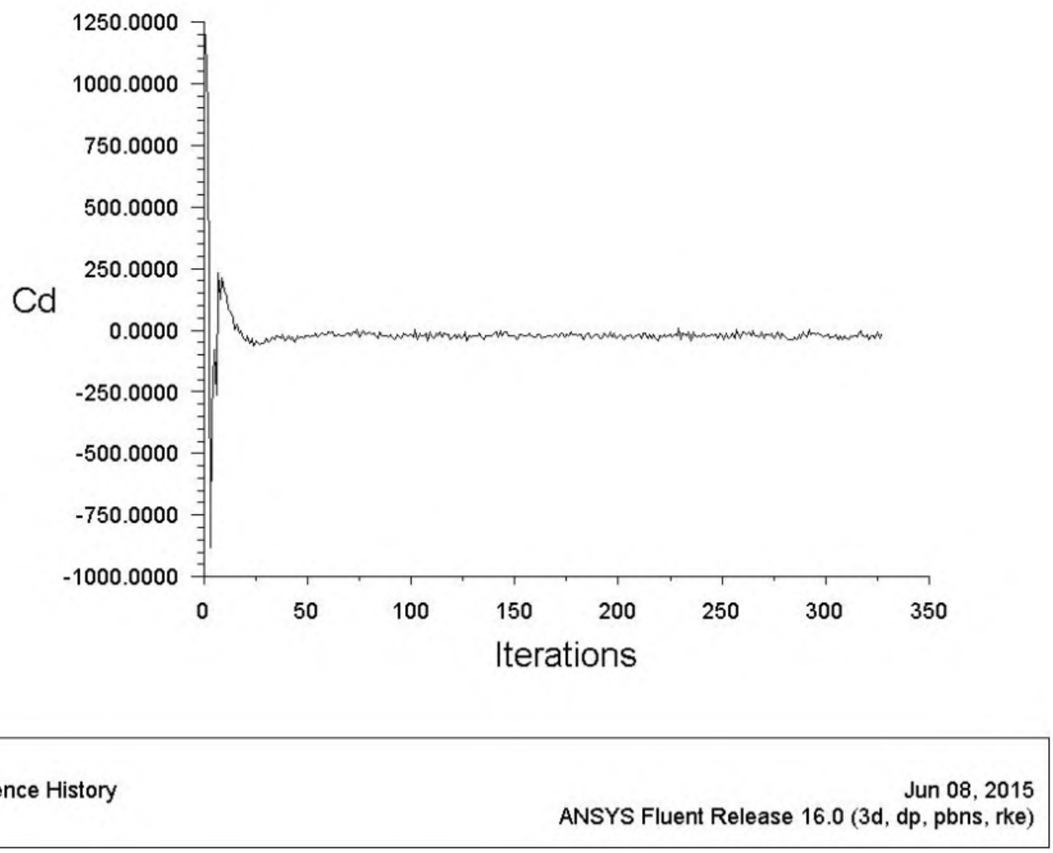


**Figure 31.** CD

This figure shows variation of drag coefficients with iterations. Drag is a force that acts parallel and in the same direction as the airflow. Coefficient of drag is proportional to the drag force which act on the body immersed in the fluid; namely, less drag coefficient indicate less drag force.

**CL**

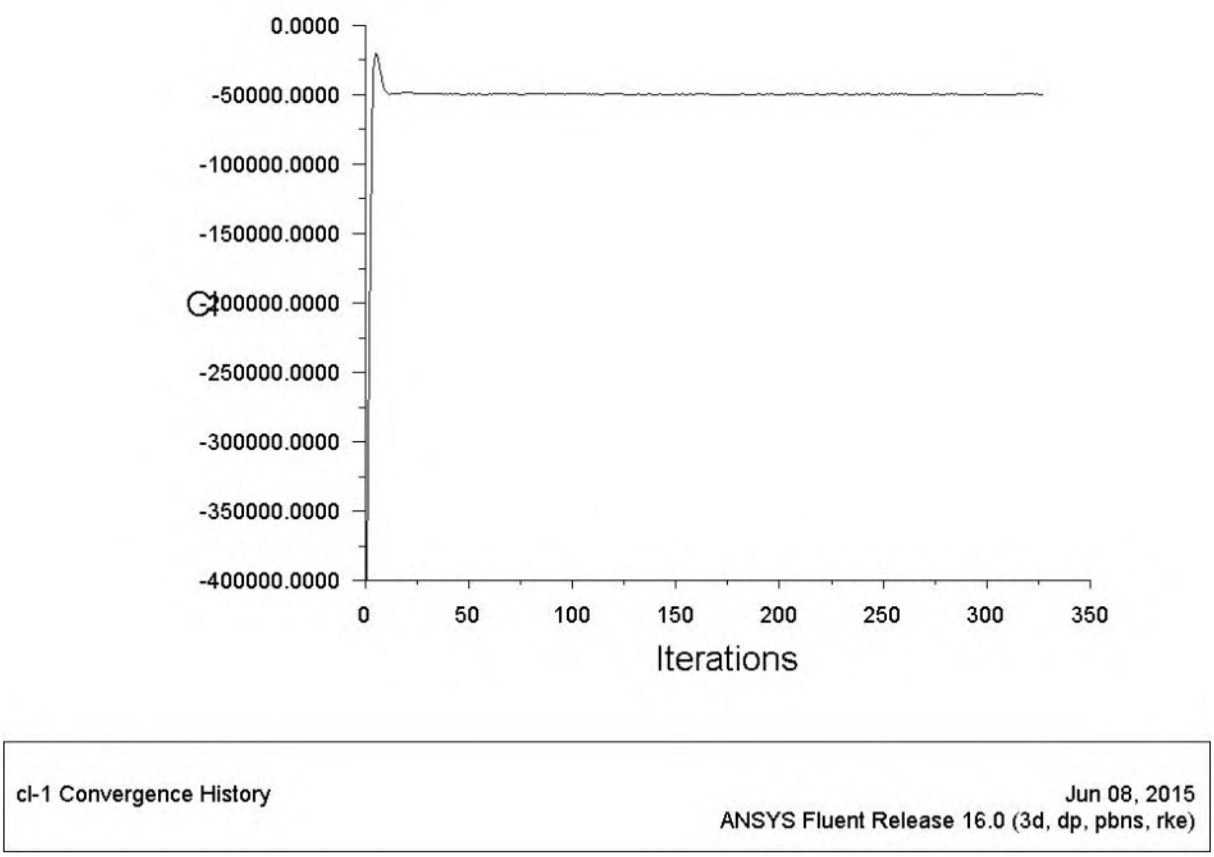


**Figure 32.** CL

This figure shows variation of lift coefficients with iterations. Lift is the force generated perpendicular to the direction of travel for an object moving through a fluid (gas or liquid). Coefficient of lift is proportional to the lift force.

## 3.2.CASE 2

Case 2 includes only wind turbine. So 2 plane is used for calculating pressure and velocity. In the analysis of this case the operating conditions of them are:

- Operating pressure : 101325 Pa = 1atm
- Velocity inlet : 16 m/s

**Boundary conditions:**

- Top : OUTLET
- Bottom: WALL
- İnlet: VELOCITY_INLET
- Outlet: PRESSURE_OUTLET
- Blades: WALL
- Building: WALL

**Continuum conditions:**

- Airflow: FLUID

### 3.2.1.Plane 1

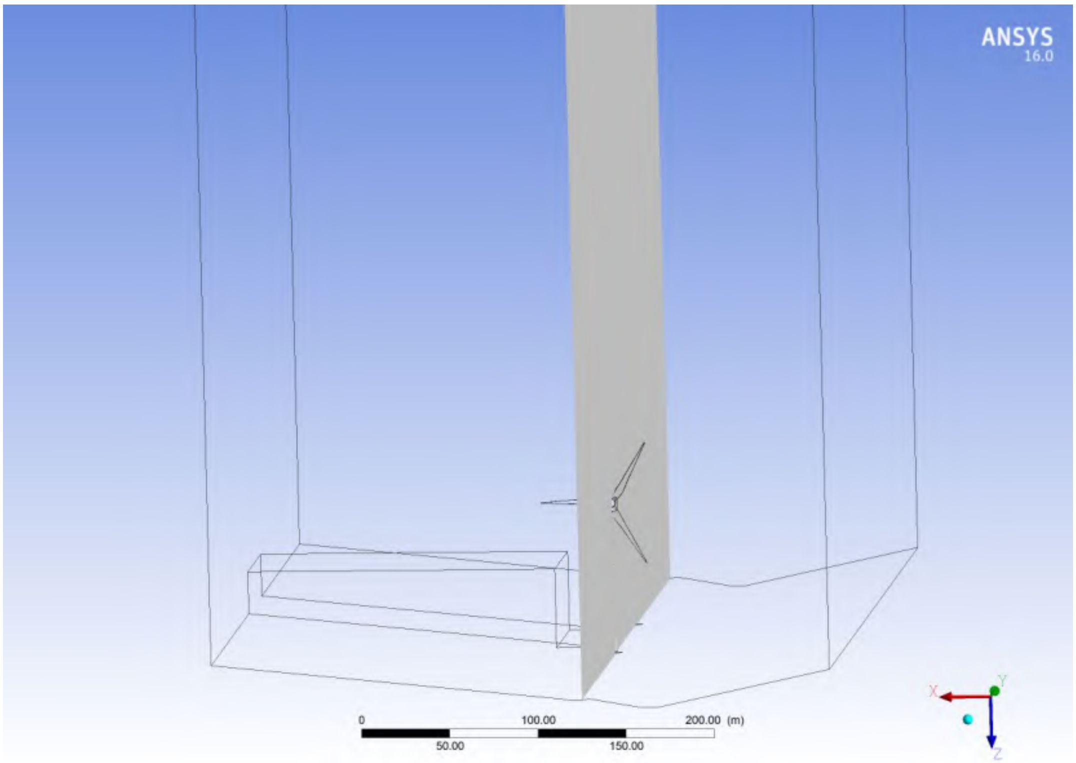


**Figure 33.** Case-2 Plane 1

We put into plane 1 at the middle of hub for case 2.

#### 3.2.1.1. Plane 1's Results

Pressure and velocity are calculated by using CFD programme.

**Pressure**

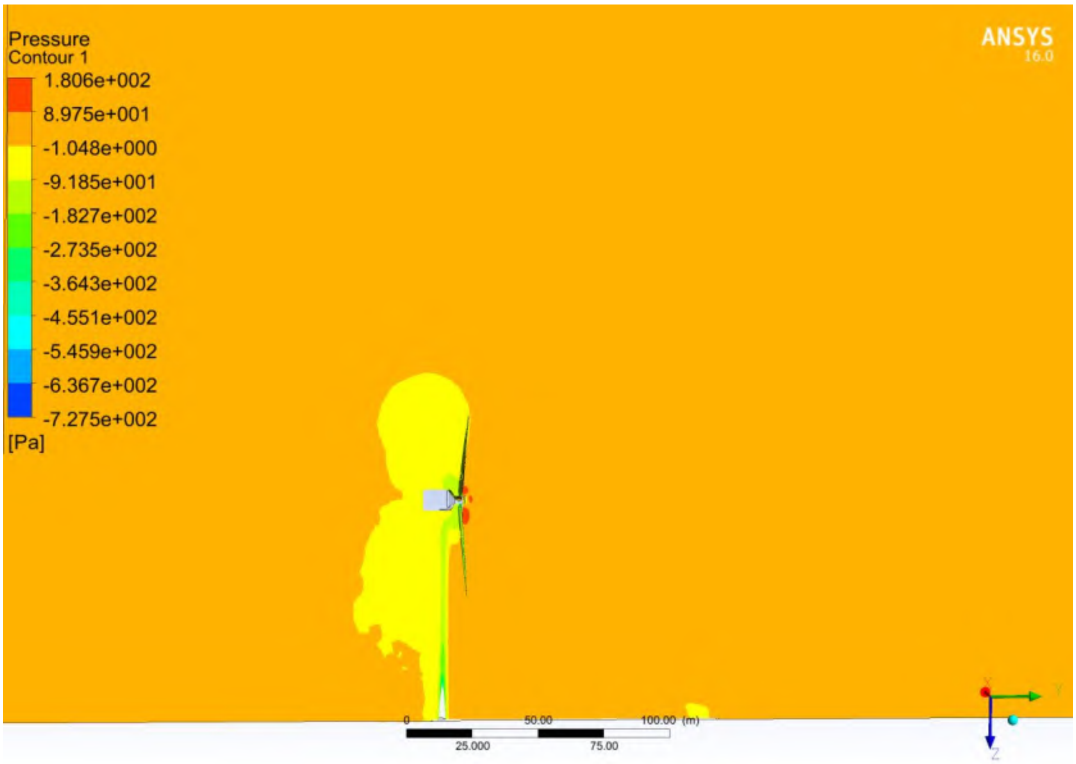


**Figure 34.** Case-2 Plane 1 Pressure

We measured at pressure of plane 1 by affecting to wind turbine. The maximum pressure is on the red regions because this regions are stagnation points. And the stagnation pressure is 180.6 Pa.

**Velocity**

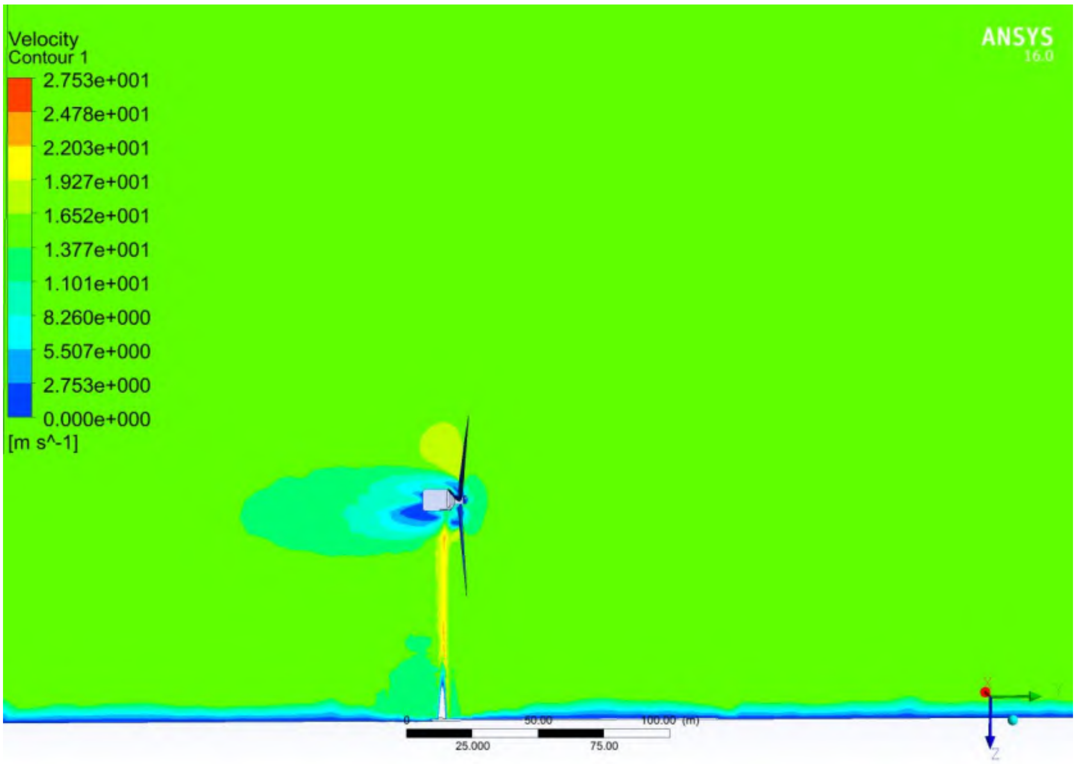


**Figure 35.** Case-2 Plane 1 Velocity

The hub and the blades are stagnation points.Therefore velocity is zero on these areas. And average velocity is 16.5 m/s. The velocity of ground is also zero because of no slip condition.

**Streamline**

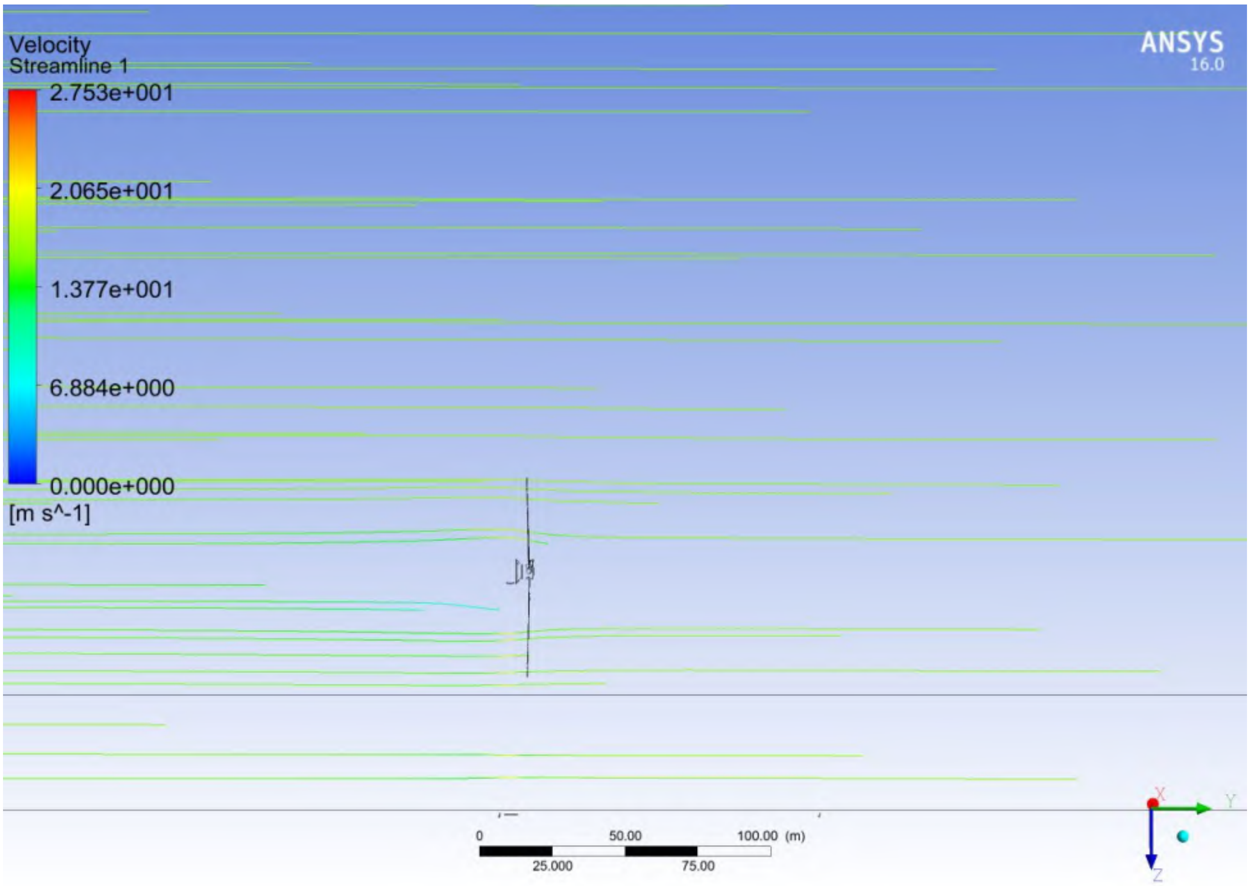


**Figure 36.** Case-2 Plane 1 Streamline

The streamlines in this plot group show the instantaneous fluid velocity as wind flows toward, through, and away from wind turbine. Also the velocity is zero behind the hub because of wake effect.

### 3.2.2.Plane 2

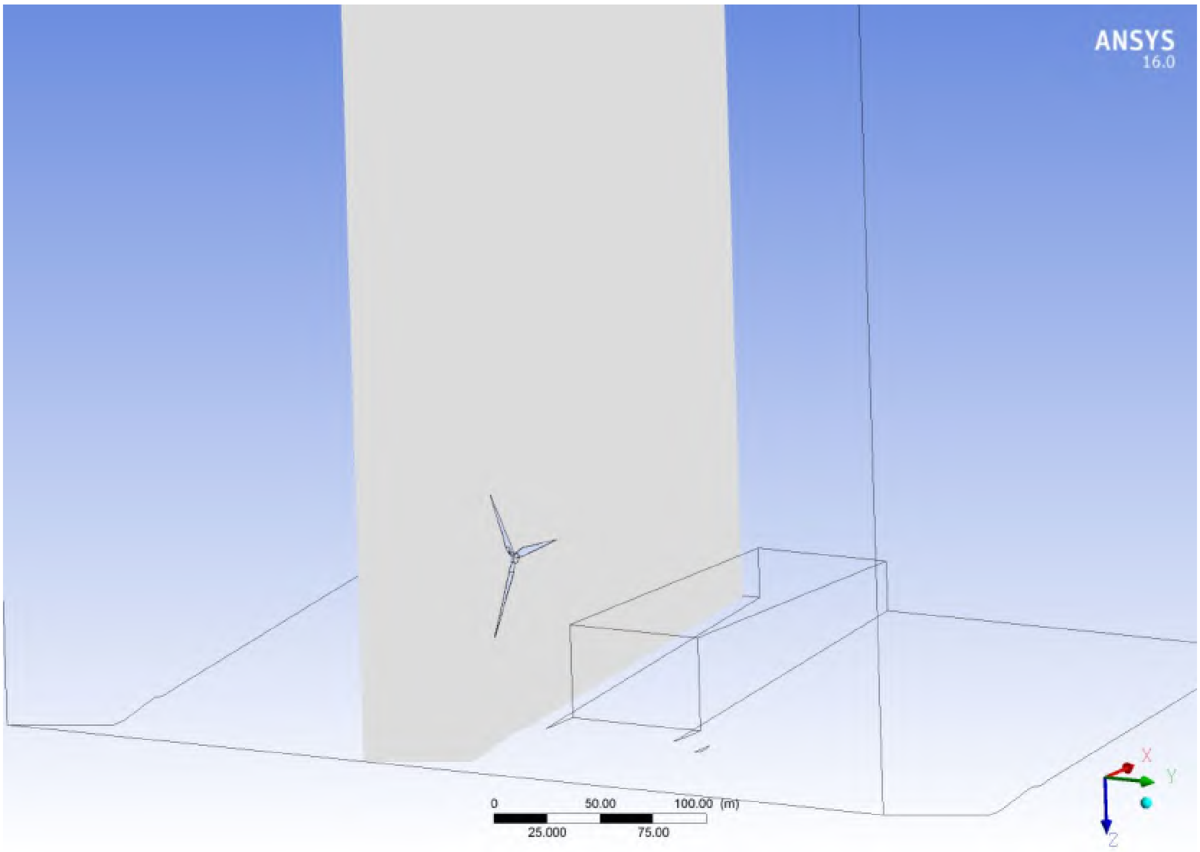


**Figure 37.** Case-2 Plane 2

We put into plane 1 at the middle of blades for case 2.

### 3.2.2.1.Plane 2's Results

Pressure and velocity are calculated by using CFD programme.

**Pressure**

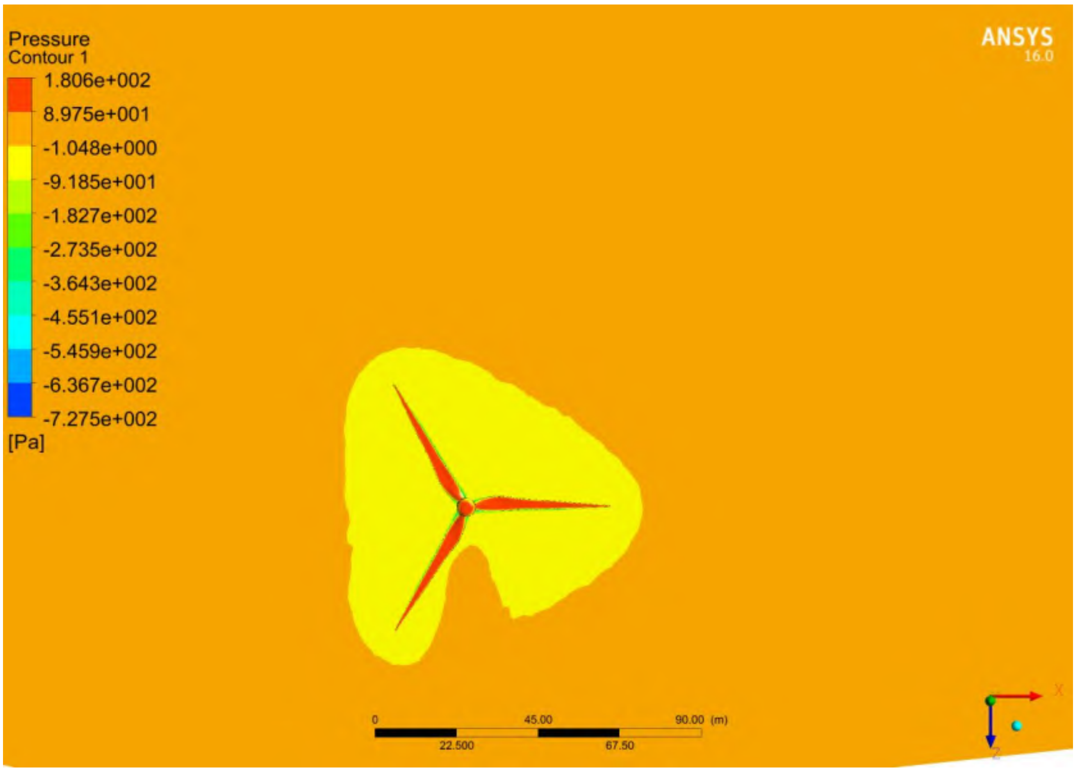


**Figure 38.** Case-2 Plane 2 Pressure

We measured at pressure of plane 2 by affecting to wind turbine. Furthermore the pressure are the greatest values on red regions of wind turbine. The maximum pressure is on the red regions because of stagnation points.And the maximum pressure is 180.6 Pa in these regions.

### Velocity

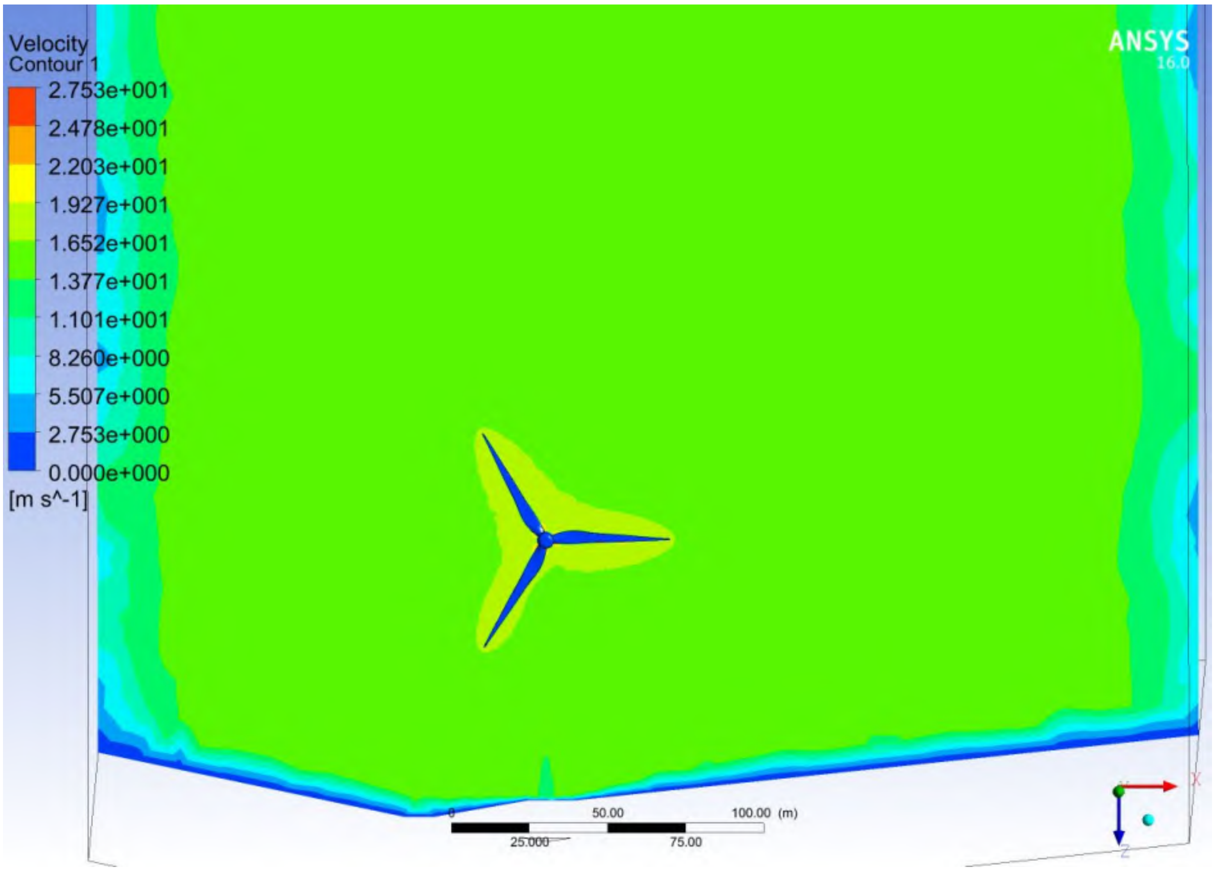


**Figure 39.** Case-2 Plane 2 Velocity

The velocity is zero on the blades and hub. Because these areas are stagnation areas. And the ground velocity is also zero because of no slip condition.

**Drag & Lift Coefficients of Case 2**

The results of the drag&lift coefficients of Case 2 obtained iterating in Fluent are the pictures shown below:

**CD**

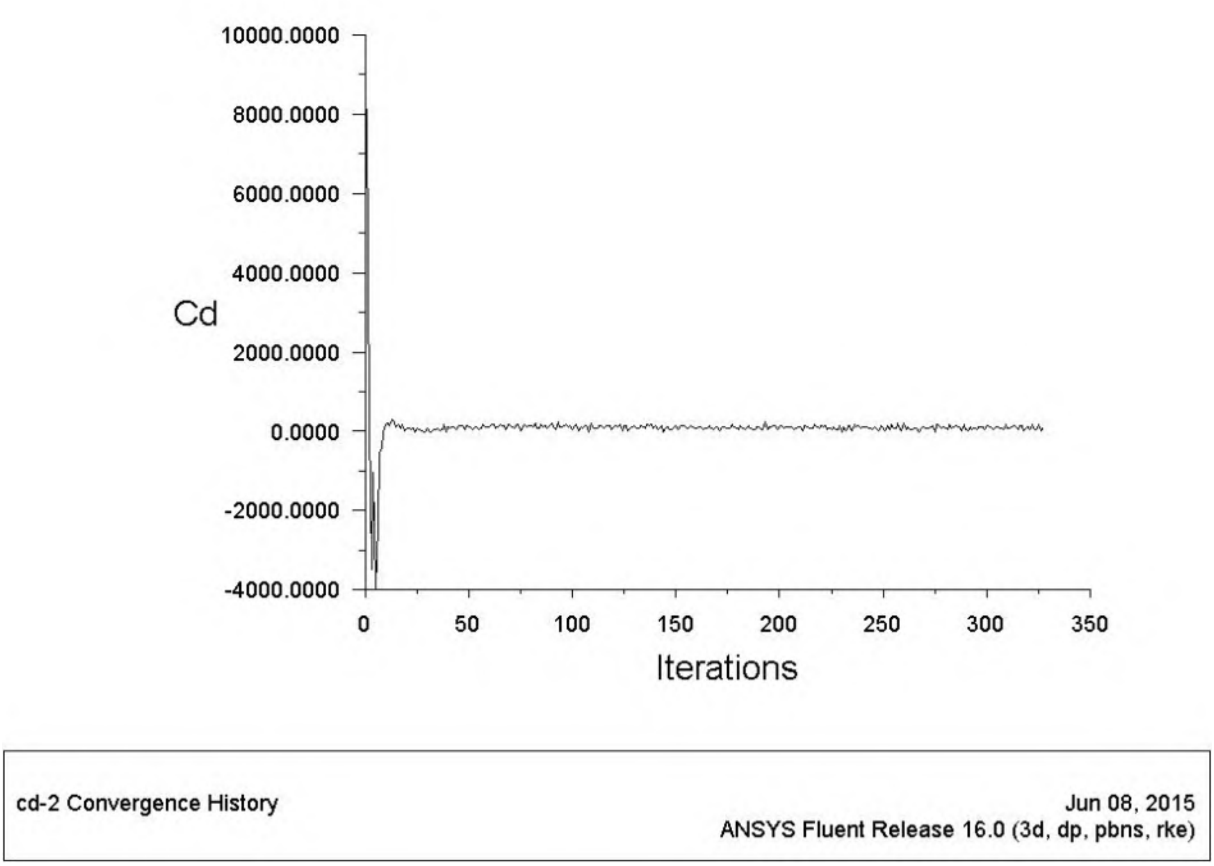


**Figure 40.** CD

**CL**

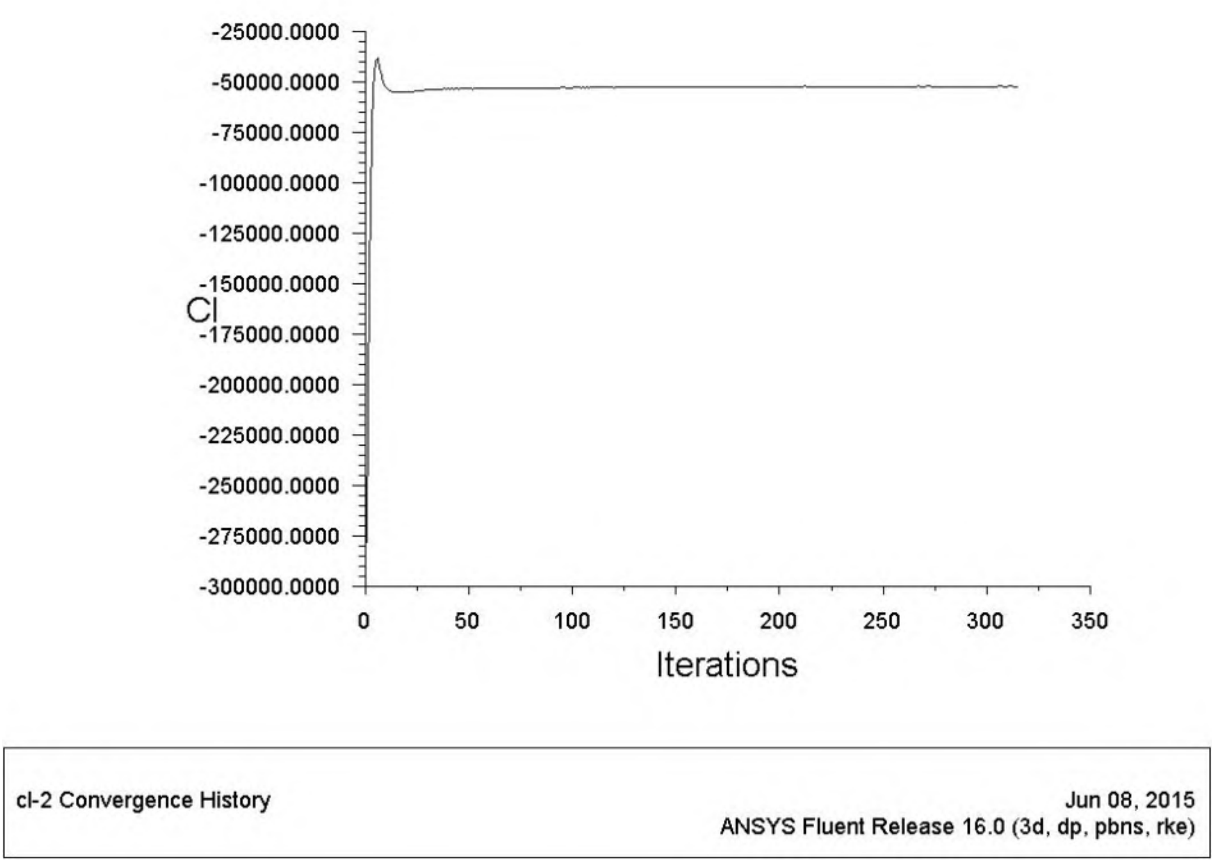


**Figure 41.** CL

## DISCUSSION OF CASES

The Cases results is not reliable.Because continuity is not supplied for these cases.Besides lift and drag coefficients are proportionality constants that enable the calculation of aerodynamic forces.

# 4. Conclusion

Based on the research work, the aims and objections of the research project have not been achieved because residual continuity error is too high, more than $10^{-4}$. The significant findings are summarized below.

1. Velocity results of analysis is higher than expected velocity results. There are several reasons for this situation. These are probably boundary conditions, selected turbulence model and mesh quality. In this analysis boundary conditions are constant. Therefore we consider selected turbulence model and mesh quality. Firstly, all turbulence models were tested on the geometic model but the results do not change. Furthermore analysis model does not based on selected turbulence model. Secondly, we considered the mesh quality. All mesh types were tested on geometric model but ANSYS is used automatic pattern for meshing. Therefore we can not fix the mesh. By the way these types of automatic meshes can not give correct solution. In conclusion; a better mesh quality guarantees a more accurate solution. For improving the mesh quality for accurate solution, one may need to refine the mesh at certain areas of the geometry where the gradients of the field whose solution is sought is high. Also this means that, if a mesh is not sufficiently refined, the accuracy of the solution is more limited. Thus the required accuracy in turn dictates the mesh quality.

2. When the cases were compared with each other, Case 1's velocity is higher than the Case 2's velocity. Because Case 1's area is smaller than the Case 2's area. This comparison is based on the unreliable results

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