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A thesis submitted to the Department of Electrical and Electronic Engineering (EEE), Islamic University of Technology (IUT), in the fulfillment of the requirement for a BSc in Electrical Engineering.

Prepared By:

Mohamed Abdullahi (160021168)

Mohamed Ali (170021162)

Eid Ali (170021157)

Abdikhayr Mohamed (170021177)

Supervised By: Asif Newaz

(Lecturer, EEE department)

Department of Electrical and Electronic Engineering

Islamic University of Technology

BOARD BAZAR, GAZIPUR-1704, BANGLADESH
Tel : 9291250, 9291252 PABX : 9291254-59 Fax : 880-2-9291260 e-mail : vc@iut-dhaka.edu website : www.iutoic-dhaka.edu

CERTIFICATE OF RESEARCH:

The thesis title submitted by Mohamed Abdullahi (160021168), Mohamed Ali(170021162), Eid Ali (170021157), Abdikhayr Mohamed (170021177).

“Generation of electricity using wind turbine at IUT campus”, has been accepted as satisfactory in fulfillment of the requirement for BSc in Electrical Engineering.

Signature of the Supervisor

Mr. Asif Newaz

(Lecturer, EEE Department)

Department of Electrical and Electronic Engineering

Approved by

Prof. Dr. Mohammad Rakibul Islam

Head, Department of EEE, IUT

CANDIDAT'S DECLARATION

It is hereby declared that this thesis or

any part of it has not been submitted elsewhere for the award of any degree.

Signature of the Candidates

______________________ ______________________

Mohamed Abdullahi — **ID:160021168**

Mohamed Ali — **ID: 170021162**

______________________ ______________________

Eid Ali — **ID:170021157**

Abdikhayr Mohamed — **ID:170021177**

Signature of the Supervisor: ______________________

Mr. Asif Newaz

(Lecturer, EEE Department)

Islamic university of technology (IUT), OIC

Board Bazar, Gazipur Bangladesh.

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We seek excuse for any errors that might be in this report despite of our best effort.

CHAPTER ONE

I. <u>Background information</u>

Electricity is the set of physical phenomena associated with the presence and motion of electric charge. Although initially considered a phenomenon separate from magnetism, since the development of Maxwell's equation, both are recognized as part of a single phenomenon: electromagnetism. Various common phenomena are related to electricity, including lightning, static electricity, electric heating, electric discharges and many others.

The presence of an electric charge, which can be either positive or negative, produces an electric field. The movement of electric charges is an electric current and produces a magnetic field.

When a charge is placed in a location with a non-zero electric field, a force will act on it. The magnitude of this force is given by coulombs law. Thus, if that charge were to move, the electric field would be doing work on the electric charge. Thus we can speak of electric potential at a certain point in space, which is equal to the work done by an external agent in carrying a unit of positive charge from an arbitrarily chosen reference point to that point without any acceleration and is typically measured in volts. Electricity is at the heart of many modern technologies, being used for:

- **Electric power** where electric current is used to energize equipment;
- **Electronics** which deals with electrical circuit that involve active electrical component such as vacuum tubes, transistors, diodes and integrated circuit, and associated passive interconnection technologies.

Electrical phenomena have been studied since antiquity, though progress in theoretical understanding remained slow until the seventeenth and eighteenth centuries. Even then, practical applications for electricity were few, and it would not be until the late nineteenth century that electrical engineers were able to put it to industrial and residential use. The rapid expansion in electrical technology at this time transformed industry and society, becoming a driving force for the second industrial revolution. Electricity's extraordinary versatility means it can be put to an almost limitless set of applications which include transport, heating, lightning, communications, and computation. Electrical power is now the backbone of modern industrial society.

i. Generation and transmition

In the 6th century BC, the Greek philosopher **Thales of Miletus** experimented with amber rods and these experiments were the first studies into the production of electrical energy. While this method, now known as the triboelectric effect, can lift light objects and generate sparks, it is extremely inefficient, it was not until the invention of the voltaic pile in the eighteenth century that a viable source of electricity became available. The voltaic pile, and its modern descendant, the electrical battery, store energy chemically and make it available on demand in the form of electrical energy.[1] The battery is a versatile and very common power source which is ideally suited to many applications, but its energy storage is finite, and once discharged it must be disposed of or recharged. For large electrical demands electrical energy must be generated and transmitted continuously over conductive transmission lines.

Electrical power is usually generated by electromechanical generators driven by steam produced from fossil fuel combustion, or the heat released from nuclear reactions; or from other sources such as kinetic energy extracted from wind or flowing water. The modern steam turbine invented by **Sir Charles Parsons** in 1884 today generates about 80 percent of the electric power in the world using a variety of heat sources. Such generators bear no resemblance to Faraday's homo polar disc generator of 1831, but they still rely on his electromagnetic principle that a conductor linking a changing magnetic field induces a potential difference across its ends. The invention in the late nineteenth century of the transformer meant that electrical power could be transmitted more efficiently at a higher voltage but lower current. Efficient electrical transmission meant in turn that electricity could be generated at centralized power stations, where it benefited from economies of scale, and then be dispatched relatively long distances to where it was needed.

Since electrical energy cannot easily be stored in quantities large enough to meet demands on a national scale, at all times exactly as much must be produced as is required. This requires electricity utilities to make careful predictions of their electrical loads, and maintain constant co-ordination with their power stations. A certain amount of generation must always be held in reserve to cushion an electrical grid against inevitable disturbances and losses.

Demand for electricity grows with great rapidity as a nation modernizes and its economy develops. The United States showed a 12% increase in demand during each year of the first three decades of the twentieth century, a rate of growth that is now being experienced by emerging economies such as those of India or China. Historically, the growth rate for electricity demand has outstripped that for other forms of energy.

Throughout the years the fossil energy source become more less and environmental concerns with electricity generation have led to an increased focus on generation from renewable sources, in particular from wind, solar and hydropower. While debate can be expected to continue over the environmental impact of different means of electricity production, its final form is relatively clean. This paper will focus on the generation of electricity using wind turbine.

ii. **Early System**

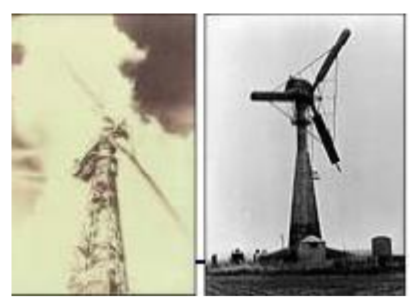
- The first Wind Energy Systems were developed in the ancient civilization in the Near East known as the Persia about 500 – 900 AD. It is of vertical-axis wind-mill with sails connected to a vertical shaft connected to a grinding stone for milling.

- In the middle ages, the Northern Europe introduced the post mill system. It is basically a horizontal-axis wind mill with sails connected to a horizontal shaft on a tower encasing gears and axles for translating horizontal into rotational motion.

- In 1888s, Charles Brush builds the first large-size wind electricity generation turbine of 17 m diameter wind rose configuration with 12 kW generator.

- In 1890s, Lewis Electric Company of New York sells generators to retro-fit onto existing wind mills.

- 1920s-1950s: Propeller-type 2 & 3 blade horizontal-axis **wind electricity conversion systems** were developed.



- 1940s – 1960s: Rural Electrification in US and Europe leads to decline in wind electricity conversion systems use.

- In this modern era the wind turbine system has the following attribute:

    - Scale increase
    - Commercialization
    - Competitiveness
    - Grid integration [1].

II. Definition and classification

A wind turbine is a device that converts the kinetic energy of the wind into mechanical energy. This mechanical energy can be used for specific tasks (such as grinding grain or pumping water) or for driving a generator that converts the mechanical energy into electricity that is supplied to the power grid or individual users.

The wind is a clean, free, and readily available renewable energy source. Each day, around the world, wind turbines are capturing the wind's power and converting it to electricity. This source of power generation plays an increasingly important role in the way we power our world

- According to the design, wind turbine is classify into two kinds:

i. Horizontal axis wind turbine

A horizontal-axis wind turbine (HAWT) is a wind turbine in which the axis of the rotor's rotation is parallel to the wind stream and the ground. All grid-connected commercial wind turbines today are built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). Most horizontal axis turbines built today are two- or three-bladed, although some have fewer or more blades. The purpose of the rotor is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. The same basic principle is used in a modern water turbine, where the flow of water is parallel to the rotational axis of the turbine blades.

The wind passes over both surfaces of the airfoil shaped blade but passes more rapidly over the longer (upper) side of the airfoil, thus creating a lower-pressure area above the airfoil. The pressure differential between top and bottom surfaces results in aerodynamic lift. In an aircraft wing, this force causes the airfoil to rise, lifting the aircraft off the ground. Since the blades of a wind turbine are constrained to move in a plane with the hub as its center, the lift force causes rotation about the hub. In addition to the lift force, a drag force perpendicular to the lift force impedes rotor rotation. A prime objective in wind turbine design is for the blade to have a relatively high lift-to-drag ratio. This ratio can be varied along the length of the blade to optimize the turbine's energy output at various wind speeds. HAWTs can be subdivided into **upwind wind turbines** and **downwind wind turbines**. Compare with **vertical-axis wind turbine**.

The horizontal wind turbine, has two to three blades. This type functions best when it is directly facing the wind.

Horizontal-axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and may be pointed into or out of the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a **wind** sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator [2].

In a HAWT, the shaft is mounted horizontally, parallel to the ground. HAWTs need to constantly align themselves with the direction of the wind. This type of turbine uses a tower as a base and the components are at an optimum elevation for wind speed. As such, each tower takes up very little space since almost all of the components are up in the air. Most large modern wind turbines are horizontal-axis turbines.

Fig.1: Horizontal wind turbine [2].

ii. Vertical wind turbine

The Vertical Axis Wind Turbine is the most popular of the turbines that people are adding to make their home a source of renewable energy. While it is not as commonly used as the Horizontal Axis Wind Turbine, they are great for placement at residential locations and more.

In vertical axis turbines the shaft the blades are connected to is vertical to the ground. All of the main components are close to the ground. Also, the wind turbine itself is near the ground, unlike horizontal where everything is on a tower. There are two types of vertical axis wind turbines; lift based and drag based. Lift based designs are generally much more efficient than drag, or ‘paddle’ designs [3].

In a VAWT, the shaft is mounted on a vertical axis perpendicular to the ground – like an eggbeater. VAWT’s are always aligned with the winds; as such adjustment is not necessary when the wind direction changes. Some of the disadvantages of the VAWT are that it cannot start moving by itself, it needs a boost from its electrical system to get started. Also, instead of a tower, it typically uses guy wires for support, so rotor elevation is lower. Lower elevation means slower wind due to ground interference, which contributes to lower efficiency. All equipment is at ground level for easy installation and servicing; but that means a larger footprint for the turbine, which is a big negative in farming areas. This design is rarely used in large wind farms.

Figure 2: Vertical axis wind turbine (lift type) [3]

- According to the size, wind turbine is classify into five category:

i. **Ultra large wind turbine**: are the wind turbine where the power generated exceed 10 MW.

ii. **Large wind turbine:** are the wind turbine where the power generated is up to 10 MW.

iii. **Medium wind turbine:** when the power generated is in between 1 MW and 100 KW the wind turbine is called medium wind turbine.

iv. **Small wind turbine:** when the wind turbine is less than 100 KW the wind turbine is called small wind turbine.

v. **Micro-wind turbine:** when the power generated is of several Kilometer then the wind turbine is called micro-wind turbine [4].

Wind Turbine Size and Power Ratings

Wind turbines are available in a variety of sizes, and therefore power ratings. The largest machine has blades that span more than the length of a football field, stands 20 building stories high, and produces enough electricity to power 1,400 homes. A small home-sized wind machine has rotors between 8 and 25 feet in diameter and stands upwards of 30 feet and can supply the power needs of an all-electric home or small business. **Utility-scale turbines** range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.

Advantages and Disadvantages of Wind-Generated Electricity:

A Renewable Non-Polluting Resource

Wind energy is a **free, renewable resource**, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of **clean, non-polluting, electricity**. Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases. According to the U.S. Department of Energy, in 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality. **Cost Issues**

Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a **higher initial investment** than fossil-fueled generators. Roughly 80% of the cost is the machinery, with the balance being site preparation and installation. If wind generating systems are compared with fossilfueled systems on a "life-cycle" cost basis (counting fuel and operating expenses for the life of the generator), however, wind costs are much more competitive with other generating technologies because there is no fuel to purchase and minimal operating expenses.

Environmental Concerns

Although wind power plants have relatively little impact on the environment compared to fossil fuel power plants, there is some concern over the **noise** produced by the rotor blades, **aesthetic (visual) impacts**, and birds and bats having been killed (**avian/bat mortality**) by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

Supply and Transport Issues

The major challenge to using wind as a source of power is that it is **intermittent** and does not always blow when electricity is needed. Wind cannot be stored (although wind-generated electricity can be stored, if batteries are used), and not all winds can be harnessed to meet the timing of electricity demands. Further, good wind sites are often located in **remote locations** far from areas of electric power demand (such as cities). Finally, wind resource development may compete with other uses for the land, and those **alternative uses** may be more highly valued than electricity generation. However, wind turbines can be located on land that is also used for grazing or even farming(b)

III. Components

A wind turbines is a system of systems. Each has a particular function and while wind turbines can vary considerably, as to height, blade length and generating capacity, they all have the same basic design. The following are the main components of a wind turbine that must be shipped.

1. **Blades:** The blades are basically the sails of the system; in their simplest form, they act as barriers to the wind (more modern blade designs go beyond the barrier method). When the wind forces the blades to move, it has transferred some of its energy to the rotor. The modern rotor blades are made of composite materials, making them light but durable. Blades are often made of fiberglass, reinforced with polyester or wood epoxy. Vacuum resin infusion is a new material which is gaining popularity among manufacturers. Most wind turbines have three blades. Blades are generally 30 to 50 meters (100 to 165 feet) long, with the most common size around 40 meters (130 feet). Blades typically represent approximately 22% of the value of a wind turbine.
2. **Rotor:** Sometimes called the hub, this is used to connect the blades to the gear box and power generation train within the nacelle.

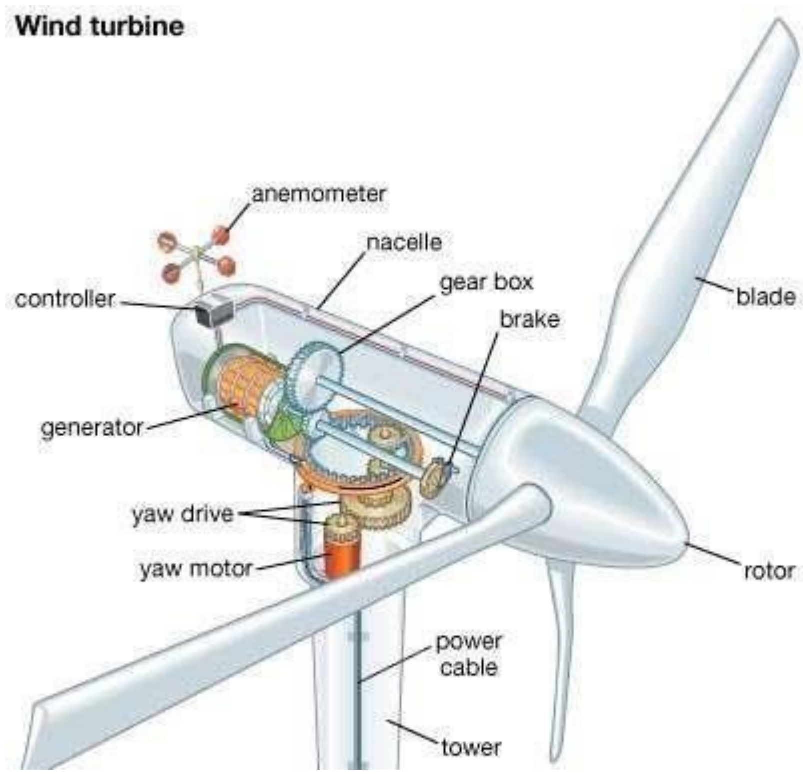


Fig.3: wind turbine components [5]

3. **Nacelle:** an enclosure which contains the electrical and mechanical components, namely the gear box, the brake, the speed and direction monitor [5].
4. **The yaw system:** is the component responsible for the orientation of the wind turbine rotor towards the wind.
   a. **Yaw bearing:** It can be of the roller or gliding type and it serves as a rotatable connection between the tower and the nacelle of the wind turbine. The yaw bearing should be able to handle very high loads, which apart from the weight of the nacelle and rotor (the weight of which is in the range of several tenths of tons) include also the bending moments caused by the rotor during the extraction of the kinetic energy of the wind [6].
   b. **Yaw drives:** Each yaw drive consists of powerful electric motor (usually AC) with its electric drive and a large gearbox, which increases the torque. The maximum static torque of the biggest

yaw drives is in the range of 200.000Nm with gearbox reduction ratios in the range of 2000:1 Consequently, the yawing of the large modern turbines is relatively slow with a 360° turn lasting several minutes.

c. **Gearbox:** Many turbines have a gearbox that increases the rotational speed of the shaft to match the required rotation speed of the generator/alternator. Some smaller turbines (under 10 KW) use direct drive generators that do not require a gearbox.

d. **Generator:** Wind turbines typically have an AC generator (housed in the nacelle) that converts the mechanical energy from the wind turbine's rotation into electrical energy. Synchronous generators require less rotational speed than asynchronous ones and thus are often operated without gearbox even in bigger wind turbines.

5. **Shaft:** The wind-turbine shaft is connected to the centre of the rotor. When the rotor spins, the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to the shaft, which enters an electrical generator on the other end.
6. **Tower:** Towers are usually tubular steel structures (about 80 m/260 feet high) which support the rotor and nacelle. It also raises the rotor high in the air where the blades are exposed to stronger winds. They consist of several sections of varying heights. The tower sits on a reinforced concrete foundation, so that it is well fixed onto the ground [7].
7. **Transformer:** The electricity generated by wind turbines must be delivered to the electrical grid. In order to do this, the voltage needs to be stepped up for energy transmission. There is usually, at least, one large transformer that is shipped with a wind turbine project and is considered a critical component especially for DSU and operational BI.

8. **Anemometer:** The measurement of wind speeds is usually done using a cup anemometer. The cup anemometer has a vertical axis and three cups which capture the wind. The number of revolutions per minute is registered electronically.

   Normally, the anemometer is fitted with a wind vane to detect the wind direction.

   Instead of cups, anemometers may be fitted with propellers, although this is not common.

   Other anemometer types include ultrasonic or laser anemometers which detect the phase shifting of sound or coherent light reflected from the air molecules. Hot wire anemometers detect the wind speed through minute temperature differences between wires placed in the wind and in the wind shade (the lee side) [8].

IV. Working principle

By definition a wind turbine is system that concerts the kinetic energy into mechanical energy which can be used directly or be converted in its turn into electrical energy. The working principle of a wind turbine can be described in accordance to the following steps:

i. Wind (moving air that contains kinetic energy) blows toward the turbine's rotor blades. ii. The rotors spin around, capturing some of the kinetic energy from the wind, and turning the central drive shaft that supports them. Although the outer edges of the rotor blades move very fast, the central axle (drive shaft) they're connected to turns quite slowly. iii. In most large modern turbines, the rotor blades can swivel on the hub at the front so they meet the wind at the best angle (or "pitch") for harvesting energy. This is called the pitch control mechanism. On big turbines, small electric motors or hydraulic rams swivel the blades back and forth under precise electronic control. On smaller turbines, the pitch control is often completely mechanical. However, many turbines have fixed rotors and no pitch control at all.

iv. Inside the nacelle (the main body of the turbine sitting on top of the tower and behind the blades), the gearbox converts the low-speed rotation of the drive shaft (perhaps, 16 revolutions per minute, rpm) into high-speed (perhaps, 1600 rpm) rotation fast enough to drive the generator efficiently.

v. The generator, immediately behind the gearbox, takes kinetic energy from the spinning drive shaft and turns it into electrical energy. Running at maximum capacity, a typical 2MW turbine generator will produce 2 million watts of power at about 700 volts.

vi. Anemometers (automatic speed measuring devices) and wind vanes on the back of the nacelle provide measurements of the wind speed and direction.

vii. Using these measurements, the entire top part of the turbine (the rotors and nacelle) can be rotated by a yaw motor, mounted between the nacelle and the tower, so it faces directly into the oncoming wind and captures the maximum amount of energy. If it's too windy or turbulent, brakes are applied to stop the rotors from turning (for safety reasons). The brakes are also applied during routine maintenance.

viii. The electric current produced by the generator flows through a cable running down through the inside of the turbine tower.

ix. A step-up transformer converts the electricity to about 50 times higher voltage so it can be transmitted efficiently to the power grid (or to nearby buildings or communities). If the electricity is flowing to the grid, it's converted to an even higher voltage (130,000 volts or more) by a substation nearby, which services many turbines.

x. Homes enjoy clean, green energy: the turbine has produced no greenhouse gas emissions or pollution as it operates.
xi. Wind carries on blowing past the turbine, but with less speed and energy (for reasons explained below) and more turbulence (since the turbine has disrupted its flow) [9].

CHAPTER TWO

Electric load Calculation:

Islamic university of technology (IUT) is a university located in Gazipur district in Bangladesh. In this study, we are going to try to estimate the consumption in the hall of residence and use the obtain data to determine how many wind turbine will require to use as an alternating power source. In the campus two main hall of residences exist. In each one of them there is 5 levels, each level contains 30 rooms, 6 toilettes and 5 hallways.

Considering that there are 3 students in each room and 60 % of the students have laptops of 60W (average) and 40% have Desktops of 160W (average), and in each room there are 6 LED tube light of 16w, 2 Fans of 24W. The daily operating hours for lighting and for the computer in each room were considered as 6h and 5h respectively irrespective of any season. On the other hand, Fans are used in summer only during 15h.

In the toilettes ,considering that there are 4 LED tube light of 16 W .The daily operating hours for lighting in each toilette were considered 13h .

Each hallway contains 9 LED bulbs light of 3W, and the daily operating hours were considered 6h.

To determine the load consuming in the hall , lets first determine the energy consuming in one room , one toilette and one hallway, and then summarized for the hall.

1. Load consuming in one room per day:

Energy of fans (in summer) = number of fan x power consuming by the fan x daily working hours

= 2 x 24W x 15h

Energy of fans (in summer) =0.72 kWh /day

Energy of (Desktop & laptop) = number of PC x power consuming by one PC x daily working hours

Considering that 60% of the students in south hall are using laptop and 40% are using Desktop,

So the power consuming by the Laptop and Desktop is:

= 3 x (0.6 x 60W+ 0.4 x 160W) x 5h

=1.5 kWh/day

Energy of Desktop & **Laptop** = 1.5 kWh /day

Energy of light = number of light x power consuming by one daily working= 6x 9W x 6h

Energy of light = 0.324 kWh/day

As the fans are used only in summer during 15h per day, the load consuming in one room has to be determine according to the season (summer and winter)

Energy consuming in one room (in summer) = energy of light + energy of

PC+ energy of fans

= 0.324kWh + 1.5kWh +0.72 kW

Energy consuming in one room (in summer) = 2.544kWh/day

In winter fans are not used, so the load consuming by the fans will not be included

Energy consuming in one room (winter) = energy for light + energy for

Desktop = 0.324kWh/day + 1.5 kWh /day

Energy consuming in one room (winter) = 1.824 kWh/day

2. Load consuming in one hallway per day:

One hallway contains 9LED tubes light of 3W, and working during 6hours a day.

Energy for one hallway = number of tube light x power consuming by one tube light x working hours

= 9 x 3W x 6h

Energy for one hallway= 0.162kwh/day

3. Load consuming in one toilette:

One toilette contains 4 LED bulbs light of 3W, and the daily operating hours were considered 13. So the energy consuming in on toilette is:

Energy for one toilette = number light in the toilette x power of each light x daily operating hours

= 4 x 3W x 13h

Energy for one toilette =0.156 kwh/day

4. Load consuming in one level:

One level contains 30 rooms, 6 toilettes and one hallway, so the load consuming in one level is determined by the following formula.

Load consuming in one level(in summer) = number of rooms in one level **x** Energy consuming in one room in summer**+** number of toilette in one level **x** Energy consuming in one toilette **+** number of hallway Energy consuming in the hallway

= 30 x2.544kWh/day **+** 6 x 0.156kwh + 0.162kwh

Load consuming in one level in summer = **77.418kwh/day**

Load consuming in one level in winter =number of room in one level x Energy consuming in one room in winter **+** number of toilette in one level **x** Energy consuming in one toilette **+** number of hallway Energy consuming in the hallway

= 6 x 0.156kwh +0.162kwh+ 30 x1.824kWh/day

Load consuming in one level in winter =55.818kWh/day

5. Load consuming in the Stairway:

The hall has 6 stairways on witch ,each stairway from level one to level 5 ,contains 4 tubes light of 3W,and the daily operation hours were considered 6. So the load consuming in the stairway by 24 tubes light in the whole building has to be determined using the following formula

Load consuming in the Stairway = number of stairway x number of tube light on each stairway x power consumed by each tube light x daily operating hour

= 6 x 4 x 3W x 6h

Load consuming in the Stairway = 0.432 **kW/day**

6. The total load consuming:

The totally load consumed in the south hall has to be determined depending to the season, as in winter the fans are not used. In Bangladesh, the summer starts from April to October, and winter from November to March.

The peak energy requirement during summer = load consuming during summer in one level x the number of level

+ load consuming in the stairway

=5 x 77.418kwh/day + 0.432 kW/day

The peak energy requirement during summer season=**<u>0.3875MWh/day</u>**

The peak energy requirement during winter = load consuming during winter in one level x the number of level + load consuming in the stairway

= 5 x 55.818kWh/day + 0.432 kW/day

The peak energy requirement during winter =***0.2795*MWh/day**

7.The peak load:

The peak load is the maximum load of electrical power demand. And it is the sum of the power present in the system. Our system contains

2 fans of 24W, 3 Desktops of 160W (average) and 3LED tube light of 16W for 150 rooms. Also 3 LED tube light of 16W in 30 toilettes. Again 5 hallways where each has 9 LED bulb lights of 3W.
It contains also 6 stairways where each one has 4 LED tubes light of 16W.

- The power of fans = 2 x 150 x24= 7.2kW

- The power of Desktop = 3 x 150 x 0.4 x 160 = 28.8kw

- The power of Laptop = 3 x 150 x 0.6 x 60 =16.2 kW

- The power of LED bulb light in the rooms= 6x 150 x 9= 8.1kW

- The power of the LED bulb light in the toilettes = 4x 3x 30 =0.36kW

- The power of light in the stairways = 4 x 6 x 3 =0.072kW

- The power light in the hallways = 5 x 9 x 3 = 0.135KW

The peak load = **<u>60.732 Kw</u>**

CHAPTER THREE

Power calculation

To calculate the amount of power a turbine can actually generate from the wind, you need to know the wind speed at the turbine site and the turbine power rating. Most large turbines produce their maximum power at wind speeds around 15 meters per second (33 mph). Considering steady wind speeds, it's the diameter of the rotor that determines how much energy a turbine can generate. Keep in mind that as a rotor diameter increases, the height of the tower increases as well, which means more access to faster winds.

Rotor Size and Maximum Power Output	
Rotor Diameter (meters)	Power Output (kW)
10	25
17	100
27	225
33	300
40	500
44	600
48	750
54	1000
64	1500
72	2000
80	2500
Sources: Danish Wind Industry Association, American Wind Energy Association	

At 33 mph, most large turbines generate their rated power capacity, and at 45 mph (20 meters per second), most large turbines shut down. There are a number of safety systems that can turn off a turbine if wind speeds threaten the structure, including a remarkably simple vibration sensor used in some turbines that basically consists of a metal ball attached to a chain, poised on a tiny pedestal. If the turbine starts vibrating above a certain threshold, the ball falls off the pedestal, pulling on the chain and triggering a shut down. [13]

I. **Scenario**

Wind turbines work by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy that can be supplied later or directly. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine. When planning a wind farm it is important to know the expected power and energy output of each wind turbine to be able to calculate its economic viability.

II. **PROBLEM STATEMENT**

With the knowledge that it is of critical economic importance to know the power and therefore energy produced by different types of wind turbine in different conditions, in this exemplar we will calculate the rotational kinetic power produced in a wind turbine at its rated wind speed. This is the minimum wind speed at which a wind turbine produces its rated power.

III. **Wind turbine power equation**

Let consider the following variable:

- E = kinetic energy (J);
- ρ = air density (kg/m^3;

- m = mass (kg);
- A = swept area (m^2);
- v = wind speed (m/s);
- C_p = power coefficient
- P = power (W);
- r = rotor blade radius (m);
- $\frac{dm}{dt}$ = mass flow rate (kg/s);
- $\frac{dE}{dt}$ = energy flow rate (J/s);
- x = distance (m);
- t = time (s); we know that, Under constant acceleration, the kinetic energy of an object having mass *m* and velocity *v* is equal to the work done *W* in displacing that object from rest to a distance *s* under a force *F* , i.e.: ***E = W = Fs***

From Newton's second law of motion,

$$F = ma$$

Hence,

$$E = mas\ldots\ldots\ldots\ldots(i)$$

Using the third equation of motion:

$$V^2 = u^2 + 2as$$

Rearranging yields:

$$a = (V^2 - u^2)/2s$$

Since the initial velocity of an object equal zero that is **u = 0,** we get:

$$a = V^2/2s$$

Substituting it into equation (i), we get that the kinetic energy of a mass in motion is:

$$E = \tfrac{1}{2} mV^2 \text{ ………….. } (ii)$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \tfrac{1}{2} V^2 \frac{dm}{dt} \text{ ……………… } (iii)$$

As mass flow rate is given by:

$$\frac{dm}{dt} = \rho A \frac{dx}{dt}$$

And the rate of change of distance is given by:

$$\frac{dx}{dt} = V$$

We get:

$$\frac{dm}{dt} = \rho AV$$

Hence, from equation (iii), the power can be defined as:

$$P = \tfrac{1}{2} \rho AV^3 \text{ …………….. } (iv)$$

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the **Betz Limit** or **Betz' Law.** The theoretical maximum **power efficiency** of *any* design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the “power coefficient” and is defined as:

$$C_{pmax} = 0.59$$

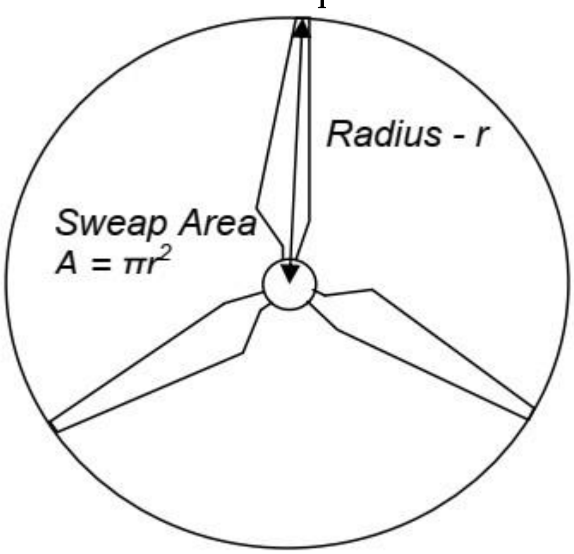
Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular. The real world limit is well below the *Betz Limit* with values of 0.35-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine system - e.g. the gearbox, bearings, and generator and so on - only 10-30% of the power of the wind is ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in equation (4) and the extractable power from the wind is given by: [14]

$$P = \tfrac{1}{2}\,\rho A V^3 C_p \;\ldots\ldots\ldots\ldots\ldots\; (V)$$

The swept area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$$A = \pi r^2 \;\ldots\ldots\ldots\ldots.\; (vi)$$

Where the radius is equal to the blade length as shown in the figure below:



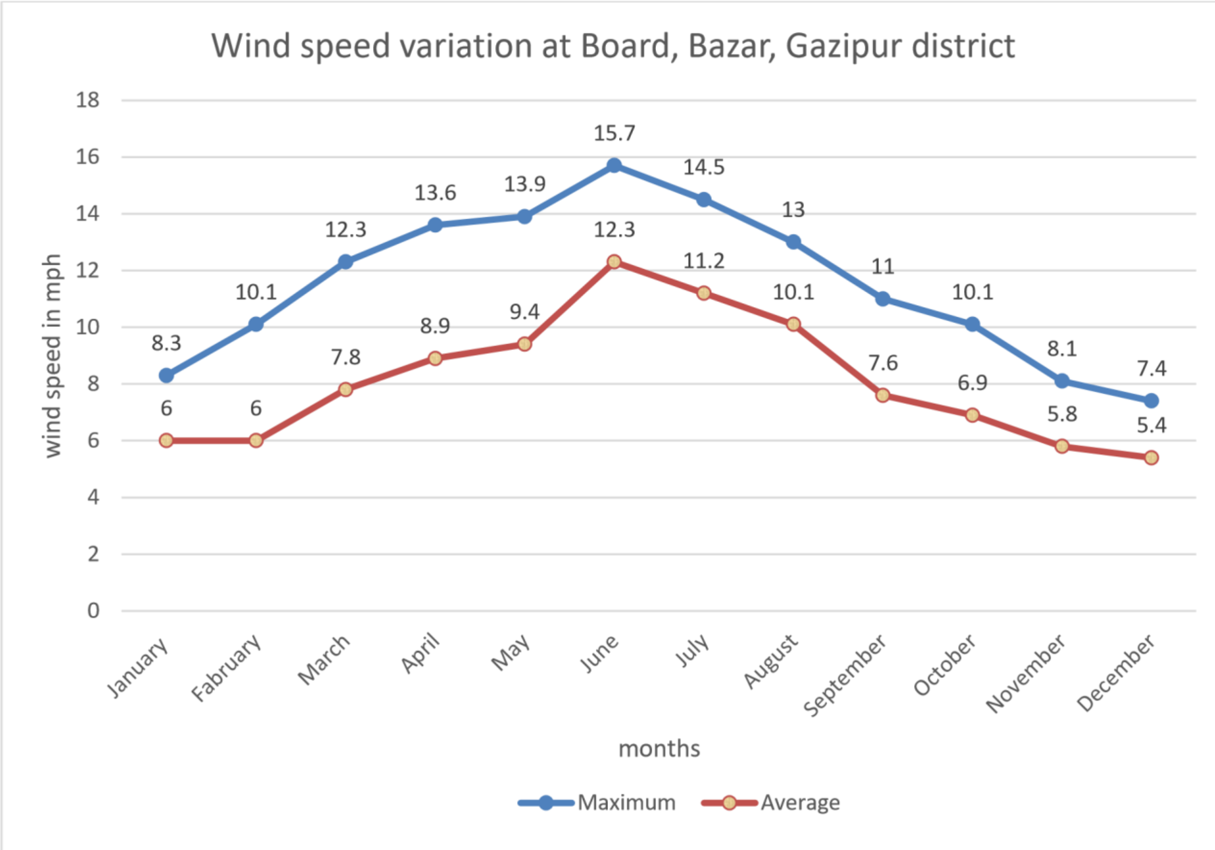
IV. wind speed at Board, Bazar district

According to the world weather online data, the maximum and average wind speed at Board, Bazar district, where Islamic University of Technology is located are given in the following table respectively with respect to each month.

Wind speed (mph)	months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	8.3	10.1	12.3	13.6	13.9	15.7	14.5	13	11	10.1	8.1	7.4
Avg	6	6	7.8	8.9	9.4	12.3	11.2	10.1	7.6	6.9	5.8	5.4

From the above table it is clear that the maximum wind speed in Board, Bazar district vary between 15.7 mph in June to 7.4 mph in December and the average wind speed vary between 12.3 mph also in June and 5.4 mph in December. Thus June can be considered to be the month with higher wind speed in both maximum value and average value and in the other hand December with the lower wind speed. [15]

The wind variation can be clearly observed in the following graph:



V. **Calculation with assumed data:**

For the calculation purposes, the following data are assumed:

- Wind speed, V = 5.4 mph = 2.4 m/s
- Blade length, l = r = 60 m
- Air density, $\rho = 1.23\ kg/m^3$
- Power coefficient, $C_p = 0.4$

From equation (vi),

$$A = \pi r^2 = \pi\,(60)^2 = \underline{11309.7\ m^2}$$ Now

using equation (v), we get:

$$P = ½\,\rho A V^3 C_p$$

$$= ½\ 1.23 * 11309.7 * (2.4)^3 * 0.4$$

$$= 38461\ W = 38.461\ kW$$

Thus the power outputted from a wind turbine of **60m rotor radius,** located in a region having a **wind speed of 2.4m/s** is:

$$\underline{P = 38.461\ kW}$$

From the calculation done in chapter two, it is found that the peak power consumption in the south hall of Islamic University of Technology man dormitory is:

$$P_{peak} = 60.732\ kW$$

Therefore, to satisfy this power requirement the power obtain from the wind turbine must exceed the peak power and the power from one wind turbine want be enough but with two wind turbines, the total power outputted is:

$$P_{total} = 38.461 * 2 = 76.922\ kW$$ Which

is more than enough to power the south hall.

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