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دراسة امكانية استخدام التوربينات الهوائية فى السودان

Study probability of using wind turbines in Sudan

A project Submitted in Partial Fulfilment for the Requirement of The Degree of B.E. (Honour) In Mechanical Engineering

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October 2017

الآية

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قال تعالى:

((وَمِنْ آيَاتِهِ أَنْ يُرْسِلَ الرِّيَاحَ مُبَشِّرَاتٍ وَلِيُذِيقَكُمْ مِنْ رَحْمَتِهِ وَلِتَجْرِيَ الْفُلْكُ بِأَمْرِهِ وَلِتَبْتَغُوا مِنْ فَضْلِهِ وَلَعَلَّكُمْ تَشْكُرُونَ)) .

الروم(46)

الإهداء

الى من كان سببا فى وجودى بعد الله؛ الى من سهر الليالى فى سبيل راحتى؛ الى ابى رحمه الله وغفره له؛ الى امى واخوانى وكل زملائى.

الى والدى العزيزان؛ واسرتى العزيزة واخوالى وخالاتى وبالاخص د/أمال موسى ود/عمران موسى وكل من ساهم فى مسيرتى التعليمية.

الشكر والتقدير

نتوجه بخالص الشكر والتقدير لكل الاساتذة الأجلاة فى مدرسة الهندسة الميكانية وبالاخص مشرفنا العزيز د/ توفيق احمد جمال لصبره علينا و مساعدتنا طوال فترة المشروع وشركة خاص مقدم لأسرة ورشة السيارات والبرادة.

ABSTRACT

In this research study of a three-blade wind turbine has been accomplished, the past wind data records gathered, it was found that the average wind velocity in the four previous years was 4.374 m\s. The module had been designed, shaped and manufactured.

Three experiments were done to measure the wind velocity and the equivalent turbine speeds. The calculation to get the force, torque and power had been accomplished, the max power and torque can this turbine extract in the geography of Sudan was calculated and it was about 140.6539 W and12.50257 N.m, when the velocity is 6.3 m\s and rotor diameter is 112 cm, and this power is enough for generation of electricity.

المستخلص

فى هذا البحث تم دراسة توربين رياحى ذو ثلاث ريش , تم جمع بيانات الرياح السابقة و وجد ان متوسط سرعة الرياح للاربع سنوات السابقة كان 4,374 م/ث بعد ذلك تم تصميم النموذج و تصنيعه.

تم اجراء ثلاث تجارب لقياس سرعة الرياح وسرعة دوران التوربينة المكافئة.بعد ذلك تم اجراء الحساب وايجاد القوة والعزم وقدرة التوربينة,ومن خلال الحسابات وجد ان اقصى قدرة هى 140.6539 وات واقصى عزم هو 12.50257 نيوتن فى المتر, وذلك عند سرعة الرياح 6.3 متر فى الثانية وقطر العضو الدوار 112 سنتيميتر,وهذاه القدرة يمكن استخدامها فى انتاج الطاقة الكهربائية .

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T	Temperature
R_g	it the gas constant
P	pressure applied on the wind turbine
P_w	Power in the moving wind
P	it is the air density
A	area against the wind
V	velocity of the moving air
E	Kinetic energy of the moving air
m	mass of the moving air
P_t	Turbine power
T	The Torque
Ω	It is the angular velocity
γ	Tip speed ratio
R	Rotor radius
N	Speed of rotation
F	force applied by wind
C_p	coefficient of performance for a wind turbine
$m^{\bullet}$	mass flow rate
M	The amount of momentum
α	the axial induction factor
a	blade area
c	blade cord

L	blade length
r	the hub radius
S	solidity

CHAPTER ONE

CHAPTER ONE

INTRODUCTION

1.1 Introduction:

The world faces such a big problem which it is lack of power generate and high cost of fossil fuels, limited supply also damages related to generating power using traditional methods including environment pollution and increase in greenhouse gases. All this issue motivates the world to search for new sources of power to generate cleaner and cheaper, renewable and environmental friendly.

The problem can be solved by using renewable energy technologies (hydro, wind, solar, biomass, geothermal, and ocean). Renewable energy is energy which can be obtained from natural resources that can be constantly replenished. Wind energy it is important of renewable energy source it is generated by converting wind currents into other forms of energy using wind turbines.

Windmills have been used for at least 3000 years, mainly for grinding grain or pumping water, while in sailing ships the wind has been an essential source of power for even longer. Since the thirteenth century, horizontal-axis windmills were an integral part of the rural economy. Using of windmills (or wind turbines) to generate electricity can be traced back to the late nineteenth century with the 12 kW DC windmill generator constructed by Brush in the USA [7].

Sudan lies within the tropics, the climate ranges from arid in the north to tropical wet-and-dry in the far southwest. Variations in the length of the dry season depend on which of two air flows predominates, dry north easterly wind or south westerly wind. After 1980, as the supply of conventional energy has not been able to follow the tremendous increase of the production demand in generation of Sudan, a renewed interest for the application of wind energy has shown in many places. Therefore, the Sudanese government began to pay more attention to wind energy utilization in generation.

At this project we will study the using of wind turbine at small application in Sudan by design a model

1.2Problem statement:

Although Sudan has great resources of renewable energies specifically wind energy, yet this resource is not utilized in aperfect way and Sudan Still depending in fossil fuels in power generation which leads to increase of greenhouse gases and environment pollution. Also, Sudan faces lack of electricity generation.

1.3 Research Objectives:

• Design a three-blade wind turbine.

• produce electric power from this turbine

•Contribution of wind energy in Reduce the environmental pollution and greenhouse gases.

1.4 Scope

The selected design for the turbine module is 3-blade (HAWT) and the material used in manufacturing is (PVC). The experiment it is assumed to be executing in Sudan University of Science and Technology (The South). The air condition in the site is assumed to be the standard conditions; Temperature (36 C), Pressure (1 atom). The average wind speed in previous four years (2016, 2015, 2014, 2013) is acknowledged. during the processes of design and analysis the generator is neglected for simplification of the design.

1.5 Methodology:

The experiential methods are used to gain the needed outputs from the research. First, we design the model by suitable dimensions and gather the data relative to wind speed in Khartoum for the four last years ago and measuring wind speed at location, Second, we calculate the power and torque at the wind turbine after that we will draw a graph to analysis the past data records and results.

CHAPTER TOW

CHAPTER TOW
LITERATURE REVIEW

2.1 Introduction:

Energy policy to increase the share of renewable energy (i.e., geothermal, wind, solar and biomass) in total energy consumption is accepted as the main requirement of sustainable development because non-renewable energy (i.e., coal, oil and natural gas) is considered to be main driver of global warming and climate change. In addition to with environmental concerns, since the fluctuations in fossil fuel prices which negatively affect investment, decisions and exhaustible feature of fossil fuel sources, renewable energy becomes preferably alternative to non-renewable energy. On the other hand, it is crucial to sustain economic growth for development of renewable energy sector but the economic growth of most of the countries is still based on non-renewable consumption. Therefore, rational policy is to reduce non-renewable energy consumption without damaging economic activities. Investments on renewable energy sector are growing rapidly across the world based on mentioned advantages of renewable energy however according to the Renewable Global Status Report; developing countries are the most investor countries on renewable energy in recent years [1]

Wind energy represents a mainstream energy source of new power generation and an important player in the world's energy market. As a leading energy technology, wind power’s technical maturity and speed of deployment is acknowledged, along with the fact that there is no practical upper limit to the percentage of wind that can be integrated into the electricity system [2].

It has been estimated that the total solar power received by the earth is approximately 1.8 *10^11 MW. Of this solar input, only 2% (i.e. 3.6 * 10^9 MW) is converted into wind energy and about35% of wind energy is dissipated within 1000 m of the earth's surface. Therefore, the available wind power that can be converted into other forms of energy is approximately 1.26 *10^ 9 MW. Because this value represents 20 times the rate of the present global energy consumption, wind energy in principle could meet entire energy needs of the world [2].

Compared with traditional energy sources, wind energy has a number of benefits and advantages. Unlike fossil fuels that emit harmful gases and nuclear power that generates radioactive wastes, wind power is a clean and environmentally friendly energy source. As an inexhaustible and free energy source, it is available and plentiful in most regions of the earth. In addition, more extensive use of wind power would help reduce the demands for fossil fuels, which may run out sometime in this century, according to their present consumptions. Furthermore, the cost per kWh of wind power is much lower than that of solar power. thus, as the most promising energy source, wind energy is believed to play a critical role in global power supply in the 21st century [2].

2.2 History of wind power:

Windmills have been used for at least 3000 years, mainly for grinding grain or pumping water, while in sailing ships the wind has been an essential source of power for even longer. From as early as the thirteenth century, horizontal-axis windmills were an integral part of the rural economy and only fell into disuse with the advent of cheap fossilfuelled engines and then the spread of rural electrification. The use of windmills (or wind turbines) to generate electricity can be traced back to the late nineteenth century with the 12 kW DC windmill generator constructed by Brush in the USA and the research undertaken by La Cour in Denmark. However, for much of the twentieth century there was little interest in using wind energy other than for battery charging for remote dwellings and these low-power systems were quickly replaced once access to the electricity grid became available. One notable exception was the 1250 kW Smith–Putnam wind turbine constructed in the USA in 1941. This remarkable machine had a steel rotor 53 m in diameter, full-span pitch control and flapping blades to reduce loads. Although a blade spar failed catastrophically in 1945, it remained the largest wind turbine constructed for some 40 years.

Wind energy was identified as having a key role to play in the supply of renewable energy with an increase in installed wind turbine capacity from 2.5 GW in 1995 to 40 GW by 2010. This target is likely to be achievable since at the time of writing, January 2001, there was some 12 GW of installed wind-turbine capacity in Europe, 2.5 GW of which was constructed in 2000 compared with only 300 MW in 1993.The reasons development of wind energy in some countries is flourishing while in others it is not fulfilling the potential that might be anticipated from a simple consideration of the wind resource, are complex. Important factors include the financial-support mechanisms for wind-generated electricity, the process by which the local planning authorities give permission for the construction of wind farms, and the perception of the general population particularly with respect to visual impact. In order to overcome the concerns of the rural population over the environmental impact of wind farms there is now increasing interest in the development of sites offshore [3].

2.3 Wind Turbine Components:

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.

Rotor: Sometimes called the hub, this is used to connect the blades to the gear box and power generation train within the nacelle. The rotor system consists of three NACA 63-622 blades made of carbon fibre and epoxy. Its profile [14–21] allows the efficient conversion of wind linear movement in to alternator rotational movement [4, 5].

Nacelle: an enclosure which contains the electrical and mechanical components, namely the gear box, the brake, the speed and direction monitor, the yaw mechanism and the generator.

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.

Generator: Wind turbines typically have an AC generator (housed in the nacelle) that converts the mechanical energy from the wind turbines 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.

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. [4,1]

Blades: The modern rotor blades are made of composite materials, making them light but durable. Blades are often made of fibre glass, 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 [4].

Tail: The tail keeps the rotor aligned into the wind except when the wind speed exceeds security limits. When this happens, the special articulation system turns the rotor sideways to the wind to limit the rotor speed in high winds, but the turbine continues producing power [1].

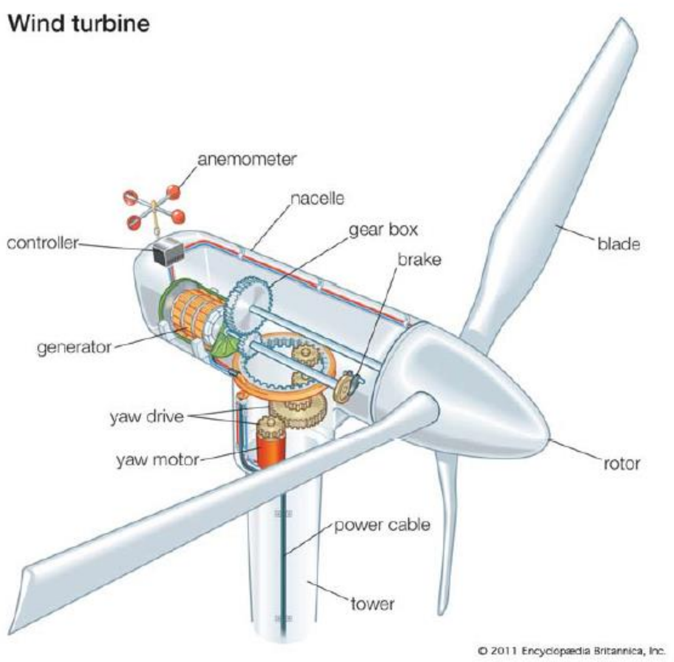


Figure [2.1]: parts of wind turbine

2.4 Wind turbine classification:

Wind turbines can be classify according to the turbine generator configuration, air flow path relatively to the turbine rotor, turbine capacity, the generator-driving pattern, the power supply mode, and the location of turbine installation**.** Modern wind turbines can be classified into:

2.4.1 Horizontal-axis and vertical-axis turbines:

Most commercial wind turbines today belong to the horizontal-axis type, in which the rotating axis of blades is parallel to the wind stream. The advantages of this type of wind turbines include the high turbine efficiency, high power density, low cut-in wind speeds, and low cost per unit power output.

2.4.2 Vertical-axis wind turbines:

Rotate with respect to their vertical axes that are perpendicular to the ground. A significant advantage of vertical-axis wind turbine is that the turbine can accept wind from any direction and thus no yaw control is needed. Since the wind generator, gearbox, and other main turbine components can be set up on the ground, it greatly simplifies the wind tower design and construction, and consequently reduces the turbine cost. However, the vertical-axis wind turbines must use an external energy source to rotate the blades during initialization. Because the axis of the wind turbine is supported only on one end at the ground, its maximum practical height is thus limited. Due to the lower wind power efficiency, vertical-axis wind turbines today make up only a small percentage of wind turbines [2, 1].

2.5Types of Wind Turbines:

2.5.1 Propeller wind turbine:

The popular wind turbine that you know and may have seen, with three blades, on top of a mast or tower is called a propeller turbine. This is because it looks like the propeller of an airplane. A propeller turbine is a lift -type turbine since it works based on the lift force on the blades. Although usually it comes with three blades, it can have a smaller or larger number of blades. It can work with two or even one blade. It can have four, five, or more blades. Research, however, has shown that three blades are the best combination; that is, from balance, efficiency, and other viewpoints such as how it looks and the impact it has on an observer. In a propeller turbine, wind flow is along the turbine shaft; that is, wind blows perpendicular to the blade plane (an imaginary plane that contains the blades). Since in the open air, wind normally blows horizontally, the propeller turbine shaft has to be horizontal. Thus, a propeller turbine is a horizontal-axis wind turbine. If a propeller turbine is mounted vertically on its mast, so that its blades can move horizontally, it is less likely that they will rotate at all. [6]

2.5.2 Three blades wind turbine:

Most modern wind turbines are three-bladed designs with the rotor position maintained upwind (on the windy side of the tower) using electrical motors in their yaw mechanism. This design is usually called the classical Danish concept, and tends to be a standard against which other concepts are evaluated. The vast majority of the turbines sold in world markets have this design. The basic design was first introduced with the renowned Gedser wind turbine. Another characteristic is the use of an asynchronous generator. You may read more about the Danish concept in the articles section of this web site [7].

Figure [2.2]: Three blade wind turbine

2.5.3 Darrieus Wind turbine:

Another prominent type of VAWT is the Darrieus turbine. A Darrieus turbine uses thin blades to capture and convert wind energy into mechanical or electrical energy. The Darrieus type relies on two or more curved blades that rely on wind to revolve around a central column [8].

Figure [2.3]: Darrieus Wind turbine

2.5.4 Savonius:

One of the more prevalent types of VAWTs is the Savonius Rotor. The Savonius rotor is less powerful than most HAWTs, and it has a high power to weight ratio. However, the Savonius rotor is particularly useful for situations that do not require a large amount of electric power. Also, because of the simple design of the Savonius, it is relatively simple to build [8].

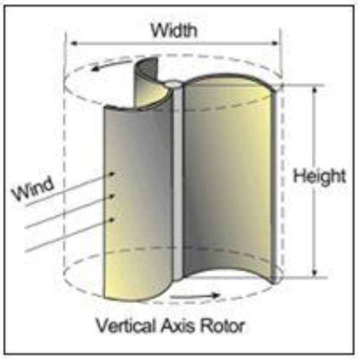


Figure [2.4]: Savonius rotor

2.5.5 Traditional Windmill:

A traditional windmill operates at low speed and produces high torque. It is generally used to produce mechanical power. This design has also been around for many decades allowing for many design advancements and a large data base [8].

Figure [2.5]: Traditional Windmill

2.5.6Aerocon:

An Aerocam is a HAWT that uses multiple aerodynamic blades which cut a profile in the air that is similar to a water wheel. This also allows it to follow the path of the wind as the blades rotate, which means it requires no mechanical yaw correction. This wind turbine is used for electricity production. One disadvantage of this type of wind turbine is that it is stationary, meaning that it is only one-directional [8].

Figure [2.6]: Aerocam

2.5.7 Helix Turbine:

A helix wind turbine uses long blade scoops that are helically shaped to catch the wind from any direction. The helix is similar to the Savonius since it uses drag forces provided by the wind and is self-starting. This is one of the more innovative designs that manipulate the direction of the wind through its blades to increase its rotational velocity. An example of this design is provided in Figure (2.6) [8].

Figure [2.7]: Helix Turbine

2.6 Application of Wind Turbine:

2.6.1Water Pumping:

Uses of water-pumping wind turbines include land irrigation, human or livestock water supply, and drainage. Pumping water with wind power requires the rotor to deliver higher torque than that required by an electrical generator of the same rated power. Prior to the 19th century development of back gearing (speed reduction), torque requirements were particularly high when one revolution of the rotor completed one pump cycle. Designs of water-pumping windmills and wind turbines reflect their application, depending on the flow required, the type of well, and the head (the distance from the well water to the outlet). In the United States, most of these applications are low flow (approximately 1 m3/h) and medium head (from 15 to 45 m). In the developing world, the flow desired may be similar, but the head is often less. The windmill may be driving a piston, air-lift, or diaphragm pump [4].

2.6.2 Electricity generating:

The first electricity-generating wind turbine was a battery charging machine installed in July 1887 by Scottish academic James Blyth to light his holiday home in Marykirk, Scotland. Some months later American inventor Charles F. Brush was able to build the first automatically operated wind turbine after consulting local University professors and colleagues Jacob S. Gibbs and Brinsley Coleberd and successfully getting the blueprints peer-reviewed for electricity production in Cleveland, Ohio. Although Blyth's turbine was considered uneconomical in the

United Kingdom, electricity generation by wind turbines was more cost effective in countries with widely scattered populations.

2.7 The coefficient of performance of wind turbines

The conversion of wind energy to electrical energy involves primarily two stages: in the first stage, kinetic energy in wind is converted into mechanical energy to drive the shaft of a wind generator. The critical converting devices in this stage are wind blades. For maximizing the capture of wind energy, wind blades need to be carefully designed [2]. The figure below shows coefficient of performance for different types of wind turbines.

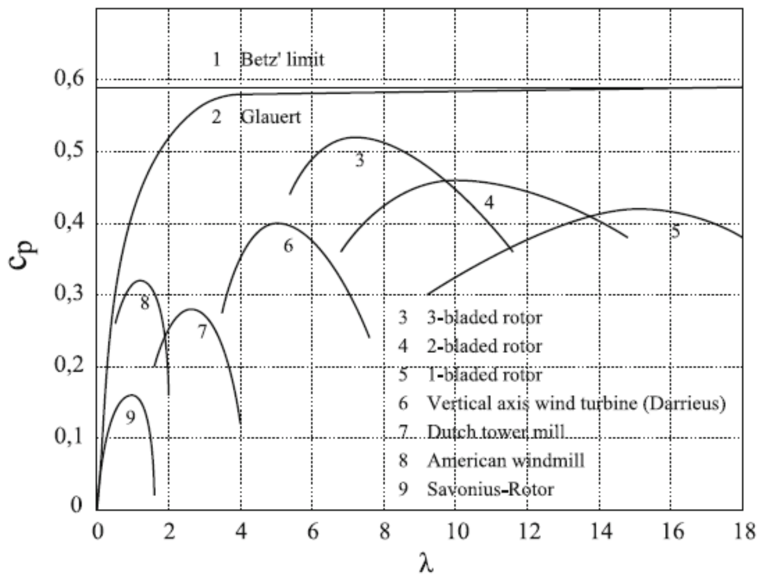


Figure [2.8]: Tip speed ratio vs Coefficient of performance

2.8 The Power output from a wind turbine

The effective electrical power output from a wind turbine Pelf is directly proportional to the available wind power P_w and the total effective wind turbine efficiency. The power curve of a wind turbine displays the power output (either the real electrical power output or the percentage of the rated power) of the turbine as a function of the mean wind speed. Power curves are usually determined from the field measurements; the wind turbine starts to produce usable power at a low wind speed, defined as the cut-in speed. The power output increases continuously with the increase of the wind speed. [2]

The figure below illustrates a power curve for the turbines

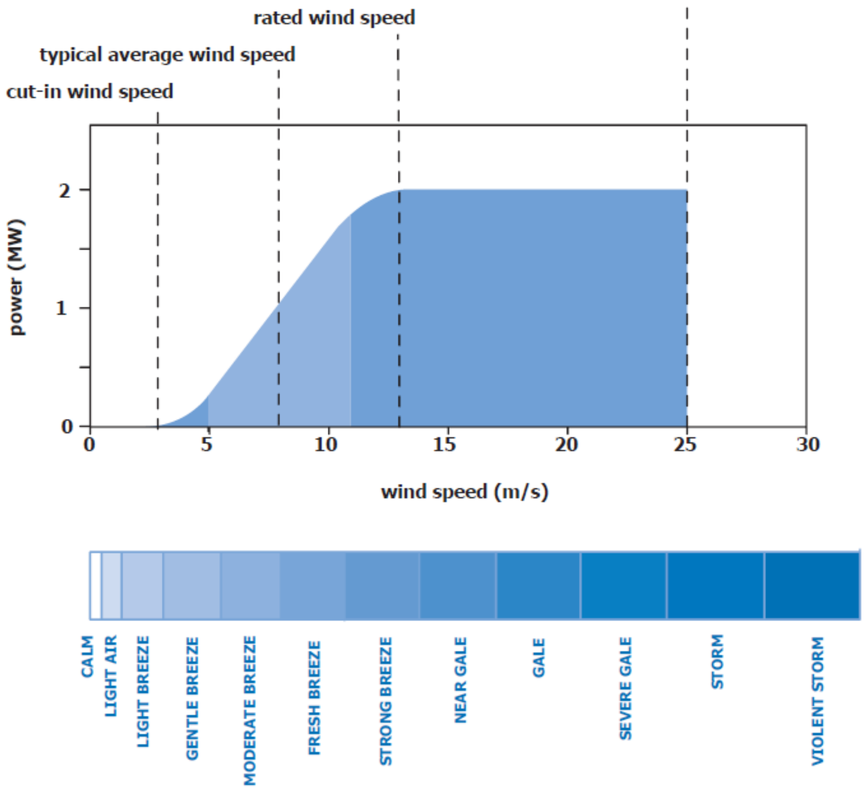


Figure [2.9]: Typical power curve of a wind turbine

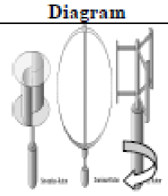
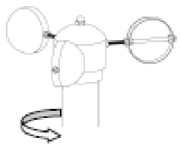
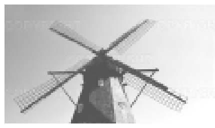
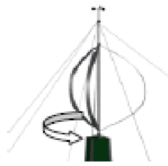
2.9 Comparisons between wind turbines:

The coefficient of performance differs from one type of wind turbine to another, regarded to the number of the blades, length of the blades, speed and the amount of torque applied the blade. The table below shows the variation of coefficient of performance for the wind turbines.

Table 2.1: Comparison between different types of wind turbines

Type	Speed	Torque	C_p (rotor efficiency)	Lift or Drag	Use
Multi Blade	Low	High	0.25-.4	Both	Mechanical Power
Three Bladed aero foil	High	Low	Up to 0.45	Both	Electricity production
Aerocam	Very Low – Low	High	0.48	Lift	Electricity production
Panemone	Low	Medium	Less than 0.1	Drag	Mechanical Power
Darrieus	Moderate	Very low	0.25-0.35	Lift	Electricity production
Savonius	Low	High	0.1-0.2 (max ~0.3)	Drag	Water pumping, Grinding grain
Combined Savonius and Darrieus	Low – Moderate	High	0.25-0.35	Both	Mechanical Power/ Electricity production
Helix	Low	High	N/A	N/A	Electricity production

Table [2.2]: Modern and historical rotor designs.

Ref No.	Design	Orientation	Use	Propulsion	* Peak Efficiency	Diagram
1	Savonius rotor	VAWT	Historic Persian windmill to modern day ventilation	Drag	16%	
2	Cup	VAWT	Modern day cup anemometer	Drag	8%	
3	American farm windmill	HAWT	18th century to present day, farm use for Pumping water, grinding wheat, generating electricity	Lift	31%	
4	Dutch Windmill	HAWT	16th Century, used for grinding wheat.	Lift	27%	
5	Darrieus Rotor (egg beater)	VAWT	20th century, electricity generation	Lift	40%	
6	Modern Wind Turbine	HAWT	20th century, electricity generation	Lift	Blade Qty / efficiency 1 / 43% 2 / 47% 3 / 50%	

2.10 Wind energy in Sudan:

The climate of Sudan is temperate. There is a season of heavy rain from mid-June to the end of September. During the rest of the year there is no rain. The season through the year may be divided as follows: December± March is the period of the dry season or winter season; April± June is the advancing monsoon period; and October± November is the retiring monsoon period. [3]

92% of Sudan’s primary energy consumption is from fossil fuels, with 8% accounting for hydro. Yet, current installed capacity is for 60% from hydropower. The country is making efforts to further integrate other renewable energy resources, and aims to have 11% of electricity generation come from renewable energy by 2031, excluding hydro. Sudan also adopted a NEEAP in 2012 and has set cumulative energy efficiency targets of 11,8%, aiming at 32% by 2020[9].

Sudan is rich in wind; about 50% of Sudan's area is suitable for generating electricity (annual average wind speed more than 5 m\s), and 75% of Sudan's area is suitable for pumping water (annual average wind speed 3±5 msÿ1). In areas where there is wind energy potential but no connection to the electric grid, the challenge is simplicity of design, and higher efficiency. The research and development in the field of wind machines should be directed towards utilizing local skills and local available materials. Local production of wind machines should be encouraged in both public and private organizations. [3]

2.11 Theory:

2.11.1 Power in the wind:

The question is: How much energy can be taken from the wind? The wind turbine decelerates the wind, thereby reducing the kinetic energy in the wind. But the wind speed cannot be reduced to zero– as a consequence, where should the air be stored? As first time shown by Betz, there is an optimum for the reduction of the wind speed, and this is what is to be outlined in this chapter.

The kinetic energy in the moving air is determined by equation

$$E = \frac{1}{2} m V^2 \qquad (2.1)$$

The wind power can be obtained by differentiating the kinetic energy in wind with respect to time.

$$P_w = \frac{\partial E}{\partial t} = \frac{1}{2} m^{\bullet} * V^2 \qquad (2.2)$$

When wind passes through a wind turbine and drives blades to rotate, the

Corresponding wind mass flow rate is

$$m^{\cdot} = \rho A V \qquad (2.3)$$

Substituting (3.3) into (3.2), the available power in wind P can be expressed as

$$P_w = \frac{1}{2} \rho A V^3 \qquad (2.4)$$

Where P_w is the power in the wind

2.11.2 Power extracted by the wind turbine:

$$P_t = T * \omega \qquad (2.5)$$

Where T is torque applied on the turbine rotor and ω is the angular velocity.

2.11.3The tip speed ratio:

It is defined as the ratio between speed of the blade tip to the wind speed

$$\gamma = \frac{\omega R}{V} \qquad (2.6)$$

2.11.4 Speed of rotation of wind turbine:

It donates how times the turbine rotates in a minute. It is measured experimentally using tachometer.

2.11.5 The Angular velocity:

$$\omega = \frac{2\pi N}{60} \qquad (2.7)$$

Where ω angular velocity and N is is the speed of rotation

2.11.6 The force acting on the wind turbine:

It is the force applied by the wind on the rotor blades.

$$F = \frac{1}{2}\rho A V^2 \qquad (2.8)$$

2.11.7 Torque:

The torque on the rotor is the resulting moment of the rotor axis of the aerodynamic forces on the blades.

The torque applied on wind turbine is calculate from the equation

$$T = F * R \qquad (2.9)$$

Where F is the force done by the wind on the turbine and R is the radius of the wind turbine

3.1.8 Power coefficient:

In analysing of flow through a control volume, this analysis uses the following assumptions:

. Homogenous, incompressible, steady state fluid flow;

. No frictional drag;

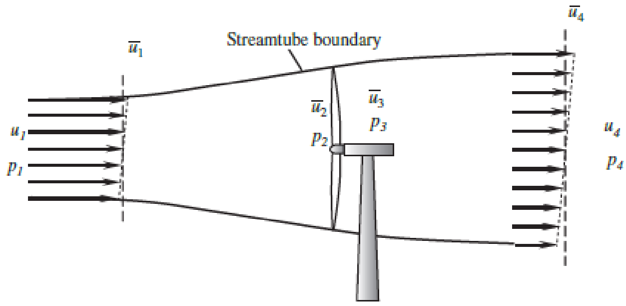
. An infinite number of blades;

. Uniform thrust over the disc or rotor area;

. A non–rotating wake;

. The static pressure far upstream and far downstream of the rotor is equal to the undisturbed ambient static pressure.

Figure [2.10]: Actuator disc model for wind turbine



For the control volume in figure [2.10] the amount of momentum

$$M = m^{\cdot} * V \qquad (2.10)$$

Where M is momentum and m• is the mass flow rate, that equal to amount of thrust applied on the turbine.

Assuming that velocities just downstream and upstream are equals, that's yields to:

$$V_2 = V_3$$

Taking the pressures for downstream and upstream equals the stagnation pressure:

$$P_1 = P_4 = P$$

$$m^{\cdot} = \rho A_2 V_2 = \rho A_1 V_1 = \rho A_4 V_4$$

According to the conversion of momentum theory, the force applied on actuator is equal the change in momentum in the air stream.

$$F = m^{\cdot}(V_1 - V_4) \qquad (2.11)$$

Also, the Force is equal to

$$T = A_2(P_2 - P_3) \qquad (2.12)$$

The energy equation is:

$$P + \frac{1}{2}\rho u^2 = const \qquad (2.13)$$

Appling energy equation upstream and downstream that yield to

$$P_1 + \frac{1}{2}\rho_1 {V_1}^2 = P_2 + \frac{1}{2}\rho u {V_2}^2 \qquad (2.14)$$

$$P_3 + \frac{1}{2}\rho_3 {V_3}^2 = P_4 + \frac{1}{2}\rho {V_4}^2 \qquad (2.15)$$

Solving equation (1) and (2) yields:

$$P_2 - P_3 = \frac{1}{2}\rho\left({V_1}^2 - {V_4}^2\right)(2.16)$$

From (2.12) and (2.14)

$$T = \frac{1}{2}\rho A_2\left({V_1}^2 - {V_4}^2\right) \qquad (2.16)$$

From (2.12) and (2.16)

$$\rho A_2 u_2 = \frac{1}{2}\rho A_2\left({V_1}^2 - {V_4}^2\right) \qquad (2.17)$$

There for,

$$u_2 = \frac{V_1 + V_4}{2}$$

If one defines the axial induction factor, as the fractional decrease in wind velocity betwee7n the free stream and the rotor plane, then

$$\alpha = \frac{V_1 - V_4}{V_1}$$

$$V_2 = V_1(1 - \alpha)$$

$$V_4 = V_1(1 - 2\alpha)$$

That result

$$F = \frac{1}{2}\rho A V^2 4a(1-a) \qquad (2.18)$$

And

$$P = \frac{1}{2}\rho A V^3 4a^2(1-a) \qquad (2.19)$$

The power coefficient Cp is equal to

$$C_p = \frac{Rotor\ power}{power\ in\ the\ wind}$$

$$C_p = \frac{\frac{1}{2}\rho A u^3 4a(1-a)\ ^2}{\frac{1}{2}\rho A u^3}$$

$$C_p = 4a^2(1-a)$$

$$C_p = 4a^2 - 4a^3$$

Taking the derivative of equation and sitting it to zero to the max C_p

$$\frac{dC_p}{d\alpha} = 8a - 12a^2 = 0$$

Solving the equation gives us the max C_p

$$C_p = 0.5926$$

2.11.9 Air Density:

The air density is assumed to be calculated at atmospheric pressure and reference temperature (40 C)

$$\rho = \frac{P}{RT} \qquad (2.20)$$

2.11.10 Mass flow rate:

$$m^{\bullet} = \rho * A * V \qquad (2.21)$$

3.11.11 Area of the blade:

I t equal to the area of one blade, and can be calculated from formula (2.22).

$$a = C * L \qquad (2.22)$$

Where C is the blade width and L is the blade length.

2.11.12Rotor area:

It is the area against which the wind force is acting; it can be calculated by equation below

$$A = \frac{\pi D^2}{4} \; (3.21)$$

Where D rotor diameter equals 2*R.

2.11.13 Solidity:

Solidity is the ratio of total rotor plan form area to total swept area.

$$S = \frac{Blades\ area}{Swept\ area} \qquad (3.22)$$

CHAPTER THREE

CHAPTER THREE
METHODOLOGY AND DESIGN

3.1 Research Methodology:

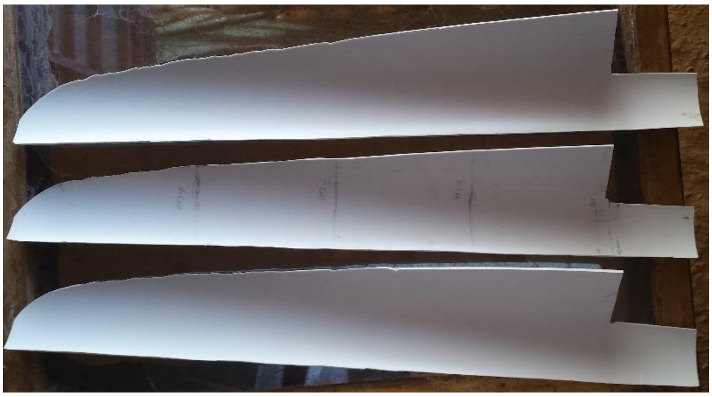
To achieve the main purpose of the research a horizontal axis wind turbine module had been developed and designed, the material used in shaping the blades was simple(PVC pipes), that's due to reduce to cost of manufacturing, the site was selected the temperature is assumed to be 36 C° and the we calculate the air density. Three experiments where done to measure the wind velocity as well as the turbine speed. The calculation had accomplished and the force, torque and power were calculated, then the analytics was established using excel which leads to produce of three charts also the power curve was gain.

3.2Design parameters:

3.2.1The Blades:

The selected shape for the blades was simple and the material used to manufacture of the blades is PVC. The mean diameter of the cord was 7.5cm and the length is 49.5cm. The figure below shows cross-section shape of the blades.

Figure [3.1]: Wind turbine blades.



3.2.2 Rotor

The rotor was made by connecting the hub which is made from galvanized steel to the blade via screws.

Figure [3.2]: Wind turbine Rotor

3.2.4 The Nacelle:

The nacelle is constructed from 1PVC pipes, with length of 9.5 cm and 1 standard T coupler.

3.2.5 The Tower:

It is made by using a I PVC pipe with an overall length of 76.5 cm.

Figure [3.3]: The Tower

3.2.6 The base:

It is designed by using a 5 PVC pipes with length of 50 cm,4 PVC standard T coupler and 5 PVC standard 90 elbow.

Figure [3.4]: The base

3.2.7 The Yaw control:

It is made to be simple and it is used by connecting two bearings located inside a PVC joint, the two bearing are connected by one nail so that the nacelle can move smoothly towards the direction of the wind, the tail is made from Galvanized steel and it is design to guarantee a full orientation of the rotor towards the wind direction.

Figure [3.5]: Yaw control system

3.2.8 The Tail:

The tail was made from one PVC pipe and one plate made from galvanized steel. The figure below shows front view for the tail.

Figure [3.6]: The Tail

3.3 Tools and devices:

3.3.1 The anemometer :

It is a device used for measuring the wind speed at certain area

Figure [3.7]: The anemometer

3.3.2The tachometer:

It a device used to measure the amount of torque applied on an axis.

Figure [3.8]: The Tachometer.

3.3.3 Hand tools:

During the construction of the wind turbine we needed for many hand use tools, such as Screwdriver, pliers and meter. The figure below shows a picture for the tools.

Figure [3.9]: Hand use Tools

3.3.4 Mechanical tools:

Different mechanical machines had been used during the design such as:

•Drills: used to drill the hub Slots that match the screws.

•Cutter: used in shaping the blades.

3.4 Dimensions of the module of the wind turbine:

Table below shows the dimensions of different parts of the wind turbine.

Table [3.1]: The module dimensions

Part	**Dimensions**
Cross-sectional shape	Simple
No of blades	3 blades
Radius of the rotor	56 cm
Blade length	49.5 cm
Tower height	76.5 cm
Hub radius	9.6 cm
angle	120 degrees
Blade mean width	7.6 cm

3.5 Khartoum State Wind Data for the last four years:

Table [3.2]: Wind data

Year\month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2013	4.5	5	4.5	3.5	3	3.5	4.5	4	4.5	4	4	4.5
2014	4.5	4.5	5	4.5	4	3	5	4.5	4	4	4.5	4
2015	5	4.5	5	5.5	4	4	4	5	4	3.5	5	5.5
2016	5.5	5	4.5	4	4	4.5	5	4.5	4	3.5	4	5.5

3.6 Experiential wind data and measure turbine speeds:

Three experiments had accomplished, the wind velocity and the turbine speed were measured using anemometer and tachometer, the table below shows various measured data:

Table [3.3]: Wind velocities and turbine speeds.

Exp No	**Wind velocity(m\s)**	**Turbine speed(rpm)**
1	3	106.7
2	3.1	221.2
3	3.2	352
4	3.3	497
5	3.4	518.7
6	3.5	520.6
7	3.6	572.1
8	3.7	584.7
9	3.8	619.6
10	4.3	652
11	4.5	680
12	4.9	786
13	5.1	820
14	5.5	894.2
15	5.7	910
16	5.8	979.8
17	5.9	1041
18	6.1	1167
19	6.3	1364

CHAPTER FOUR

CHAPTER FOUR

CALCULATION, ANALYSIS AND RESULTS

4.1Calculations:

4.1.1 Blade Area:

Using formula (2.22) and data from table [3.1] to calculate the blade area

$$a = 0.076*0.495 = 0.03762\ m^2$$

4.1.2 Blade area:

By using equation (2.23) and taking rotor diameter equals to

$$A= \pi*1.12\hat{}2\backslash 4 =0.9847\ m^2$$

4.1.3 Solidity of the turbine:

$$S = 0.03762/0.4709 = 0.08$$

4.1.4 Air density:

Assuming air Temperature in site is 36 C° and the atmospheric pressure is 1 atom (101.325 kpa) the air density calculated using equation

$$\rho = \frac{101.325}{0.287*309} = 1.1425\ kg\backslash m^3$$

4.1.5 Angular velocity;

The angular is determined using equation (2.7), and from table 3.2 we choose value of turbine speed opposite to wind speed of 4.5 m\s which is 680 rpm, so the angular speed is2

$$\omega= 2*\pi*680\backslash 60 = 71.17\ rad\backslash s$$

4.1.6 Tip speed ratio:

From the formula (2.6) and table [3.1] taking the rotor radius 56 cm, tip speed ratio equals

$$\gamma= 71.17*0.56\backslash 4.5 = 8.856\sim 9$$

4.1.7 The average power gained from the turbine using standard data:

By the data records about wind velocities in the past four years we can calculate the mean wind velocity during years 2013,2014,2015 and 2016 calculated using data from table (2.2), that yields to the results in table below:

Table [4.1]: Yearly average wind velocity in Sudan

Year	Mean wind speed
2013	4.125
2014	4.291
2015	4.583
2016	4.5

Now we calculate the average wind velocity during the past four years in Sudan.

V_{avg}= (4.125+4.291+4.583.4.5)/4 =4.374 m\s

This average wind speed can be using to calculate the average power that the wind turbine can produce during al months of the year.

P_t = 1\2 * 1.1425*0.9847*4.374^3 =47 W

4.1.8 The average power gained using experiment's data;

From table the average wind velocity measured experientially is:

V= (3+3.1+3.2+3.3+3.4+3.5+3.6+3.7+3.8+4.3+4.5+4.9+5.1+5.5+5.7+5.8+5.9+6.1+6.3) \19 =4.457 m\s

Know the average power that turbine extracted calculated using formula (2.4):

P_t =0.5*1.1425*0.9847*4.457^3 =50W

Here notice there slightly increase in power generated from that power calculated using standard wind data.

4.1.9 The max power can be extracted from the turbine:

From table [3.2] we can see that the max wind velocity is 6.3m\s so the power that this turbine can produce is:

P_{max} = 0.5 *1.1425*0.9847*6.3^3 = 140.65 W

4.2 Results:

Using data in table [3.2] we calculate the power of the turbine module for every wind velocity during the experiments using formula (2.4), also the force and torque can be calculated using equations (2.8) and (2.9). table below shows the different calculated data:

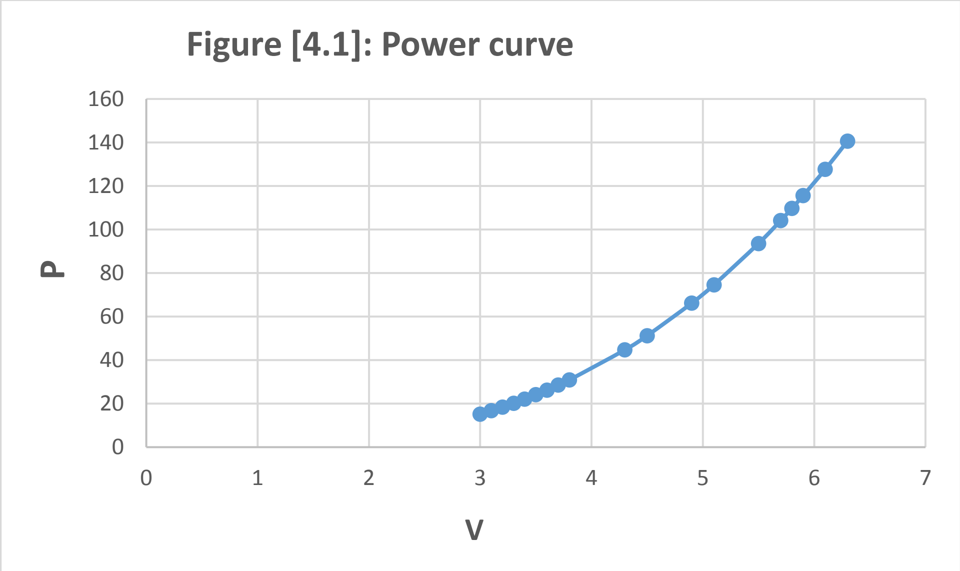
Table 4.2: Results measured from the experiments

No\Data	V(m\s)	N (rpm)	ω(rad\s)	F(pa)	T (N.m)	P_w (W)
1	3	106.7	11.16793	5.062589	2.83505	15.18777
2	3.1	221.2	23.15227	5.40572	3.027203	16.75773
3	3.2	352	36.84267	5.760101	3.225657	18.43232
4	3.3	497	52.01933	6.125733	3.43041	20.21492
5	3.4	518.7	54.2906	6.502614	3.641464	22.10889
6	3.5	520.6	54.48947	6.890746	3.858818	24.11761
7	3.6	572.1	59.8798	7.290128	4.082472	26.24446
8	3.7	584.7	61.1986	7.70076	4.312426	28.49281
9	3.8	619.6	64.85147	8.122643	4.54868	30.86604
10	4.3	652	68.24267	10.40081	5.824452	44.72347
11	4.5	680	71.17333	11.39082	6.378862	51.25871
12	4.9	786	82.268	13.50586	7.563283	66.17872
13	5.1	820	85.82667	14.63088	8.193294	74.6175
14	5.5	894.2	93.59293	17.01592	9.528917	93.58758
15	5.7	910	95.24667	18.27595	10.23453	104.1729
16	5.8	979.8	102.5524	18.92283	10.59679	109.7524
17	5.9	1041	108.958	19.58097	10.96534	115.5277
18	6.1	1167	122.146	20.93099	11.72136	127.6791
19	6.3	1364	142.7653	22.32602	12.50257	140.6539

4.3 Analysis:

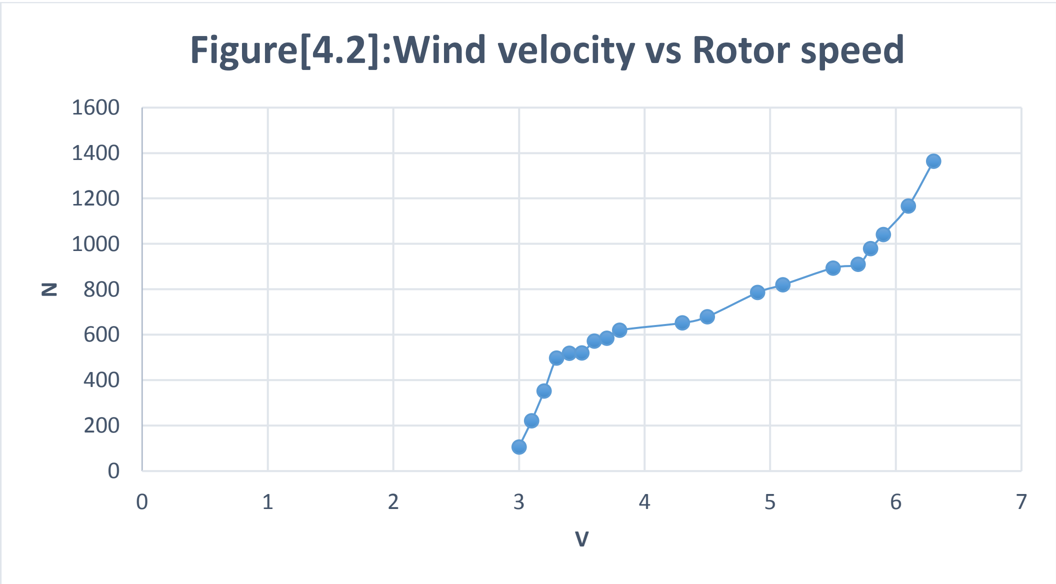
4.3.1 Power curve:

The power curve is obtained by using data in table 4.1 to draw a chart between the wind velocity and power produced.



4.3.2 Effect of wind velocity in rotor speed:

From table [4.1] we can draw the chart of rotor speed regarded to measured wind velocity.



From the curve we notice that the rotor speed increase as the wind velocity increase, and it rich it maximum value (1364) when the wind velocity is at maximum value which is 6.3 m\s.

4.3.3 Effect of rotor diameter on the power extracted by the wind turbine:

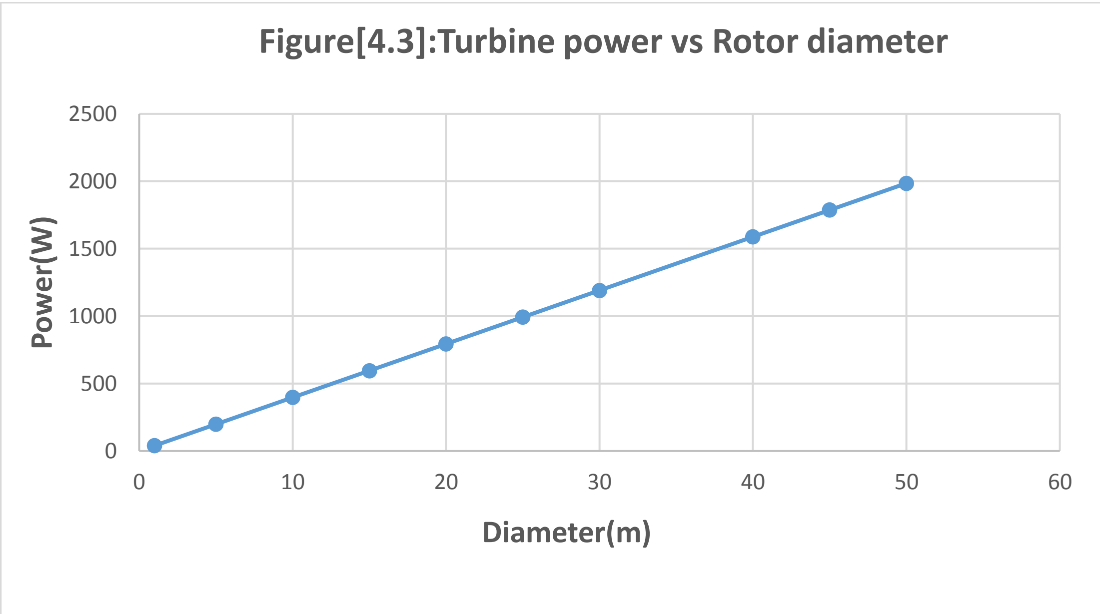
As we increase the rotor diameter the power extracted by the turbine increase, that because the area against which the wind force act is increased. For large scale wind turbine with high rotor diameter and high tower heights the power captured by this turbine is increased significantly, the table below shows

Table [4.3]: Turbine power related to rotor radius

Rotor dia(m)	Turbine power (W)
1	39.70304
5	198.5152
10	397.0304
15	595.5456
20	794.0608
25	992.576
30	1191.091
40	1588.122
45	1786.637
50	1985.152

.

Curve below shows the relation between the rotor diameter and rotor power



From the curve above we notice that the power increase linearly with increasing the rotor diameter until it rich it max value which is (1985.152 W).

CHAPTER FIVE

CHAPTER FIVE

CONCLUSION &RECOMMENDATION

5.1 Conclusion:

. The design was constructed and the experiments were accomplished, from the calculation and results we found that there is a slightly increase in the average power produced (50 W) from the power that calculated from the past wind data (47 W).

The max power produced and torque was 140.65 W and 12.50257 N.m at max speed about 6.3 m\s. From the power curve we can see that lower power that this turbine produces about (15.18777 W) at wind speed of 3m\s (cut in speed).

Although that this power produced is lower than the power produced by non-renewable energies, this power could be stored DC batteries and then transform it to AC, after that it can be utilize in many applications like lighting small lamps or drive a motor for irrigation.

5.2 Recommendation:

For more research on the subject we recommend ate to:

1. Use a generator and connecting it to electric device so that measurement would be more effective.
2. Execution of the study in other places in Sudan, so that the results would be more accurate.
3. Execution of the experiments in various heights and studying effect of increasing height in wind velocity and power produced.
4. Construction of the study using other types of wind turbines and explore the possible application for this type.
5. Use batteries to store the power produced to face the fluctuations of wind speed during the time intervals so we can get the greater utilize of the wind power.
6. Use more shaped and detailed blades with large rotor radius to get greater power.

REFERENCES:

[1] Renewable and non-renewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality Mehmet Akif Destek, Alper Aslan PII: S0960-1481(17)30393-2 DOI: 10.1016/j.renene.2017.05.008

[2] Tong, W. (2010). Wind power generation and wind turbine design. Southampton; Boston, WIT Press.

[3] Wind energy in Sudan Abdeen Mustafa Omer ERI, PO Box 4032, Khartoum, Sudan Received 11 November 1998; accepted 18 January 1999.

[4]Spera, D. A. (2009). Wind turbine technology: fundamental concepts of wind turbine engineering. New York, NY, ASME Press.

[5]Manwell, J. F., et al. (2009). Wind energy explained: theory, design and application. Chichester, U.K., Wiley.

[6] WIND TURBINE TECHNOLOGY, Ahmad Hemami Associate of McGill University, Montreal, Canada and Iowa Lakes Community College, IA, USA

[7]http://drømstørre.dk/wpcontent/wind/miller/windpower%20web/en/tour/design/concepts.htm

[8] Design, model and simulation of windmill for rural areas, Z. Hussein, M. El-Mustafa, M. Ahmed. Sudan University of Science and Technology. Mechanical engineering, 2016

[9]http://www.rcreee.org/content/sudan

APPENDIXES:

APPENDIX [A]: Wind Turbine Module.

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APPENDIX[B]: Annual average wind speeds, annual wind powers and number of years of Observations for the 70 stations in Sudan at 10 m

Item	Name of station	Altitude (m)	Annual mean wind speeds (mph)	Annual mean wind speeds (ms^{-1})	Annual mean wind power (Wm^{-2})	Number of years of observation
1.	Halaib	52.00	11.33	5.07	49.43	10.00
2.	Wadi Halfa	190.00	10.33	4.622	37.48	4.00
3.	Station 6	470.00	10.17	4.548	35.69	10.00
4.	Port Sudan	5.00	11.25	5.032	48.36	10.00
5.	Abu Hamed	315.00	10.67	4.771	41.22	6.00
6.	Dongola	225.00	10.50	4.697	39.32	10.00
7.	Gebeit	795.00	9.00	4.026	24.76	10.00
8.	Karima	250.00	10.42	4.659	38.39	10.00
9.	Toker	20.00	9.08	4.063	25.45	9.00
10.	Aqiq	N.A.	9.25	4.138	26.88	10.00
11.	Atbara	345.00	9.42	4.212	28.36	10.00
12.	Derudeb	510.00	9.00	4.026	24.76	10.00
13.	Hudeiba	350.00	9.00	4.026	24.76	10.00
14.	Shendi	360.00	9.00	4.026	24.76	9.00
15.	Aroma	430.00	N.A.	N.A.	N.A.	N.A.
16.	Wadi Seidna	385.00	9.90	4.436	33.12	10.00
17.	Shambat	380.00	N.A.	N.A.	N.A.	N.A.
18.	Khartoum	380.00	10.00	4.473	33.96	10.00
19.	Kassal	500.00	9.00	4.026	24.76	10.00
20.	Jebel Aulia	380.00	10.08	4.510	34.82	10.00
21.	Halfa El Gedida	450.00	9.17	4.100	26.16	10.00
22.	Abu Quta	390.00	9.83	4.399	32.29	9.00
23.	El Showak	510.00	9.17	4.100	26.16	10.00
24.	Wad Madani	405.00	10.00	4.473	33.96	10.00
25.	Medina Block	405.00	10.25	4.585	36.58	7.00

26.	Kutum	1160.00	7.83	3.504	16.33	10.00
27.	El Gadarif	600.00	8.92	3.988	24.08	10.00
28.	Ed Dueim	380.00	9.00	4.026	24.76	10.00
29.	Wad El Huri	N.A.	N.A.	N.A.	N.A.	N.A.
30.	El Fasher	733.00	7.67	3.429	15.31	10.00
31.	Sennar	420.00	7.00	3.131	11.65	10.00
32.	Doka	N.A.	6.83	3.057	10.84	10.00
33.	El Geneina	805.00	6.83	3.057	10.84	10.00
34.	Kosti	380.00	9.00	4.026	24.76	10.00
35.	El Obeid	570.00	7.58	3.392	14.81	10.00
36.	Dankog	965.00	7.00	3.131	11.65	6.00
37.	Umm Benein	435.00	7.00	3.131	11.65	10.00
38.	Nierteti	N.A.	7.00	3.131	11.65	10.00
39.	Zalingei	900.00	6.00	2.684	7.34	10.00
40.	Murundu	N.A.	6.00	2.684	7.34	10.00
41.	Abu Na,ama	445.00	N.A.	N.A.	N.A.	N.A.
42.	El Nahud	565.00	8.83	3.951	23.41	10.00
43.	Derisa	N.A.	6.00	2.684	7.34	6.00
44.	Kas	N.A.	6.00	2.684	7.34	10.00
45.	Garsila	N.A.	6.00	2.684	7.34	10.00
46.	Nyala	655.00	5.75	2.572	6.46	10.00
47.	Mukgur	N.A.	6.08	2.721	7.65	10.00
48.	Rashed	885.00	6.42	2.870	8.97	10.00
49.	Ed Damazin	470.00	10.00	4.473	33.96	10.00
50.	Er Renk	380.00	6.25	2.796	8.29	10.00
51.	Ghazala Gawazat	480.00	6.75	3.019	10.45	10.00
52.	Babanusa	543.00	6.17	2.758	7.96	6.00
53.	Kadugli	501.00	5.92	2.647	7.03	10.00
54.	Kurmuk	690.00	6.25	2.796	8.29	8.00
55.	Malakal	387.00	6.25	2.796	8.29	10.00
56.	Bentiu	390.00	6.08	2.721	7.65	10.00
57.	Aweil	415.00	6.00	2.684	7.34	10.00
58.	Nasir	400.00	8.00	3.578	17.39	10.00
59.	Raga	545.00	6.00	2.684	7.34	10.00
60.	Gambeila	450.00	6.00	2.684	7.34	17.00
61.	Akobo	400.00	N.A.	N.A.	N.A.	N.A.
62.	Wau	435.00	3.83	1.715	1.91	10.00
63.	Tonj	430.00	5.67	2.535	6.18	10.00
64.	Rumbek	420.00	6.00	2.684	7.34	10.00
65.	Bor	420.00	6.00	2.684	7.34	10.00
66.	Maridi	750.00	6.00	2.684	7.34	10.00
67.	Juba	460.00	3.42	1.528	1.35	10.00
68.	Yambio	650.00	6.00	2.684	7.34	8.00
69.	Torit	625.00	6.42	2.870	8.97	7.00
70.	Yei	830.00	6.25	2.796	8.29	10.00

APPENDIX[C]: experiment’s data

APPENDIX[D]: The turbine speeds

APPENDIX[F]: Wind Data

MINISTRY OF ENVIROMENT,NATURAL RESOURCES AND PHYSYCAL DEVELOPMENT METEOREGICAL AUTHORITY
COMPUTER CENTER

ELFASHER MEAN MONTHLY SPEED IN KNOTS

	jan	fep	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2013	5	5	6	7	7	7	6	5	5	4	4	5
2014	5	5	6	6	6	7	6	5	5	6	5	5
2015	5	6	7	6	6	7	6	5	5	5	5	6
2016	6	6	7	6	7	6	6	6	6	6	6	6

KHARTOUM MEAN MONTHLY SPEED IN KNOTS

	jan	fep	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2013	9	10	9	7	6	7	9	8	9	8	8	9
2014	9	9	10	9	8	6	10	9	8	8	9	8
2015	10	9	10	11	8	8	8	10	8	7	10	11
2016	11	10	9	8	8	9	10	9	8	7	8	11

DONGOLA MEAN MONTHLY SPEED IN KNOTS

	jan	fep	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2013	5	5	4	5	5	6	4	3	3	3	3	3
2014	4	4	4	4	4	5	6	4	3	3	4	3
2015	9	8	10	10	8	8	7	9	10	8	8	9
2016	9	11	9	9	10	8	10	10	12	11	8	10

P-SUDAN MEAN MONTHLY SPEED IN KNOTS

	jan	fep	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
2013	9	3	9	9	8	9	8	9	8	7	9	11
2014	10	10	8	8	8	8	8	9	8	8	10	9
2015	10	9	10	10	8	8	8	8	7	7	10	12
2016	9	10	6	8	8	11	9	8	7	6	9	12

NOTE: KNOT = 1.85 KM/H
KNOT = 0.5 M/SEC