DESIGN AND CONSTRUCTION OF A SELF-ERECTING TOWER FOR A WIND TURBINE

By

AUWAL IBRAHIM

SPS/13/MME/00009

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Supervised by

Prof. I. S. Diso

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Declaration

I hereby declare that this work is the product of my own research efforts, undertaken under the supervision of Prof. I. S. Diso, and has not been presented anywhere for the award of a degree or certificate. All sources of information have been duly acknowledged.

Sign/date ________________________________

Auwal Ibrahim (SPS/13/MME/00009)

Certification

This is to certify that the reseach work for this dissertation, and the subsquent preparation of this dissertation by Auwal Ibrahim (SPS/13/MME/00009) were carried out under my supervision.

Supervisor ___________________________________

Prof. I. S. Diso

Head of Department ___________________________________

Dr. I. A. Yola

Approval

This dissertation has been examined and approved for the award of Masters in Energy Engineering.

External Examiner: ____

Prof. H. Dandakouta

Internal Examiner: ____

Dr. A. A. Adamu

Supervisor: ____

Prof. I. S. Diso

Head of Department: ____

Dr. I. A. Yola

Rep. to Board of SPS: ______________________________ Sign/date: ________________________

Acknowledgement

Praise is to the merciful God, whom by His blessings all good things are perfected. It is He who gave me the opportunity and ability to conduct this reseach work successfully. And this is the point where I will seek for God guidance, forgiveness and assistance to all my family and relatives for their maximum support throughout my studies.

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Dedication

This dissertation is dedicated to my parents and teachers, for being the back bone of my success I am able to achieve in life.

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ABSTRACT

Generally tower is a tall structure, taller than its width by a signficant margin, among the several functions of tower was the installation of horizontal-axis wind turbines aloft, to access the high speed wind current of the atmosphere. Towers for horizontal-axis wind turbines are of many types among which there is the tubular steel tower, which is a tall steel pipe structure usually conical in shape, used to expose horizontal-axis wind turbines to the available wind current. The major challenge in the installation of horizontal-axis wind turbines is the use of mobile crane to install the components. That is why in some areas it is considered impractical to use wind turbines, because of their inaccessibility to a mobile crane such as inside houses. But this research work looks at the new method of installing the tower, without the use of a mobile crane. This dissertation introduces the self-erecting design, in which the whole components of tower and turbine will be assembled at the installation site. The highest peak wind spead measured for the site is 56km/h, the thickness of base plates material that conneted the tower to the base is 11mm, and the calculated size of jack recommended to lift the tower is 2575kg. Also the stiffness of the weak section of the tower was calculated to be 8633kN/m, and the frequency of vibration of the tower was found 191Hz. The dissertation studied the energy consumption pattern of the site, and therefore determined the energy needs of the site to be 72.963kWh. A 48V, 1600W wind turbine was also supplied to be installed. Two anemometers were also installed at different heights at the site, and the wind speed data was recorded during the raining seoson, which is the windiest period in Kano, and the best time to record data for this kind of structural design. The design considered a tubular steel tower, from steel pipes that are symmetrical in diameter, but with the diameter of the pipes increasing toward the base: 51mm, 73mm and 89mm. The pipes were assembled together using steel reducer sockets, and then welded to obtain a permanent solid tower. The erection of the tower was achieved by the use of a screw jack, that is selected and attached to the tower at the fulcrum, while the tower is tilting at the pivot that connected the tower to the base. The tower was constructed using the materials available in Kano markets, and the self-erection mechanism was tested and achieved. However, it is recommended to use an electric jack, that requires less effort to operate.

CHAPTER ONE

1.0 INTRODUCTION

1.1.0 Background of the Study

The term wind energy or wind power describes the process by which wind is used to generate mechanical power from which electricity can be produced. Wind power machines use wind turbine, which is a rotary device that extracts energy from the wind. The kinetic energy of the wind turns the blades of the turbine, which spin a shaft that is connected to a generator, and electricity is produced. The primary source of wind is as a result of atmospheric temperature differences, generated from the uneven heating of the earth by the sun which in turn gives rise to pressure differentials (Frank and Goswami, 2007). The use of wind power is said to have its origin in the civilization of china, India, Afghanistan and Persia. (Cheremisinff, 1978).

Wind energy has long been considered as a clean and renewable source of energy, and has been widely used for mechanical power and battery charging. In recent years, environmental concerns on the rapid depletion of the ozone layer, and the escalating cost of power bills brought the need for alternative and renewable energy sources into the limelight.

The Nigeria National Energy Policy and the Renewable Energy Master Plan stipulate the country's desire to increase electricity production through the development of its alternative energy sources (FMPS, 2006), of which wind, solar and biogas are major. Thus, efforts at measuring and assessing these resources for electricity generation are vital to Nigeria’s energy development.

As an international issue, growing global population along with fast depleting reserves of fossil fuels is influencing researchers to look for a clean and pollution-free sources of energy such as solar, wind, and bio-energies. Globally different sources of energy production which include fossil fuel burning, small and large scale hydro, nuclear power, biomass burning, etc., have made major headlines in national and regional discussions of energy development. Some of these sources indeed have produced adequate amount of energy for community and national electricity production. However, the need to secure the environment while also developing the national economy has driven the trend toward diversification of energy production modules across the globe (Islam, 2012). More so, the finite nature of conventional energy sources renders them unsustainable for long-term energy planning. Based on this, the focus of energy development and planning has shifted to include the non-conventional yet environmentally friendly sources of wind, solar, biomass, geothermal, and other renewable energy sources.

Wind energy is a never ending natural resource which has shown its great potential in combating climate change while ensuring clean and efficient energy. Further, rapid advances in wind turbine technology led to significant growth of wind power generation across the world. However, wind energy is more sensitive to variations with topography and wind patterns compared to solar energy. Wind energy can be harvested economically if the turbines are installed in a windy area and a suitable turbine is properly selected.

Constructing a wind turbine to be economically viable at homes or farms strongly depends on the quality of the wind resource. Generally, most small wind turbines need an average wind speed of 4.5metres per second (16.2km/h) to operate effectively to produce enough electricity to be cost-effective (EECA, 2015). A very useful resource for evaluating a site for its wind energy potential is a wind resource potential map.

Good selection of a wind turbine site is a critical factor that influences the value of energy to be produced. It may be useful to check wind speed measurements that have been recorded at a local weather station. Wind turbine construction is economically viable at home or farm depending on the weather station. It is important to consider that siting factors at these weather stations, such as nearby trees and buildings, might influence any wind speed measurement.

The primary precondition in siting the wind turbine is to choose a location and height at which the machine can best be exposed to the available wind current, with no surrounding obstruction. Higher towers involve higher cost, but will be necessary where drag effects of surrounding forces or building interfere seriously with available wind flow to the machine.

Generally, tower is a tall structure, taller than it is width, often by a significant margin. Towers are distinguished from masts by their lack of guy-wires and are therefore, along with tall buildings, and self- supporting structures.

Towers can be stand-alone structures or be supported by adjacent buildings or can be a feature on top of a large structure or building. Towers are specifically distinguished from buildings in that they are not built to be habitable but to serve other functions. The principal function of towers is the use of their height to enable various functions to be achieved including visibility of other features attached to the tower such as clock towers, as part of a larger structure or device to increase the visibility of the surroundings as in a fortified building such as a castle, or as a structural feature as an integral part of a bridge, and can also be used to harness the available sources of energy in the atmosphere.

The trends in wind turbine design are towards larger machines (over 1MW) and towards taller supporting towers. Both of these trends task the ability of conventional installation methods which rely on mobile cranes to install the components.

But another study examined possible methods of installing the tower and wind turbine without the use of cranes. One of the methods selected by this dissertation was a system involving self-erecting design, in which the whole components can be erected up and down by changing the angle of inclination of tower, between any angles above zero degree to the horizontal, to the highest angle of 90 degrees to the horizontal. This self-erection of the tower will enable easy access to the components of turbine during installation and maintenance of the machine.

1.2.0 Statement of the Problem

Wind turbines are installed on a long tower usually of cylindrical metal, which exposes the turbine to a higher wind current, but which makes accessibility to the turbine difficult, especially during maintenance and repair of the machine. With this research work, of self-erecting tower for the wind turbine, which expressed the idea that the whole turbine machine can be erected up and down without the use of a mobile crane, this difficulty can be overcome especially for small wind turbines that can be used for domestic power generation.

1.3.0 Aim and objectives

The aim of this dissertation is to design and construct a self-erecting tower for a horizontal-axis wind turbine.

Objectives of this work are:

i. To study the energy consumption and energy need of the research site;

ii. To design the tower by analyzing the component of forces on the tower; and

iii. To construct and install the tower in a residential area.

1.4.0 Significance of the Study

This work will simplify the installation and minimize maintenance cost of a wind generator erected on a tall tubular tower. It will encourage the use of small wind turbines especially for domestic applications, and this is a welcome development in fighting the global warming. It will also demonstrate the conversion of alternative source of energy ‘‘wind’’ to electrical energy as against the current predominance of conversion from conventional fossil fuel which is not environmentally friendly.

1.5.0 Justification of the Study

A self-erecting tower to be developed in this work will reduce the challenges faced by Engineers who are involved in the installation of a wind turbine. The idea will serve as a useful technique to reduce the difficulty and cost of installing the wind turbine, especially for small wind turbines that’s meant for domestic use. The inconveniencies associated with the access of mobile cranes to the installation site which may be inside houses is completely eliminated, and the turbine machine can easily be brought down for lubrication and repair services at the owner’s convenient time without the need of any supporting machine which might attract additional cost. The idea will also encourage the use of small wind turbines in our houses, and sites with wind energy resources that were previously considered impractical because they were inaccessible to mobile cranes, and which is among the best option in fighting the atmospheric pollution.

1.6.0 Methodology

The methodology employed in this research work involved the following:

i. Collection of wind speed data;
ii. Calculation of the average wind speed of the area and determining the peak wind speed;

iii. Measurement of weight of the wind turbine and its accessories;

iv. Calculation of the tower diameter in steps of length, from the largest diameter at the base of the tower to the smallest diameter at the top of the tower;

v. Selection of the size of jack to lift the tower by analyzing the moment of forces on the jack;

vi. Calculation of the base plates thickness, hinges and size of bolts and nuts to be used;

vii. Construction and installation of the tower; and

viii. Erecting the tower up, down and up to test the workability of the self-erection mechanism.

1.7.0 Scope and Limitation

1.7.1 Scope

The scope of this research work is to design the tower to a maximum height of about 18.5 meters, construct the tower and install the tower in a residential area at Gwale Local Government Area in Kano city. This dissertation will only design and construct the main components of the tower, and will adopt the appropriate size of a screw jack available in Kano markets for the self-erection of the tower.

1.7.2 Limitations

This dissertation will construct the tubular steel tower using the available materials in Kano markets, and therefore cannot produce the tower in its usual conical shape as it is in the standard shape of tubular steel towers. This research work will therefore produce the tower using standard steel pipes that are uniformly symmetrical in diameter, but will compensate for its usual conical shape by producing the tower in steps of size of its diameter, with the diameter of the tower materials increasing toward the base. Also an electric jack is best to be used for this kind self-erecting tower, but due to the lack of availability of the required size in Kano markets, the screw jack will be selected.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.0 Introduction

Wind energy has been used for thousands of years to propel boats and ships, and to provide rotary windmill power to reduce the physical burden of man. The wind turbine is an intervention that dates from the earliest time of an invention history (Elwakil, 1984).

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 (Price, 2004). Although Blyth's turbine was considered uneconomical in the United Kingdom, but some months later, in 1888 American inventor Charles F. Brush built the first automatically operated wind turbine for electricity production in Cleveland, Ohio (Price, 2004). The Brush machine was a post mill with a multiple-bladed "picket-fence" rotor 17 meters in diameter, featuring a large tail hinged to turn the rotor out of the wind. It was the first windmill to incorporate a step-up gearbox (with a ratio of 50:1) in order to turn a direct current generator at its required operational speed (in this case 500 RPM). Despite its relative success in operating for 20 years, the Brush windmill demonstrated the limitations of low-speed, high-solidity rotor for electricity production applications (TelosNet, 2008). Electricity generation by wind turbines was more cost effective in countries with widely scattered populations (Morthost, Redlinger, Robert, and Andersen, 2002).

In Denmark by the 1900s, there were about 2500 windmills for mechanical loads such as pumps and mills, producing an estimated combined peak power of about 30 MW. The largest machines were on 24meter (79ft.) towers with four-bladed 23meter (75ft.) diameter rotors. By 1908 there were 72 wind-driven electric generators operating in the United States, generating between 5 kW to 25 kW of electricity. While in 1930s, wind generators for electricity were common on farms, mostly in the United States where distribution systems had not yet been installed. In this period, high-tensile steel was cheap, and the generators were placed at the top of prefabricated open steel lattice towers (Alan, 1986).

The first written evidence for the use of wind turbines are that of Hero of Alexandria who in the third or second century BC described as given power to an organ, but it has been discussed whether it was of any practical use apart from being a kind of toy (Energy Book, 2010). Windmills were used in Persia (present-day Iran) as early as 200 B.C. (TelosNet, 2008). The wind wheel of Hero of Alexandria marks one of the first known instances of wind powering a machine in history (Drachmann, 1961 and Dietrich, 1995). However, the first known practical windmills were built in Sistani, an Eastern province of Iran, from the 7th century. These "Panemone " were vertical-axis windmills, which had long vertical drive shafts with rectangular blades made of six to twelve sails covered in reed matting or cloth material (Hassan, 1986). These windmills were used to grind grain or draw up water, and were used in the grist milling and sugarcane industries (Donald, 1991). Windmills first appeared in Europe during the middle Ages. The first historical records of their use in England dated to the 11th or 12th centuries and there were reports of German crusaders taking their windmill-making skills to Syria around 1190 (Morthost, Redlinger, Robert, and Andersen, 2002). By the 14th century, Dutch windmills were in use to drain areas of the Rhine delta. Advanced wind mills were described by Venetian inventor Fausto Veranzio. In his book Machinae Novae (1595) he described vertical axis wind turbines with curved or V-shaped blades. A forerunner of modern horizontal-axis wind generators was in service at Yalta, USSR in 1931. This was a 100kW generator on a 30meter (98ft.) tower, connected to the local 6.3kV distribution system. It was reported to have an annual capacity factor of 32 percent, not much different from the current wind machines (Alan, 1986). The first automatically operated wind turbine, built in Cleveland in 1887 by Charles F. Brush, was 60 feet (18m) tall, weighed 4 tons (3.6 metric tons) and powered a 12 kW generator (Charles, 2008). In 1997, about 200-250 wind machines have been installed in Botswana here in Africa, mainly in the agricultural sector for pumping water from bore holes (Stephen and Timothy, 1997).

Wind turbines research and construction project can also be found in Nigeria, such as in Ahmadu Bello University Zaria where 700W, three blades horizontal-axis wind turbine project was conducted by Isyaku (2010), in which 290W was generated at a rated speed of 6.22m/s. Also, in Kano University of Science and Technology Wudil, a group project by Wudil, Dare, Job and Isah (2011) designed a 500W horizontal-axis wind turbine and generated 240W at a rated wind speed of 6.74m/s.

In another research conducted in 20's, by German professor Albert Bertz of the German Aerodynamics Research Center in Gottingen, who made some path-breaking theoretical studies on wind turbines, he calculated that, "no wind turbine (even if 100% efficient) could convert more than 59.3% of the kinetic energy of the wind in to mechanical energy turning a rotor" (EECA, 2015). This is known as the Bertz limit, and is the theoretical maximum coefficient of power for any wind turbine. However, practically good wind turbines generally converts 35-45% of the available wind energy to electricity. The amount of energy generated by a wind turbine is dependent upon the height of a tower to which the wind turbine is installed.

Generally, towers have been used by mankind since prehistoric times. The oldest known may be the circular stone tower in walls of Neolithic Jericho (8000 BC). Some of the earliest towers were ziggurats, which existed in Sumerian architecture since the 4th millennium BC. The most famous ziggurats include the Sumerian Ziggurat of Ur, built in the 3rd millennium BC, and the Etemenanki, one of the most famous examples of Babylonian architecture. The latter was built in Babylon during the 2nd millennium BC and was considered the tallest tower of the ancient world (Michael, 2007).

Some of the earliest surviving examples are the broch structures in northern Scotland, which are conical tower houses. These and other examples from Phoenician and Roman cultures emphasized the use of a tower in fortification and sentinel roles. The Romans utilized octagonal towers as elements of Diocletian's Palace in Croatia, which is a monument dates to approximately 300 AD, while the Serbian Walls (4th century BC) and the Aurelian Walls (3rd century AD) featured square ones. The Chinese used towers as integrated elements of the Great Wall of China in 210 BC during the Qin Dynasty (Michael, 2007). Towers were also an important element of castles.

Other well-known towers include the Leaning Tower of Pisa, in Pisa Italy, built from 1173 until 1372, and the two towers in Bologna Italy built from 1109 until 1119. The Himalayan towers are stone towers located chiefly in Tibet, built approximately 14th to 15th century (Dana, 2003).

From the literature survey on the research of the existing towers, a study on high resolution tower shadow model for downwind wind turbine shows a strong impulsive response of the blade loading, when the blade is passing out of the tower shadow, which requires further investigation (Wang, 2001). Another study on along-wind response of a wind turbine tower with blade coupling subjected to rotationally sampled turbulence wind loading, shows that the resultant base shear stress is imparted in to the top of the tower (Murtagh, 2005). While a study on the static and dynamic characteristics of multi-cell jointed glass-fiber reinforced polymer (GFRP) wind turbine towers validated the results from finite element models under static loading through comparison with the experimental results (Polyzois, 2009). Another study on load and resistance factor in the design of composite columns, found that the design model is conservative, and that the scatter of the tests with respect to the American Institute of Steel Construction (AISC) design model is also high (Lundberg, 2009). In Korea, a study on optimal design of a steel tower shell thickness of 2MW class wind turbine system through the numerical analysis of natural frequency, strength, fatigue and buckling depending on the shell thickness change is carried out. It confirmed that the final proposed tower meets the tower design requirement (Kim, 2009). Also a study on vibration characteristics of steel tower for a large wind power turbine system considering wind loads and seismic loads shows that, guyed steel wire elements reduces the seismic base shear by about 15% of the design value (Hyeoksoo, 2006).

A study funded by the windPACT program examined possible methods for installing the tower and wind turbine without the use of cranes. One of the methods selected by that study was a system involving a frame which could climb the tower. In an independent study by D. H. Blatter & sons and Elgood Mayo Corporation jointly developed and assessed a specific self-erecting design concept (Fredricson and Brennan, 2000).

In December 2001, D. H. Blatter & sons Inc. (DHB) submitted a proposal to the Xcel Renewable Development Fund (RDF) for a 3-phase program to develop and commercialize a system for the self-erection of turbine (Vandenbosche, 2001). These theoretical contributions on wind turbines research, development and findings are still the foundations of today's turbine theories.

2.1.1 Useful Energy of the Wind

The range of operation of a wind turbine from the wind power depends upon the wind speed. At low wind speed, there is insufficient energy to operate the turbine coupled to the generator and no power is produced.

At the "cut-in" speed V_i, wind turbine starts to produce electric power in the generator, until rated power is produced at "rated wind speed "V_r. This is the point where the power generated reaches its peak; after this point, the turbine is controlled usually by altering the blade angle or pitch to give rated output up to a "Cut-out" speed V_o, the point at which the blades are furled and the unit is shut down to avoid excessive wind loading.

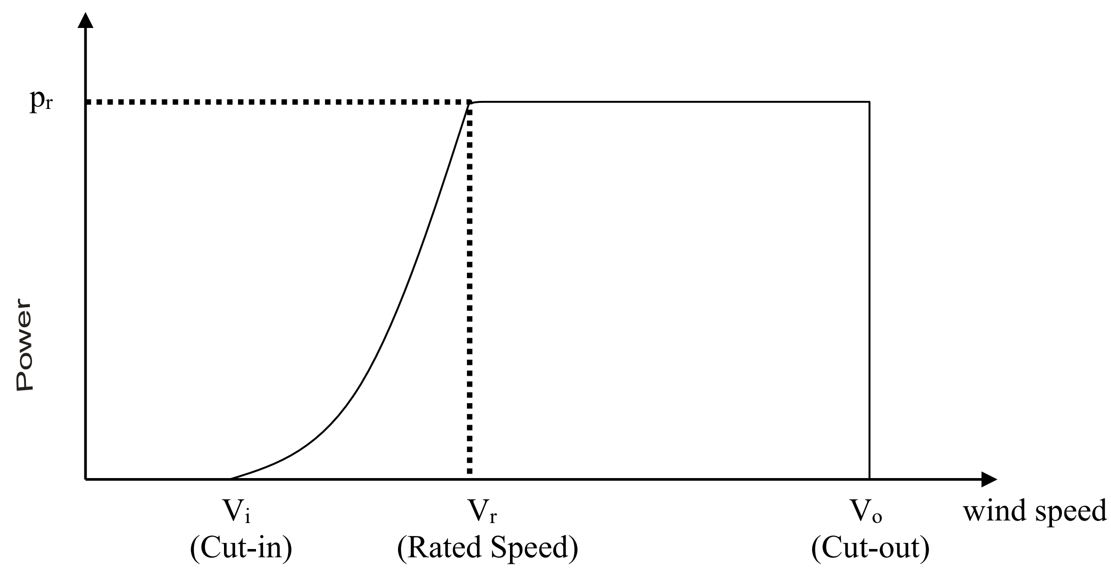


Fig. 2.1 Range of operation of wind turbine (W.P.P, 2015)

2.2.0 Sizes of Wind Turbine

Wind turbines used to generate electricity are in a wide variety of sizes. They can be divided into three classes

i. Large wind turbines

ii. Medium wind turbines

iii. Small wind turbines

2.2.1 Large Wind Turbine

Large wind turbines which are usually installed in clusters called wind farms, can generate large amounts of electricity. Large wind turbines may even produce hundreds of megawatts (MW) of electricity enough to power hundreds of homes. Large wind turbines are behemoth with rotors spanning diameters between 60 and 100m (200 to 330 ft.) (U.S.D.E, 2010). The cost effectiveness of conventional coal-fired and oil fired power plants increases with the size of the plants; but, it was originally thought that giant wind turbines would be more economical than smaller turbines. Various countries have attempted to develop commercial multi-megawatt wind turbines, but these machines have proved to be less economical and less reliable than medium size turbines.

2.2.2 Medium Wind Turbine

Most commercial wind machines are medium-size turbines. Medium-size turbines use rotors spanning diameters between 15 and 60 m (50 and 200 ft), and have a generating capacity ranging from 50 to 1,500 kilowatts. Most medium-size commercial turbines have a generating capacity in the range of 500 kilowatts to 750 kilowatts (U.S.D.E, 2010).

2.2.3 Small Wind Turbine

A small wind turbine is a wind turbine used for micro generation, as opposed to large commercial wind turbines, such as those found in wind farms, with greater individual power output. These turbines may be as small as a fifty-Watt generator for boat, caravan, or miniature refrigeration unit.

Smaller scale turbines for residential scale use are available. They are usually approximately 7 to 25 feet (2.1-7.6m) in diameter and produce electricity at a rate of 300-

10,000Watts at their tested wind speed. Some units have been designed to be very light weight in their construction, e.g. 16 kilograms (35 lb.), allowing sensitivity to minor wind movements and a rapid response to wind gusts typically found in urban settings and easy mounting much like a television antenna. The majority of small wind turbines are traditional horizontal axis wind turbines (Gipe, 2009).

The generators for small wind turbines usually are three-phase alternating current generators and the trend is to use the induction type. There is option for direct current output for battery charging and power inverters to convert the power back to AC but at constant frequency for grid connectivity. Some models utilize single-phase generators (Forsyth, 2009).

Some small wind turbines can be designed to work at low wind speeds (Luleva, 2013). Dynamic braking regulates the speed by dumping excess energy, so that the turbine continues to produce electricity even in high winds. The dynamic braking resistor may be installed inside the building to provide heat (during high winds when more heat is lost by the building, while more heat is also produced by the braking resistor). The location makes low voltage (around 12 volt) distribution practical.

Small units often have direct drive generators, direct current output, and lifetime bearings. They use a tail vane to point into the wind. Larger more costly turbines generally have geared power trains, alternating current output and are actively pointed into the wind. Direct drive generators are also used on some large wind turbines.

2.2.4 Utility Scale Turbines

Utility scale turbines range in size from 100kW to as large as several megawatts. Large turbines are grouped together into wind farms, which provide bulk power to the electrical grid.

According to Energy Efficiency and Renewable Energy (EER) Office of U.S Energy Department, single small turbines below 100kW are used for homes, telecommunications dishes, or water pumping. Small turbines are sometimes used in connections with diesel generators battery and photovoltaic systems. These systems are called hybrid wind system and are typically used in remote areas that are off-grid locations where a connection to the utility grid is not available.

2.3.0 Types of Wind Turbine

There are two basic types of wind turbines base on the axis in which the turbine rotates:

i - Horizontal axis wind turbine; and

ii - Vertical axis wind turbine.

2.3.1 Horizontal-Axis Wind Turbine

Horizontal axis turbines (more common) have the axis of rotation parallel to the wind direction. They come with a tail vane that will continuously control them in the direction of the wind. Horizontal-axis wind turbines have the main rotor shaft and electrical generator at the top of a tower. Small horizontal turbines are directed to face the wind by a simple wind vane, while large horizontal turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades in to a quicker rotation that is most suitable to drive an electrical generator, since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. The turbine blades are made stiff to prevent the blades from being pushed in to the tower by high winds.

Plate I. Horizontal-axis Wind Turbine
Source: wellsee.com

Horizontal axis wind turbines are sub-divided into the following;

i. 12th-century Windmills

These squat structures, typically have at least four blades, usually with wooden shutters or fabric sails, were developed in Europe. These windmills were pointed into the wind manually or via a tail-fan and were typically used to grind grain. In the Netherlands they were also used to pump water from low-laying land, and were instrumental in keeping its polders.

ii. 19th-century Windmills

They typically have many blades, operated at a tip speed ratio greater than one, and have good starting torque. Some have small direct-current generator used to charge storage batteries, to provide power for lighting, or to operate a radio receiver. An example of the 19th-century windmill is the eclipse windmill factory, which was established around 1988 in Beloit Wisconsin and soon became successful building mills for pumping water on farms and for filling railroad tanks. These devices are also used to generate electricity in location where it is too costly to bring in commercial power.

iii. Modern Wind Turbines

These have high tip speeds of up to six times the wind speed, high efficiency, and low torque ripple, which contribute to good reliability. The blades are usually colored light gray to blend in with the clouds and ranges in length from 20 to 40 meters (65 to 130ft) or more. The tubular steel towers range from 200 to 300 feet (60 to 90metres) tall. The blades rotate at 10-22 revolutions per minute. A gear box is usually used to step up the speed of the rotor, although designs may also use direct drive of an annular generator. These turbines are used in wind farms for commercial production of electric power and they usually have three blades and also pointed into the wind by computer-controlled motors.

The advantages of horizontal-axis wind turbines include:

1. Variable blade pitch, which gives the turbine blades the optimum angle of attack;
2. The tall tower base allows access to stronger wind in sites with wind shear; and
3. High efficiency, since the blades always move perpendicular to the wind, receiving power through the whole rotation.

2.3.2 Vertical-Axis Wind Turbine

Vertical axis turbines work in whatever direction the wind is blowing, but require a lot of ground space to support their guide wires than horizontal axis wind turbines. Vertical axis turbines are less frequently used and they have their main rotor shaft arranged vertically.

With a vertical axis wind machine, the generator and gearbox can be placed near the ground, so the tower doesn't need to support it, and it is more accessible for maintenance. The drawbacks of vertical axis wind turbine are that some designs produce pulsating torque. Drag may be created when the blade rotates into the wind. It is difficult to mount vertical-axis turbine on tower, meaning they are often installed nearer to the base on which they rest, such as the ground and rooftop. The wind speed is slower at lower altitude, so less wind energy is available for a given size turbine. Airflow near the ground and other objects can create turbulent flow, which can cause vibration, with noise and bearing wears which may affect the maintenance or shorten the service life of the wind turbine.

Vertical axis wind turbine are sub-divided into the following:

i. Darrieus Wind Turbine

They are also known as Eggbeater turbines. They have good efficiency, but produces large torque ripple and cyclic stress on the tower, which contributes to poor reliability. Generally they require some external power source, or an additional Savonius rotor to start turning, because the starting torque is very low. The torque is reduced by using three or more blades which result in a higher solidity for the rotor.

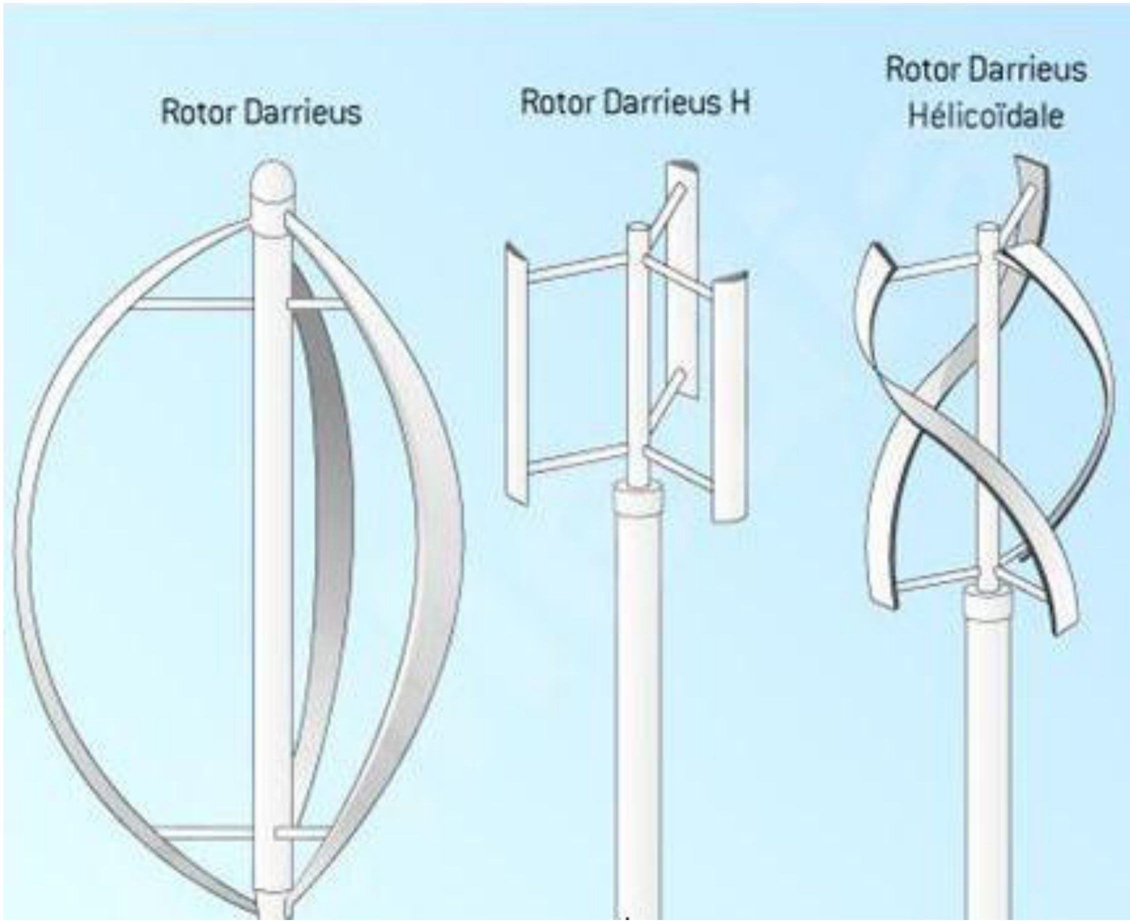


Plate II. Main Designs of Darrieus Wind Turbine
Source: eolienne.comprendrechoisir.com

ii. Savonious Wind Turbine

These are drag-type devices with two or more scoops that are used in anemometers, flatter vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines. They are always self-starting if there are at least three scoops. They sometimes have long helical scoops to give a smooth torque.

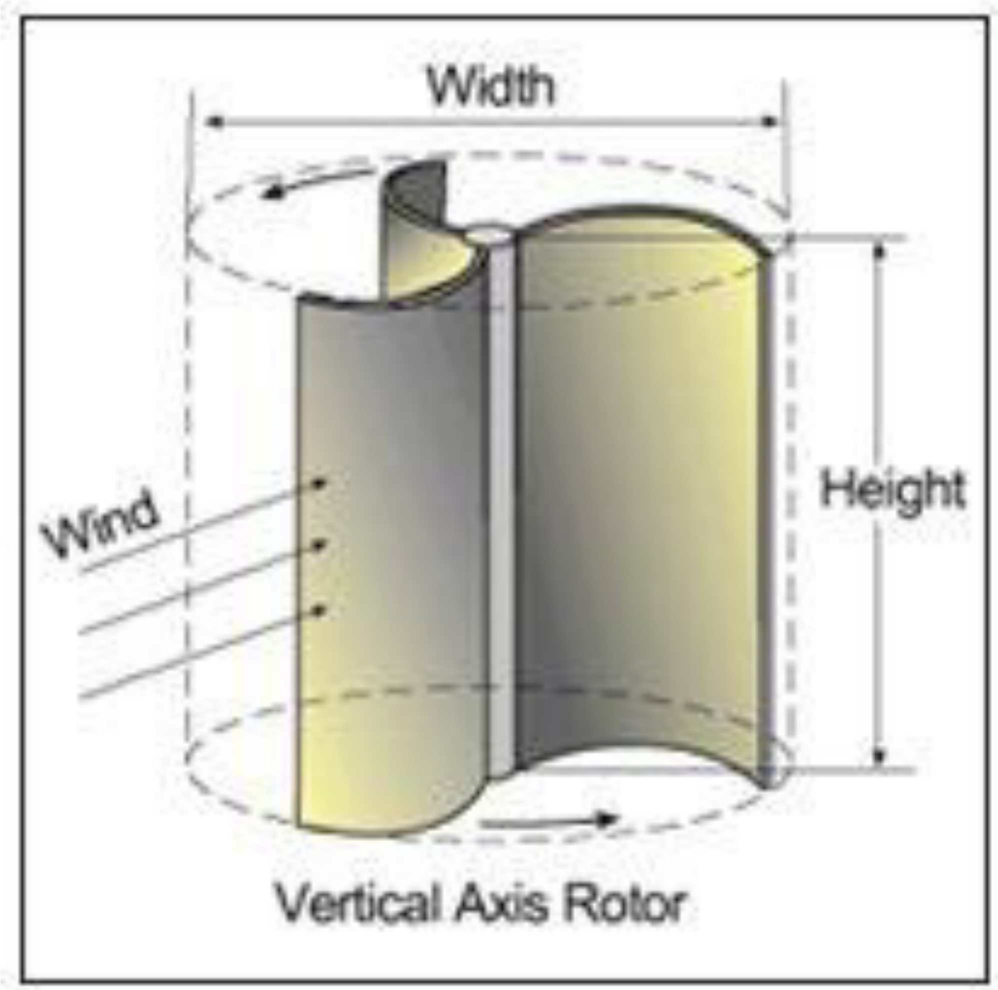


Plate III. Savonious Wind Turbine

Source: www.itv.no

The advantages of vertical-axis wind turbine are as follows (Cheremisinff, 1978):

1. A massive tower structure is less frequently used, as vertical axis wind turbine are more frequently mounted with the lower bearing mounted near the ground.
2. A vertical axis wind turbine can be located nearer to the ground, making it easier to maintain the moving parts.
3. VAWTs have lower wind start-up speeds than HAWTs, typically they start generating electricity at 6Mph.

4. VAWTs may be built at locations where taller structures are prohibited.
5. VAWTs may have a lower noise signature.

2.4.0 Towers for Horizontal-Axis Wind Turbine

A tower is a tall component used to expose the horizontal-axis wind turbines to the available wind current, it is what a horizontal wind turbine is mounted on. Vertical-axis wind turbines do exist, but they are generally built into the ground or building. The height of the tower of a horizontal wind turbine does play a role in how much wind energy will be produced. The speed of wind increases with height, and so any increase in the height of a horizontal wind turbine tower will mean larger increase in the amount of electricity that can be generated by the turbine.

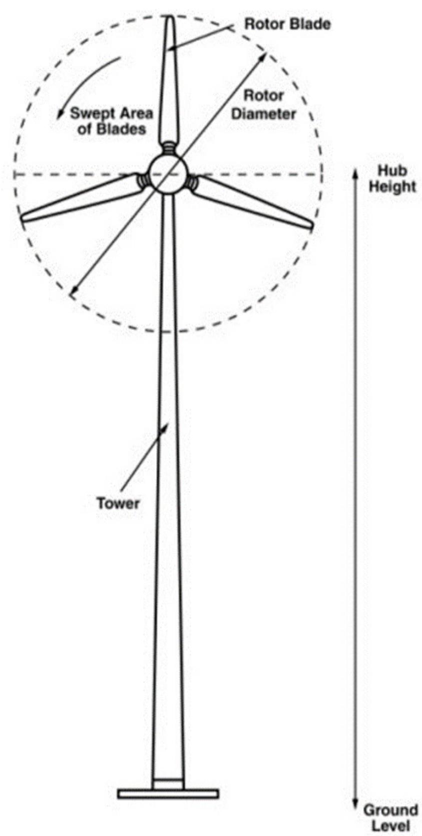


Fig. 2.2 A schematic diagram of a wind turbine
Source: www.solacity.com

Towers for horizontal-axis wind turbines may be either tubular steel towers, lattice towers, or concrete towers.

2.4.1 Lattice (Truss) Towers

Lattice towers are manufactured using welded steel profiles. The basic advantage of lattice towers is cost, since a lattice tower requires only half as much material as a freely standing tubular tower with a similar stiffness. The basic disadvantage of lattice towers is their visual appearance, (although that issue is clearly debatable). Be that as it may, for aesthetic reasons lattice towers have almost disappeared from use for large, modern wind turbines.

(a)

(b)

Plate IV. Lattice (Truss) Towers

Source: Danish Wind Industry

2.4.2 Tubular Steel (Pipe) Towers

Most large wind turbines are delivered with tubular steel towers, which are manufactured in sections with flanges at either end, and bolted together on the site. The towers are conical (i.e. with their diameter increasing towards the base) in order to increase their strength and to save materials at the same time.

(a)

(b)

Plate V. Tubular Steel (Pipe) Towers

Source: Danish Wind Industry

2.4.3 Reinforced Concrete Towers

There has been significant growth over the past years in the size of wind turbines, which went from hundreds of kilowatts to several megawatts. This change in size has also imposed very strict conditions for wind turbine components, including steel towers. The demand generated by the limitations of the current technologies of the steel towers has led to the development of technologies for precast concrete wind towers of high-energy performance that can overcome heights and weights not achievable by steel towers.

The Reinforced Concrete Tower design consists of several cylindrical reinforced concrete modules, manufactured in rotating molds, all tower elements are post-tensioned with steel cables that pass through them to the concrete foundation, and the space between the cables and concrete wall is sealed.


(a)


(b)

Plate VI. Reinforced Concrete Towers

Source: www.windpowermonthly.com

Like in steel pipe towers, a wide tower base diameter contributes to optimized load transfer from tower to foundation. Reinforced concrete towers are mainly used for large wind turbines of several megawatts.

All these towers task the ability of conventional installation methods, which rely on mobile cranes to install the components. But this research work looks at the new method of installing the tower using the self-erecting design, in which the whole components will be assembled at the installation site and erected-up by changing the angle of inclination of tower from 0^0 to the horizontal to a maximum angle of 90^0 to the horizontal.

2.5.0 Environmental Aspects of Winds Power Utilization

Opinion surveys in areas of the European Union with wind farms or many farms or many wind turbines (such as Denmark and UK) indicated that 70 to 80% of the population is generally supportive or unconcerned with respect to the wind turbines in the neighborhood. In a referendum in a Danish municipality with a very large number of wind turbines, 77% of the votes favored even more machines.

The political debate is often quite polarized. On one hand, in many countries the public in general favor renewable energy sources such as wind power. On the other hand, deploying a wind farm in a local community sometimes raises local resistance due to the neighbor’s uncertainty and negative expectation about the wind turbines. The public is concerned with environmental effects of wind power such as visual intrusion, impact on birds and birds’ inhabitant, acoustic noise, emission safety, moving shadows, etc.

In industrialized countries, public acceptance of wind power is often the most important planning restriction, and consequently a political issue. Experience in developing countries is still limited, but recent large scale applications in India and China show both reliable production and high degree of public acceptance along with private sector participation (Andersen, 1995).

2.5.1 Atmospheric Emissions

No direct atmospheric emissions are caused by the operation of wind turbines. The indirect emission from the energy used to produce, transport and decommission a wind turbine depends on the type of primary energy used.

2.5.2 Liabilities after Decommissioning

Electricity from wind turbines has no liabilities related to decommissioning of obsolete plants. Today, most metals parts of wind turbines can be re-cycled. In a very near future, other parts such as electronics and blades may be recycled almost to 100%.

2.5.3 Energy Balance

The direct environmental effects related with manufacturing of wind turbines is similar to those equipment production processes, and indirect environmental effects of the energy used to produce a wind turbine depends on the types of primary energy used. Early investigations have shown, that the energy invested in production, installation, operation and maintenance and decommissioning of typical wind turbine has ‘pay-back’ time (energy balanced) of less than a year of operation (World energy Council, 1994).

2.5.4 Land use

Wind energy is diffuse and collecting energy from the wind requires turbines to be spread over a wide area. As a rule of thumb wind farms requires 0.08 to 0.13 km^2 /MW (8-13MWkm^2). The area needed for 100,000MW is less than 0.3% of the territory covered by the European Union.

Onshore winds have the advantage of dual land use, 99% of the area occupied by a wind farm be used for agriculture or remain as natural habitat; furthermore, part of the installations can be made offshore. Consequently, limited area of land is not a physical constraint for wind power utilization, as it could be for large scale utilization of biomass in energy production.

2.6.0 Uses of Wind Turbine

Traditionally wind energy has been used since the earliest civilization to grind grains, pump water from deep wells and power sail boats. Wind mills in pre-industrial Europe were used for many things including irrigation or drainage pumping, grain grinding, saw milling of timber and the processing of other commodities such as spices, cocoa, paint and dyes, and tobacco. With the introduction of the steam engine in the 18th century, the world gradually changes its demand for power to techniques and machines based on thermodynamics processes.

Wind turbines in this days are primarily used mainly for electricity generation in alternating and direct current, and for pumping of water especially from deep wells.

2.7.0 Functions of Tower

i. Towers are used to access atmospheric conditions aloft, such as in wind turbine installation, meteorological measurement, telescope mounting and in solar power station.

ii. Its strategic advantages in security made tower throughout history to provide its users with an advantage in surveying defensive positions and obtaining a better view of the surrounding areas, including battlefields. They were constructed on defensive walls, or rolled near a target. Today, strategic-use towers are still used at prisons, military camps, and defensive perimeters.

iii. It's also used as a source of potential energy, by using gravity to move objects or substances downward, a tower can be used to store items or liquids like a storage silo or a water tower, or aim an object into the earth such as a drilling tower. Ski-jump ramps use the same idea, and in the absence of a natural mountain slope or hill, can be human-made.

iv. As a means of communication enhancement, in history, simple towers like lighthouses, bell towers, clock towers, signal towers and minarets were used to communicate information over greater distances. In more recent years, radio masts and cell phone towers facilitate communication by expanding the range of the transmitter.

v. For transportation support, towers can also be used to support bridges, and can reach heights that rival some of the tallest buildings above-water. Their use is most prevalent in suspension bridges and cable-stayed bridges. The use of the pylon, and a simple tower structure has also helped to build railroad bridges, mass-transit systems, and harbors. Control towers are nowadays used to give visibility to help direct aviation traffic.

vi. To access tall or high objects, such as in launch tower, service tower, service structure, scaffold, tower crane, and tower wagon.

vii. To lift high tension cables, for electrical power distribution in transmission towers.

viii. To take advantage of the temperature gradient inherent in a height differential, such as in cooling towers.

ix. To expel and disperse potentially harmful gases and particulates into the atmosphere, such as in chimney.

x. For industrial production such as shot tower, which is a tower designed for the production of shot balls by free-fall of molten lead, and which then caught in a water basin. The shot is used for projectiles in firearms.

xi. For surveying, such as survey tower which is used for geological survey.

xii. To drop objects, such as drop tube (drop tower), bomb tower and diving platform, which is used in sport adventure by diving into water from relatively great heights.

xiii. To test height-intensive applications, such as elevator test tower.

xiv. To provide height for training purposes, such as in fire towers for fire lookout in fire-fighting and rescue operations, and a parachute towers which is used to control the fall of an object like a satellite balloon.

xv. For recreation, such as in rock climbing towers.

xvi. And as a symbol, such as in places of worship, like in mosque and church towers.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1.0 Materials

The materials used in this research work include:

i. A steel pipes
ii. A steel reducer sockets
iii. A metal Plates
iv. A metal Rod
v. A Bushing
vi. A Metal Shaft
vii. A screw jack

The equipment used also include:

i. A Multi-meter
ii. A Weighing Balance (capacity range: 0.01g to 6.0kg)
iii. A Torque Wrench
iv. A Chain Whip Spanner
v. A Digital Vernier Caliper
vi. A Compass
vii. A Spirit Level (Bubble Level)
viii. A Pushing tape
ix. Two Anemometers, one at 10m and the other at 18.5m height

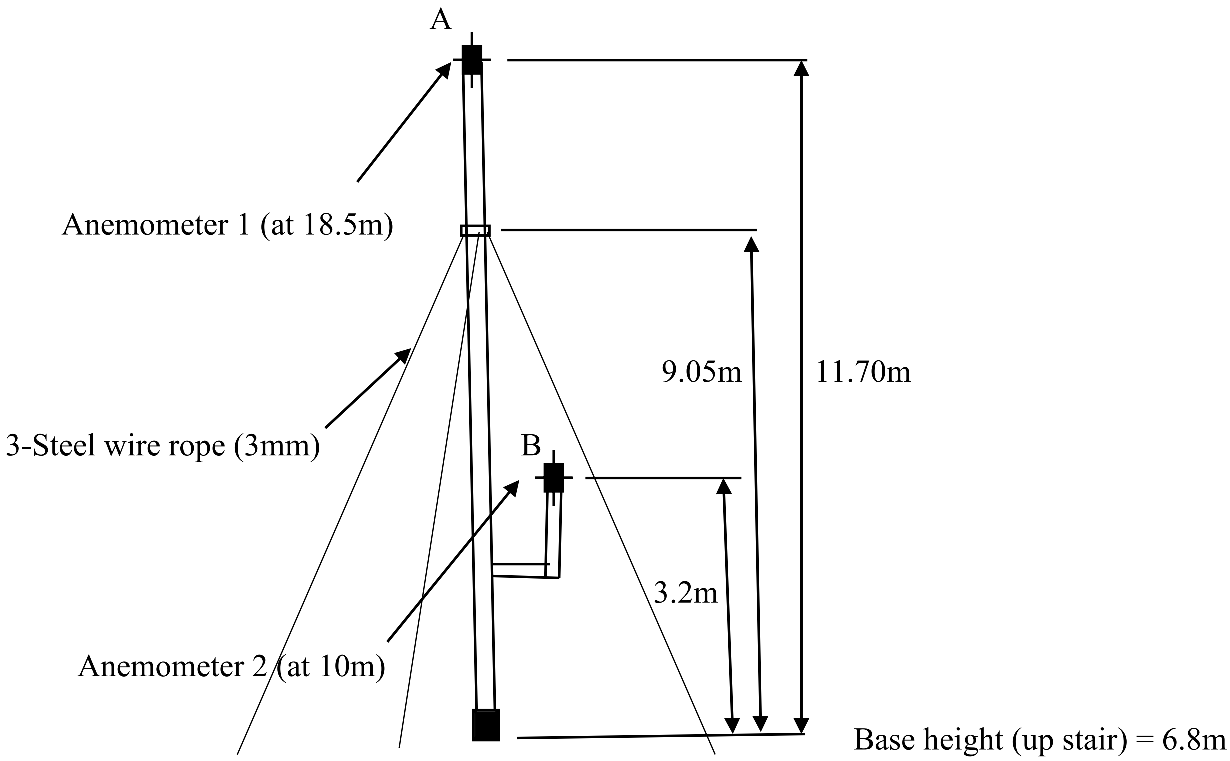


Fig. 3.1 Anemometer Installation Using Fixed-Guyed Pipe Tower

x. Two Stroboscopes

(a) A Sensor Unit A Display Unit

Plate VII. Acurite Professional Weather Anemometer Model 00502

Source: The Chaney Instrument Co., Lake Geneva, WI 53147

Table 3.1 Acurite Professional Weather Anemometer Model 00502 Specifications

TEMPERATURE RANGE	Outdoor: -40ºF to 158ºF; (-40ºC to 70ºC), Indoor: 32ºF to 122ºF; (0ºC to 50ºC)
HUMIDITY RANGE	Outdoor: 1% to 99%, Indoor: 16% to 98%
WIND SPEED	0 to 99 mph; (0 to 159 km/h)
WIND DIRECTION INDICATORS	16 points
RAINFALL	0 to 99.99 in; (0 to 253.9746 cm)
WIRELESS RANGE	330 ft / 100 m depending on home construction materials
OPERATING FREQUENCY	433 MHz
POWER	Display: 5v, 100mA power adapter, and 3 x AA alkaline batteries (optional) Sensor: 4 x AA alkaline or lithium batteries
DATA REPORTING	Wind Speed: 18 second updates; Direction: 30 seconds Outdoor temperature & humidity: 36 second updates Indoor temperature & humidity: 60 second updates

Source: The Chaney Instrument Co., Lake Geneva, WI 53147

(b) A Display Unit A Sensor Unit

Plate VIII. Acurite Weather Anemometer Model 00436/00634A1/00634A2/00634CA

Source: The Chaney Instrument Co., Lake Geneva, WI 53147

Table 3.2 Acurite Anemometer Model 00436/00634A1/00634A2/00634CA Specifications

TEMPERATURE RANGE	Outdoor: -40ºF to 158ºF; (-40ºC to 70ºC), Indoor: 32ºF to 122ºF; (0ºC to 50ºC)
HUMIDITY RANGE	Outdoor: 1% to 99%, Indoor: 16% to 98%
WIND SPEED	0 to 99 mph; (0 to 159 km/h)
WIRELESS RANGE	330 ft / 100 m depending on home construction materials
OPERATING FREQUENCY	433 MHz
POWER	7 x AA alkaline or lithium batteries (not included)
DATA REPORTING	Wind Speed: 18 second updates Outdoor temperature & humidity: 18 second updates Indoor temperature & humidity: 60 second updates

Source: The Chaney Instrument Co., Lake Geneva, WI 5314

3.1.1 Selection of Tower Material

The selection of a proper material for engineering purposes is one of the most difficult problem for the designer. The best material is one which serves the designed objective at the minimum cost. The important properties which determine the utility of the material are physical, chemical and mechanical properties. The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load.

In this research work, it is intended to design and construct a tubular tower using steel material. Steels are classified on the basis of mechanical properties as carbon and low alloy steels, where the main criterion in the selection and inspection of steel is the tensile strength or yield stress.

A steel pipe is selected for the construction of this tower. The words pipe and tube are usually interchangeable, but in industry and engineering, the terms are uniquely defined. Depending on the applicable standard to which it is manufactured, pipe is generally specified by a nominal diameter with a constant outside diameter and a schedule that defines the thickness. Tube is most often specified by the outside diameter and wall thickness, but may be specified by any two of outside diameter, inside diameter, and wall thickness. Both "pipe" and "tube" imply a level of rigidity and permanence. In general, "pipe" is the most common term used in most of the world, whereas "tube" is more widely used in the United States.

Metallic pipes are commonly made from steel or iron, the finish and metal chemistry are peculiar to the use, fit and form. Typically, metallic piping is made of steel or iron, such as unfinished black (lacquer) steel, carbon steel, stainless steel or galvanized steel, brass, and ductile iron.

The manufacturing processes used for the preliminary shaping of the engineering components are known as primary shaping processes. Not only for steel pipes, the common operations used in Mechanical Engineering for primary shaping processes are casting, forging, extruding, rolling, drawing, bending, shearing, welding, spinning, powder metal forming, squeezing etc. Tubing, either metal or plastic, is generally extruded. But the most commonly known processes for metallic pipe manufacture are:

i. Centrifugal casting of hot alloyed metal: is one of the most prominent process, in which ductile iron pipes are generally manufactured in such a fashion.
ii. Welded pipe manufacturing process (Electric Resistance Welding "ERW" and Electric Fusion Welding "EFW"): which are formed by rolling plate and welding the seam. In pipe

manufacture, the weld flash can be removed from the outside or inside surfaces using a scarfing blade. The weld zone can also be heat treated to make the seam less visible. Welded pipe often has tighter dimensional tolerances than seamless, and can be cheaper if manufactured in the same quantities. Large-diameter pipe (25 centimeters (10 in) or greater) may be ERW, EFW or submerged arc welded (SAW) pipe.

iii. Drawing manufacturing process: is in which seamless (SMLS) pipe is formed by drawing a solid billet over a piercing rod to create the hollow shell. Hot drawn steel pipes undergo cold drawing as a further processing. This process produces steel pipes with closer dimensional tolerances, wider range of surface finishes and increases yield and tensile strengths of the material. Historically seamless pipe was regarded as withstanding pressure better than other types, and was often more easily available than welded pipe.

Hence, this research work selected a seamless drawn steel pipe for the construction of the tower.

3.2.0 Methods

The methods employed in this dissertation involved the following:

i. Review of past literature and textbooks
ii. Analysis of available wind speed data
iii. Measurement of wind speeds and directions at the chosen site
iv. Measurement/Determination of the energy consumption pattern of the site
v. Design based on given specifications
vi. Construction of parts
vii. Assembling of tower and installing

3.3.0 Design Considerations

The design process is the pattern of activities that is followed by the designer in arriving at the solution of an engineering problem. The design of any engineering component begins as a mere imagination which then transforms into design before its actualization. In carrying out the design, a number of factors have to be taken into consideration. These include the following;

3.3.1 Compactness

The need for electrical energy was a major factor in this design work. Effort was geared towards ensuring that the overall size of the tower was moderate, thereby reducing the cost of producing the tower but not at the expense of strength and efficiency of the tower.

3.3.2 Serviceability

The tower was designed such that the component parts can easily be assembled, dismantled and maintained. The extent to which the equipment can withstand the conditions it was subjected to, during operations was also carefully considered.

3.4.0 Tower Design Consideration

The tower is used in horizontal-axis turbines, vertical-axis wind turbines do exist, but they are generally built into the ground or building. The height of the tower of a horizontal-axis wind turbine does play a role in how much wind energy will be produced. The speed of wind increases with height, and so any increase in the height of a horizontal wind turbine tower will mean an increase in the amount of electricity that is generated by the turbine. The three categories of towers are tilt-up, fixed-guyed, and freestanding. And generally the four common types of towers are Reinforced concrete tower, the Tubular steel tower, the Truss tower, and the Built up shell-tube tower. The one constructed in this dissertation is the tubular steel type and freestanding tower. Towers must be specifically engineered for the lateral thrust of wind power and weight of the turbine components, and should be adequately grounded to protect equipment against high wind damage especially during raining season.

Some criteria that apply to virtually every good design, were also considered in the design of this self-erecting tower, and they are as follows:

i. Elegance of the idea employed
ii. Robustness of the tower
iii. Cost of production
iv. Resources availability
v. Time constraint
vi. Skill required
vii. Safety in use

3.4.1 Energy Consumption Analysis of the Site

The identification of energy consumption pattern, contributes in the recent development in the research on the energy balance and energy efficiency solutions. Let us consider the weekly and daily energy consumption of the construction site of this research work.

Table 3.3 Weekly Meter Readings

WEEKLY METER READINGS		
Date	Reading (kWh)	Time
7-9-2015	345.10 + 594.87	5:39pm
12-10-2015	509.10	5:18pm
19-10-2015	147.37	4:39pm

26-10-2015	349.18	4:46pm
9-11-2015	301.79	4:46pm
23-11-2015	371.74	4:43pm
7-12-2015	473.47	5:16pm
14-12-2015	203.73	5:23pm
21-12-2015	523.00	4:41pm

Table 3.4 Weekly Consumption

DATE	WEEKLY CONSUMPTION(kWh)
7-9-2015	-
12-10-2015	-
19-10-2015	361.73
26-10-2015	-
9-11-2015	-
23-11-2015	-
7-12-2015	-
14-12-2015	269.74
21-12-2015	-

Average weekly consumption = $\frac{361.73 + 269.74}{2} = 315.735kWh$

It can be seen that this average weekly power consumption reflect only consumption in October and December, which are among the most windy months but less energy demand due to low hot weather in October and high cold weather in December, while the greatest energy needs for residential area in Nigeria is the cooling energy not heating energy. Therefore, this average weekly consumption cannot be used to determine the energy demand for this residence.

Table 3.5 Daily Meter Readings

DAILY METER READINGS		
Date	Reading (kWh)	Time
8-9-2015	300.38	6:50am
9-9-2015	216.97	6:52am
10-9-2015	124.36	6:57am
11-9-2015	41.79 + 594.87	6:35am
12-9-2015	562.70	6:35am
13-9-2015	506.34	6:35am
14-9-2015	457.47	8:00am

Table 3.6 Daily Consumption

DATE	DAILY CONSUMPTION(kWh)
8-9-2015	-
9-9-2015	83.41
10-9-2015	92.61
11-9-2015	82.57
12-9-2015	73.96
13-9-2015	56.36
14-9-2015	48.87

Average daily consumption = $\frac{83.41 + 92.61 + 82.57 + 73.96 + 56.36 + 48.87}{6} = 72.963kWh$

It can also be seen, that this average daily consumption, reflects some consumptions of energy in September, although it's not among the hottest months in northern Nigeria, but it is within the period of usual consumption of cooling energy. Therefore, we consider this value as the approximate daily energy need for this residence of the construction site.

Plate IX. Low Wind Series Model Installed, 11 Carbon Fiber Blades, 48Volts 3-Phase, 1600W
Source: Amazon Internet Shop

The above wind turbine installed on the tower at 18.5m height, the 48V AC power from the turbine when connected to rectifier for conversion to DC, and then connected to battery bank, can feed up to 10kW inverter for connection to home appliances. However, the 48V battery bank when connected to (DC to AC) inverter can generate up to 7,333W (i.e 48V amplified to 220V) at maximum power generated by the turbine (1600W), which means it can feed a 7kW inverter with uninterrupted power at a continuous rated wind speed of the turbine or greater. Nevertheless, wind is un-ending natural resource, but sometimes blow with inoperative speed that generate low or no power to the wind turbine, therefore it is essential to save from the energy generated by the wind turbine in the battery bank for use in low wind speed period.

Hence, this system is best to feed not greater than 5kW inverter (in one complete day and night can supply 5kW × 24h = 120kWh), which is enough compared to daily energy needs of 72.963kWh of the residence of this project construction site. This also gives light to the need of this research work in the site, in order to achieve a free polluted and energy sufficient environment.

3.5.0 Data Collection in Tal'udu area of Gwale L.G.A in Kano City

The beginning of the rain is usually marked by the incidence of high winds and heavy but scattered squalls. The peak of the rainy season occurs through most part of northern Nigeria in August and September, when air from the Atlantic covers the entire country. This period is almost considered as the windiest period in Kano and most parts of the northern Nigeria, and therefore, this project uses the wind speed at this period, for this kind of structural design.

This dissertation launches two brands of Anemometers for weather information particularly the wind speed at 18.5meters height and 10meters height, from Acurite Professional Weather Center. However, in this work, the tower was designed for the wind turbine to operate at a height of 18.5m. Values of wind speed measured at 10m and 18.5m are shown in table 3.7 below.

Table 3.7 Wind Speed Data

Data at 18.5m height								Data at 10m height				
Date in 2015	Time	Temp (DB) ^0C	Due pt Temp ^0C	V_{max} km/h	V_{ave} km/h	V_{inst} km/h	Wind dir.	Temp (DB) ^0C	Due pt Temp ^0C	V_{max} km/h	V_{ave} km/h	V_{inst} km/h
17/08	5:10pm	33	21	16	9	13	SE	32	-	8	6	5
24/08	5:00pm	26	20	24	15	13	E	21	18	-	7	7
31/08	5:28pm	29	23	13	6	8	SW	20	18	8	8	8
7/09	5:39pm	21	21	56	21	26	W	21	19	8	3	4
14/9	1:36pm	-	-	19	9	9	SW	31	35	7	6	6
19/10	4:39pm	-	-	17	8	10	SW	38	-	10	4	6
26/10	4:46pm	-	-	19	9	7	E	36	-	15	6	5
2/11	5:53pm	-	-	15	7	7	W	32	-	12	5	5
9/11	4:43pm	-	-	14	7	11	SW	34	-	16	3	7

Source: Anemometer Readings at the Erection Site

However, a gust wind is taken into account by employing a factor of safety to a structural design like this, and the wind gust is a sudden brief increase in the speed of the wind followed by a lull, gusts at the ground are caused by either turbulence due to friction, wind shear or by solar heating of the ground. These three mechanisms can force the wind to quickly change speed as well as direction, the duration of a gust is usually less than 20 seconds.

Average velocity of wind is given by;

$$V_{av} = \sum_{i=1}^{n} \frac{V_i}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Wind speed at a given height can be obtained from the wind speed of the reference height using the relation given by Rai (2011):

$$\frac{V_2}{V_1} = \left(\frac{H_2}{H_1}\right)^{\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where; H_1 = reference height

H_2 = calculated height

V_1 = reference wind velocity

V_2 = calculated wind velocity

The exponent (α) is an empirically derived coefficient that varies dependent upon the stability of the atmosphere. It is known as Hellmann exponent and depends upon the coastal location and the shape of the terrain on the ground, and the stability of the air. From the literature survey, values of the Hellmann exponent are given as constant in areas below (Martin, Wolfgang and Andreas, 2007):

For unstable air above open water surface α = 0.06

For neutral air above open water surface α = 0.10

For unstable air above flat open coast α = 0.11

For neutral air above flat open coast α = 0.16

For stable air above open water surface α = 0.27

For unstable air above human inhabited areas α = 0.27

For neutral air above human inhabited areas α = 0.34

For stable air above flat open coast α = 0.40

For stable air above human inhabited areas α = 0.60

However, when a constant exponent is used, it does not account for the roughness of the surface, the displacement of calm winds from the surface due to the presence of obstacles (i.e zero-plane displacement), or the stability of the atmosphere (Counihan, 1975; Touma, 1977). In places where trees or structures impede the near-surface wind, the use of log wind profile is preferred, i.e:

$$\alpha = \alpha_0 \left(1 - \frac{LogV_r}{LogV_0}\right) \dots\dots\dots\dots\dots (3.3)$$

Where; V_r = reference velocity

V_0 = a fixed velocity = 67.1m/s

$$\alpha_0 = \left(\frac{Z_0}{H_r}\right)^{0.2} \dots\dots\dots\dots\dots\dots (3.4)$$

in which; Z_0 = Surface roughness length, varying widely but taken as 0.4m for evaluation purposes.

H_r = Reference height

While the use of constant value of α is more applicable over open land surfaces (Hsu, Meindl and Gilhousen, 1994).

This project uses the highest peak wind speed (V_{max} = 56km/h), obtained for the design height at the construction site, in the tower analysis to avoid possible damages by excessive wind speed loading.

3.6.0 Tower Design Analysis

The theoretical power in the wind is given by (Rai, 2011):

$$P_{theoretical} = \frac{1}{2}\rho A V^3 \ (Watt) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots .. (3.5)$$

Where; ρ = density of air (1.201 kg/m^3 at normal temperature and pressure (NTP))

V = mean air velocity (m/s)

A = swept area of blades (m^2)

And the maximum extractable power of the wind by a turbine having satisfied with the Bertz limit, and with a generator working on reasonable efficiency of η% is therefore given by:

$$P_{extractable} = \frac{1}{2}\rho A V^3 \times \frac{59.3}{100} \times \eta \dots \dots \dots \dots \dots \dots \dots .. (3.6)$$

Where η = Generator efficiency

The axial force on a turbine wheel (f_p) is given by (Rai, 2011):

$$f_p = \frac{4}{9}\rho A V_f^2 \dots \dots \dots \dots \dots \dots \dots \dots \dots . (3.7)$$

Where: ρ = density of air (1.201 kg/m^3 at NTP)

V_f = for tower is the highest peak air velocity (m/s)

A = swept area of blades (m^2)

Bending moment on tower (M_b) is given by:

M_b = force x distance

M_b = axial force of wind on rotor x distance from ground level to turbine height

$M_b = f_p \times d \dots \dots \dots \dots \dots \dots \dots . (3.8)$

For this work, a steel pipe is used, and therefore it must be admitted that, the cause of failure depend not only on the properties of the materials, but also on the stress system to which it is subjected.

According to the Maximum Shear Stress Theory, also known as the Tresca yield criterion, this assumes that "yield occurs when the shear stress exceeds the shear yield strength".

$$\tau = \frac{\sigma_1 - \sigma_3}{2} \leq \tau_y \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.9)$$

If we are to test the tower as a hollow cylindrical power transmitting material, then let us apply the general maximum shear stress equation, to analyse the tubular tower subjected to axial load and bending moment;

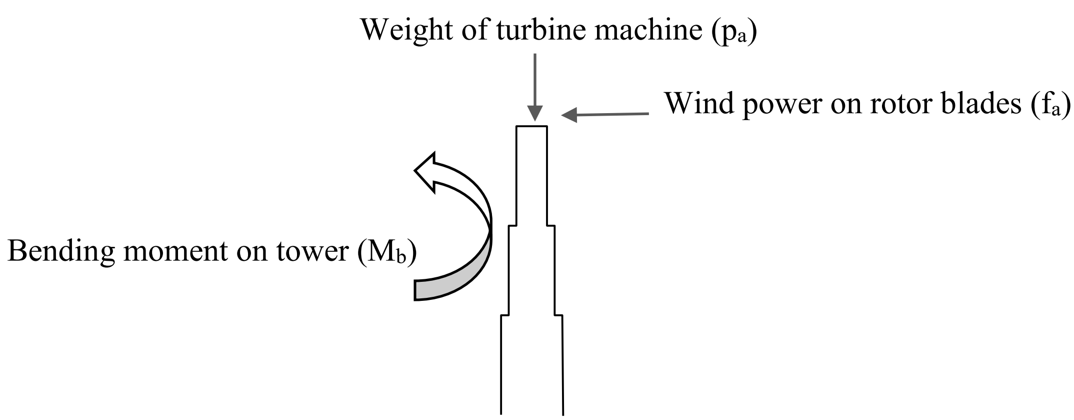


Fig. 3.2 Forces acting on a tower

The maximum shear stress may be determined using the relation given by (Karwa, 2006):

$$\tau_{max} = \frac{16}{\pi\, d^3}\sqrt{\left(K_m M_b + \alpha \frac{P_a}{8}\right)^2 + (K_t T)^2} \ldots\ldots\ldots\ldots\ldots\ldots. (3.10)$$

Where; $\tau_{max} \leq \tau_p \leq \frac{\tau_y}{FS}$

FS = Factor of safety

K_m = 1.0, for gradually applied load

K_t = 1.0, for gradually applied load

α = 1.0, if there is no column action

T = 0, since the torsional load is absent on the tower

Above are recommended values according to IS 4694 -1968.

By simplifying the equation and making d^3 the subject of the equation, we have;

$$d^3 = \frac{16\sqrt{\left(M_b + \frac{P_a}{8}\right)^2}}{\pi\tau_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.11)$$

Where; d = Tower diameter

M_b = Bending moment on tower

P_a = weight of turbine machine on tower

τ_p = 56MPa (according to ASME code permissible shear stress for shaft without keyway)

For hollow shaft (steel pipe in this case)

$$d^3 = d_o^3(1 - k^4) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3.12)$$

where; k = $\frac{d_i}{d_o}$

d_i = inside diameter

d_o = outside diameter

Therefore:

$$d_o = \sqrt[3]{\frac{d^3}{1 - k^4}} = \sqrt[3]{\frac{\frac{16\sqrt{\left(M_b + \frac{P_a}{8}\right)^2}}{\pi\tau_p}}{1 - k^4}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.13)$$

d_o = outside diameter of the tower

According to “Steel Reference Handbook” of Saginaw Pipe U.S company, a carbon steel pipe tube fabrication company ranges in sizes from $\frac{1}{8}$ inch to 48 inches. These steel pipes were manufactured in the following sample of wall thickness;

Table 3.8 Some Standard pipes Wall Thickness

Size (inch)	2	2½	3	3½	4	5
Wall thicness (mm)	2.8	3	3	3	3	4.8

Source: www.saginawpipe.com

From the above table, taking the median pipe size of 3¼ inch inside diameter, having 3mm wall thickness, after all units conversion, the factor k is obtained to be:

$$K = \frac{d_i}{d_o}$$

$$= \frac{3}{3.120} \text{ (an average ratio from the standard pipes)}$$

$$= 0.96$$

For a tower of 18.5m height, and considering the tower as having three divisions in length, i.e 6m for each of the three divisions (to comform with the length of the standard pipes), while leaving 0.5m for the base, this is because of the limitation on accessebility to the steel manufacturing company that can cast the tower in its conical shape, and which also will invite a high cost. But using the available materials in Kano, the tower construction was as shown in Fig. 3.3:

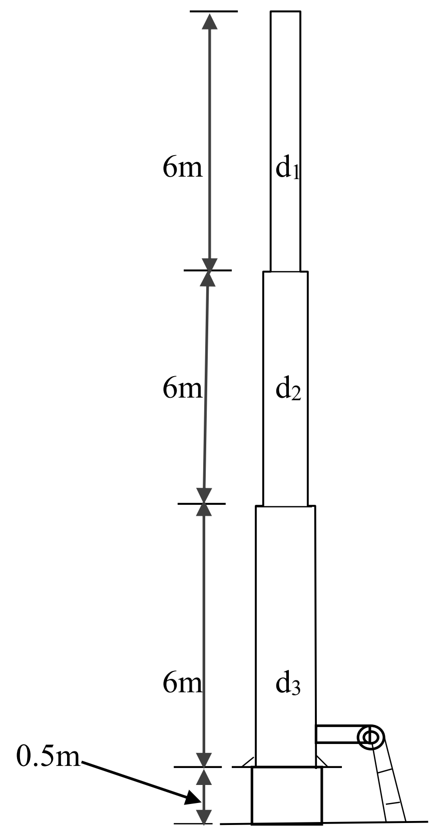


Fig 3.3 Tower diagram

For steel pipe tower diameter (d)

The highest peak wind speed of the site at the design height = 56km/h

= 15.556m/s

The swept area of the rotor blade $A = \pi r^2$

Where r is the radius of the rotor and measured to be 76cm

$$A = \pi \times 0.76^2$$

$$= 1.815m^2$$

Axial force of wind power on rotor blades $f_p = \frac{4}{9}\rho A V_f^2$

$$= \frac{4}{9} \times 1.201 \times 1.815 \times 15.556^2$$

$$= 234.441N$$

While for force due to weight normal to the tower, the total weight of the turbine machine was multiplied by the gravity, thus P_a = mass × gravity

- Weight of 3-phase A.C Alternator = 2.239kg
- Weight of 11-pieces of wind turbine blades = 2.898kg
- Weight of Tail vane = 1.492kg
- Weight of brackets and its components = 2.661kg
- Weight of hub that holds the turbine blades = 0.694kg
- Weight of bolts and nuts for assembling of parts = 0.597kg

Total weight of turbine machine on tower = 10.581kg

Therefore P_a = 10.581 × 9.81

= 103.8N

From the top 1st part of the tower (d_1)

Bending moment on tower = axial force on rotor x 6meters

= 234.441 × 6

= 1406.646Nm

$$d_{o_1} = \sqrt[3]{\frac{\frac{16\sqrt{\left(M_b + \frac{P_a}{8}\right)^2}}{\pi\tau_p}}{1-k^4}}$$

$$= \sqrt[3]{\frac{\frac{16\times\sqrt{\left(1406.646 + \frac{103.79961}{8}\right)^2}}{\pi\times 56\times 10^6}}{1-k^4}}$$

$$= \sqrt[3]{\frac{1.291 \times 10^{-4}}{1-0.96^4}}$$

= 0.095m

= 95mm

= 3.74 in

d_{o_1} = 3¾ inch pipe

2nd part of the tower (d_2)

Bending moment on tower = axial force on rotor x 12meters

= 234.441 × 12

= 2813.292Nm

$$d_{o_2} = \sqrt[3]{\frac{\frac{16 \times \sqrt{\left(2813.292 + \frac{103.79961}{8}\right)^2}}{\pi \times 56 \times 10^6}}{1 - k^4}}$$

$$= \sqrt[3]{\frac{2.57 \times 10^{-4}}{1 - 0.96^4}}$$

= 0.119m

= 119mm

= 4.69 in

d_{o_2} = 4¾ inch pipe

3rd part (base) of the tower (d_3)

Bending moment on tower = axial force on rotor x 18meters

$= 234.441 \times 18$

$= 4219.938\text{Nm}$

$$d_{o_3} = \sqrt[3]{\frac{\frac{16 \times \sqrt{\left(4219.938 + \frac{103.79961}{8}\right)^2}}{\pi \times 56 \times 10^6}}{1 - k^4}}$$

$$= \sqrt[3]{\frac{3.85 \times 10^{-4}}{1 - 0.96^4}}$$

$= 0.137\text{m}$

$= 137\text{mm}$

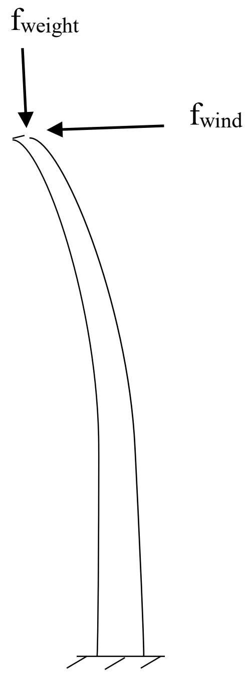
$= 5.38$ in

d_{o_3}= 5½ inch pipe

The above calculated diameters are when the tower was considered as a hollow cylindrical power transmitting material.

But a machine component subjected to an axial compressive force is called a strut. A strut may be horizontal, inclined or even vertical, a vertical strut is known as a column, pillar or stanchion.

The first rational attempt to study the stability of long columns was made by Mr. Euler. He derived an equation for the buckling load of long columns based on the bending stress, while deriving this equation, the effect of direct stress was neglected. This may be justified with the statement that "the direct stress induced in a long column is neglegible as compared to the bending stress". Consider now the tower as a column material having the end condition of "one end fixed and the other end free", with the forces acting on it as shown below:



According to Euler's Theory, the crippling or buckling load under various end conditions is represented by a general equation (Kurmi and Gupta, 2005):

$$F = \frac{C\pi^2 EI}{L^2} \dots\dots\dots\dots\dots\dots\dots\dots. (3.14)$$

Where C = Constant, representing end condition of the column or end fixicity coefficient (C=0.25 for one end fixed and other end free)

E = Modulus of Elasticity for the material of the column, for Carbon Steel, E = 200 GPa, (ETB, 2016).

I = Area Moment of Inertia (in this case for hollow cylindrical cross section)

L = Length of the column (Length of the tower for this case)

The crippling or buckling load in this case is the axial force of the wind power on rotor and the weight of the turbine machine on tower.

F = summation of forces on Tower = f_{wind} and f_{weight}

$f_{wind} = f_p \times FS$

where FS = Factor of Safety, adopting a factor of safety of 3 as for some machine design, (ETB, 2016), which means the peak wind speed measured at the site must triple at least for tower to tend to buckle.

The Axial force on a turbine wheel (f_p) is given by; $f_p = \frac{4}{9}\rho A V_f^2$

Where: ρ = density of air (1.201 kg/m^3 at NTP)

V_f = for tower is the highest peak air velocity (m/s)

The highest peak wind speed of the site at the design height = 56km/h

= 15.556m/s

A = swept area of blades (m^2)

The swept area of the rotor blade $A = \pi r^2$

Where r is the radius of the rotor and measured to be 76cm

$$A = \pi \times 0.76^2$$

$$= 1.815\text{m}^2$$

the axial force $f_p = \frac{4}{9} \times 1.201 \times 1.815 \times 15.556^2$

$$= 234.441\text{N}$$

$\therefore$ $f_{wind} = 234.441 \times 3 = 703.323N$

And f_{weight} = Weight of Turbine machine

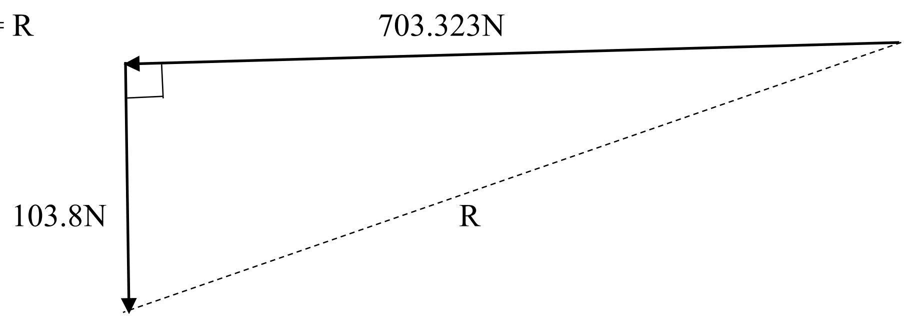
= mass in (kg) × gravity in (m/s^2)

$f_{weight} = 10.581 \times 9.81$

= 103.8N

Since f_{weight} and f_{wind} act in different directions, they cannot be added by ordinary algebraic method.

$\therefore$ F = R



By Pythagoras Theorem: $R^2 = 103.8^2 + 703.323^2$

$R = \sqrt{505437.682} = F$

F = 710.941N

$$\therefore \; F = \frac{C\pi^2 EI}{L^2} = 710.941$$

$$I = Iy = \frac{\pi(d_o^4 - d_i^4)}{64} = \frac{\pi}{64} d_o^4 (1 - K^4) \ldots\ldots\ldots\ldots..(3.15)$$

Where $K = \frac{d_i}{d_o}$

d_i = internal diameter of the tower pipe material

d_o = outside diameter of the tower pipe material

But K is already calculated to be 0.96

$$\frac{C\pi^3 E d_o^4 (1-K^4)}{64L^2} = 710.941$$

$$d_o^4 = \frac{45500.25L^2}{C\pi^3 E(1-K^4)}$$

$$d_o = \sqrt[4]{\frac{64FL^2}{C\pi^3 E(1-K^4)}} \dots\dots\dots\dots\dots\dots\dots\dots (3.16)$$

For the top 1st part of the tower (d_1)

$$d_{o_1} = \sqrt[4]{\frac{45500.25 \times 6^2}{0.25 \times \pi^3 \times 200 \times 10^9 (1-0.96^4)}}$$

= 0.051m

= 51mm

= 2.008 in

= 2 inch pipe

For the 2nd part of the tower (d_2)

$$d_{o_2} = \sqrt[4]{\frac{45500.25 \times 12^2}{0.25 \times \pi^3 \times 200 \times 10^9 (1-0.96^4)}}$$

= 0.073m

= 73mm

= 2.874 in

= 3 inch pipe

For the 3rd part (base) of the tower (d_3)

$$d_{o_3} = \sqrt[4]{\frac{45500.25 \times 18^2}{0.25 \times \pi^3 \times 200 \times 10^9(1 - 0.96^4)}}$$

= 0.089m

= 89mm

= 3.504 in

= 4 inch pipe

The above two different considerations of tower material yield two different results for tower diameter; however it is recommended to consider the tower as a long column which is satisfied by the second analysis of tower using Euler's theory. Hence, the tower was constructed based on the parameters calculated in the analysis of tower as a column material.

But failure occur mainly at the weak point of Engineering materials, the part of the tower with the smallest diameter is within the 2inch pipe. The outside and inside diameters of the pipe was measured for Danny steel (B. S1387-1983) pipe: d_o = 56.5mm,

d_i = 52.5mm

The stiffness of the tower in this section is given by:

$$K = \frac{AE}{L} \quad \ldots\ldots\ldots\ldots\ldots (3.17)$$

Where: L = length of the pipe = 6m,

E = Modulus of Elasticity, for Carbon Steel, E = 200 GPa,

A = Cross-sectional area of the pipe $= \frac{\pi}{4} \times (0.0565^2 - 0.0535^2) = 0.000259$ m^2

$$\therefore Stiffness(K) = \frac{0.000259 \times 200 \times 10^9}{6} = 8633\ kN/m$$

By knowing the stiffness of the tower, the natural frequency of the tower can also be calculated as follows:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{m}} \ldots\ldots\ldots.\ldots\ldots.(3.18)$$

Where: K = Stiffness of the tower = $8633\ kN/m$

m = mass of the tower = 79.413 kg (refer to page 59)

$$\therefore Natural\ frequeny(f_n) = \frac{1}{2\pi}\sqrt{\frac{8633333}{6}} = 191Hz$$

Note that, when a forcing frequency on a mechanical system matches the system's natural frequency of vibration, then the system is said to be at resonant frequency. This causes violent swaying motions and even catastrophic failure, which termed as resonance disaster. Avoiding resonance disasters is a major concern in every building, tower and bridge construction.

3.7.0 Selection of a Jack

A jack is a mechanical device used as a lifting device to lift heavy loads or to apply great force. Most mechanical jacks employ a screw thread for lifting heavy equipment, however a hydraulic jack uses hydraulic power to raise loads.

Some of the common jacks in use are; Scissor car jacks, which usually use mechanical advantage to allow a human to lift a vehicle by manual force alone. Hydraulic jacks use a fluid which is incompressible, that is forced into a cylinder by a pump plunger. A pneumatic jack is a hydraulic jack that is actuated by a compressed air. A strand jack is a specialized hydraulic jack that grips steel cables often used in concert, strand jacks can lift hundreds of tons and are used in Engineering and construction. A house jack also called a screw jack, is a mechanical device primarily used to lift buildings from their foundations for repairs or relocation. The farm jack is also known as a Hi-Lift Jack, it consists of a steel beam with a series of equally spaced holes along its length, and a hand operated mechanism which can be moved from one end of the beam to the other through the use of a pair of climbing pins.

But electrically operated jacks are mostly operated by electric motors, the electrical energy is used to power these jacks to raise and lower the load automatically. Electric jacks require less effort to operate.

National and international standards have been developed to standardize the safety and performance requirements for jacks and other lifting devices.

Jacks are usually rated for a maximum lifting capacity, that's why to select a jack, one has to determine the amount of weight to be lifted by the jack.

∴ Components of weight to be lifted by the jack = weight of tower + weight of turbine machine

But weight of tower = weight of 2” pipe + weight of 3” pipe + weight of 4” pipe

Inspection of steel pipe at kofar ruwa market in Kano city reveals the availability and quality standard of G-Type steel pipe with the following approximate dimensions of the required sizes of pipes;

2 inch pipe has d_o = 56.5mm, d_i = 53.5mm (Danny Steel B. S 1387-1983)

3 inch pipe has d_o = 85.1mm, d_i = 81.1mm (Danny Steel B. S 1387-1985)

4 inch pipe has d_o = 110.6mm, d_i = 105.6mm (Danny Steel B. S 1387-1987)

While the standard length of steel pipe is obtained to be 6 meters

Also, the density of carbon steel varies based on the alloying constituents. It usually ranges between 7750 kg/m^3 and 8050 kg/m^3. But the approximate value usually taken as density of steel is 7850 kg/m^3.

However, weight measurement of pipes and reducers using a weighing scale gives the following values:

Weight of 2” pipe with 3”- 2” reducer socket = 13.154 kg

Weight of 3” pipe = 21.886 kg

Weight of 4” pipe with 6”- 4” and 4”- 3” reducer sockets = 33.792 kg

Total weight of tower pipes and joining sockets materials = 68.832 kg

Weight of turbine machine ($W_{Turbine}$) = 10.581 kg

Total weight of the assembly = $W_{pipes} + W_{Turbine}$ = 79.413 kg

But the jack is lifting the load from the fulcrum not from the center of gravity of the Tower, this made the load to be a moment of forces on the jack.

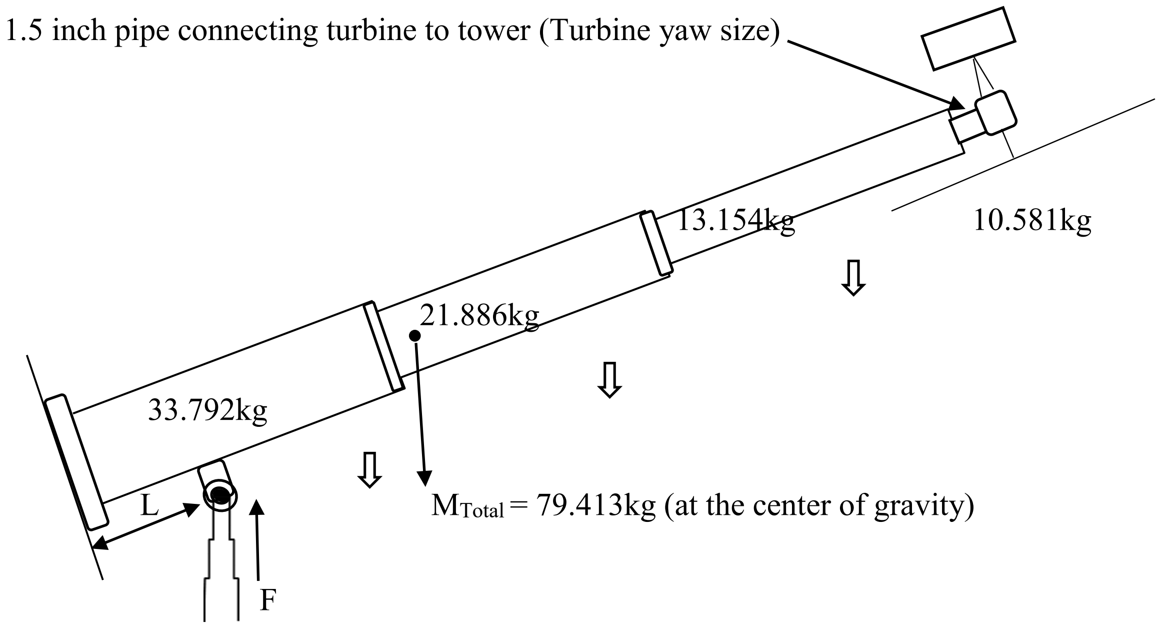


Fig. 3.4 Weights on the jack

Work done by the jack in lifting the tower = Moment of forces acting on the jack

We consider the center of gravity of each pipe to be at mid-length of the pipe

$$\therefore W_{jack} = Moment_{jack} = \sum\{3F_{p_3}, 9F_{p_2}, 15F_{p_1}, 18F_{Turbine}\} \dots\dots\dots\dots (3.19)$$

$= ((3 \times 33.792 \times 9.81) + (9 \times 21.886 \times 9.81) + (15 \times 13.154 \times 9.81) + (18 \times 10.581 \times 9.81))$

$= 6730.818$ Nm

A counter moment is required, to serve as a resisting moment to the above overturning moments on jack.

$$\text{But; Factor of safety} = \frac{Resisting\ Moment}{Overturning\ Moment} \quad \text{i.e} \quad F.S = \frac{\sum M_R}{\sum M_O} \dots\dots\dots (3.20)$$

$$\therefore \text{Resisting Moments } (\sum M_R) = F.s \times \sum M_O = 3 \times 6730.818 = 20192.454 \text{ Nm}$$

The size of the jack to overcome this moment depends on the position, distance from the pivot to which the jack lifts the tower.

Now if we are to select to lift the tower from a position 1m from the pivot

$\therefore$ Force require to lift the Tower $= \frac{20192.454\ \text{Nm}}{1m} = 20192.454$ N

= 2058.4 kg

= 4537.9 lb.

If we are to use the jack to a maximum of 80% of its recommended capacity as a means of factor of safety.

i.e. $\quad Jack\ size = \frac{Load}{4} \times 5 = 80\%$ maximum utilization

Then we are selecting a jack of size $= \frac{20192.454}{4} \times 5 \cong 25{,}250$ N at 1m from the pivot

$\cong 12{,}630$ N at 2m from the pivot

$= \frac{2058.4}{4} \times 5 \cong 2{,}575$ kg at 1m from the pivot

$\cong 1{,}290$ kg at 2m from the pivot

$= \frac{4537.9}{4} \times 5 \cong 5{,}675$ lb. at 1m from the pivot

$\cong 2{,}840$ lb. at 2m from the pivot

The selected jack may be larger than the above calculated sizes depending on the adjustment made in locating the fulcrum which will also be determined by the maximum extended length of the selected jack compared to those available in our markets. The major factor that may influence the selection of a of jack, is the availability of jacks in our markets ranging in size to or above the calculated values, that is those that can be extended in length to or above the selected height of the fulcrum. However, markets survey will prove the demand of this work, for the calculated size of jack or need of adjustment.

3.8.0 Design of Base plates, Bolts and Hinges

Let us consider the base plate to be subjected to bending stress by the action wind power on tower, therefore by knowing the tensile stress of the base plate material, the thickness of the base plate may be determined by using the bending equation given by (Khurmi and Gupta, 2005):

$$\sigma_t = \frac{M}{Z} \ldots\ldots\ldots\ldots. (3.21)$$

Where: M = Bending moment on base plate

σ_t = Tensile stress of base plate material (σ_t = allowable stress for steel = 52MPa)

$Z = \frac{1}{6} w t^2 \ldots\ldots\ldots.. (3.22)$

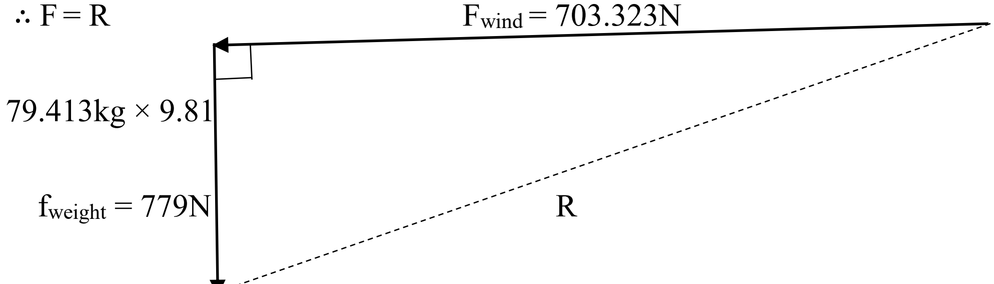
Where: w = width of the plate (w = 300mm as in Fig. 3.4)

t = thickness of the base plate

But the forces acting on the base plate are ($f_{\text{weight of tower \& turbine}}$) and ($f_{wind}$)

Since f_{weight} and f_{wind} act in different directions, they can only be added by geometric method.

∴ F = R



By Pythagoras Theorem: $R^2 = 779^2 + 703.323^2$

$$R = \sqrt{1101504.242} = F$$

$$\therefore F = 1049.526 \text{ N}$$

Therefore, from equation 3.21

$$Z = \frac{M}{\sigma_t} = \frac{F \times w}{\sigma_t} = \frac{1049.526 \times 0.3}{52 \times 10^6} = 0.00000605m^3 = \frac{1}{6}wt^2$$

$$\therefore \quad t = \sqrt{\frac{6 \times 0.00000605}{0.3}} = 0.011m$$

∴ Thickness of base plate = 11mm

Although the tower weight load is at the center of the base plate, with the action of wind power on tower, the load tilt from one side to the other, that's why the bolts were considered to be under eccentric loading.

Therefore, if d_c is the core diameter or simply the minimum diameter of the bolt and σ_t is the tensile stress for the bolt material, then the total tensile load on the heavily loaded bolt is given by (Kurmi and Gupta, 2005):

$$W_t = \frac{\pi}{4} d_c^2 \sigma_t \text{ ... ... (3.23)}$$

Where: σ_t = 52Mpa (allowable stress for steel)

$$w = \frac{Moments\ on\ Pivot}{one} = \frac{6730.818 \text{ Nm}}{1m} = 6730.818 \text{ N}$$ (i.e load supported by bolts or hinge)

Consider the base plates to be loaded parallel to the axis of bolts by an eccentric load

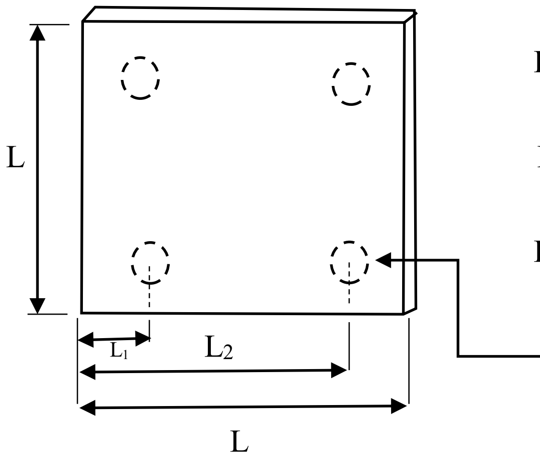


Fig. 3.5 Base plate

The load carried by each bolt = $\frac{W}{n} = \frac{6730.818}{4} = 1682.705N$

∴ Load in each bolt per unit distance from the tilting edge is given by (Khurmi and Gupta, 2005):

$$w = \frac{WL}{2[(L_1)^2 + (L_2)^2]} = \frac{6730.818 \times 300}{2(50^2 + 250^2)} = 15.533N/mm$$

Since the heavily loaded bolt is at distance L_2 from the pivot, which is the load on the hinge rod during erecting up and down of tower, therefore the load on the heavily loaded bolt which is equal to load on the hinge rod is given by:

$$w_{L_2} = wL_2 = 15.533 \times 250 = 3883.164\ N$$

Maximum tensile load on the heavily loaded bolt, which is also the maximum tensile load on the hinge rod during erecting of tower, is given by:

$$W_t = W_{tl} + W_{L2} = 1682.705 + 3883.164 = 5565.869\ \text{N}$$

$$\therefore\quad d_c = \sqrt{\frac{4W_t}{\pi\sigma_t}} = \sqrt{\frac{4 \times 5565.869}{\pi \times 52 \times 10^6}} = 11.7mm$$

∴ Hinge rod diameter = 12mm

While from the table of standard dimensions of screw threads for design of screw thread, bolts and nuts according to IS: 4218

For d_c = 11.546mm, corresponding size of bolt is M14

$$\therefore \quad Bolt\ size = M14$$

3.9.0 Tower Foundation

The component of weight tending to tilt the tower in pushing by the wind strike to rotor blades is measured to be = 79.413kg, from the turbine at the top of the tower, to the lower reducer socket on the base plate.

$$\therefore \quad W_{tower\ and\ turbine} = 79.413kg$$

Weight of 6" base pipe (0.5m long above the ground level) = volume of pipe × density of steel

$$W_{pipe} = \frac{\pi}{4}(d_o^2 - d_i^2)L \times \rho \ldots\ldots\ldots\ldots\ldots (3.24)$$

For 6 inch base pipe, d_o = 155.4mm, d_i = 152.4mm, and L = 0.5m

The approximate value usually taken as density of steel is 7850 kg/m^3.

$$\therefore W_{base\ pipe} = \frac{\pi}{4} \times (0.1554^2 - 0.1524^2) \times 0.5 \times 7850 = 2.847kg$$

The weight of two base plates of equal sizes = 2(v × ρ) = 2(l × b × t × ρ)

For base plates, l = b = 300mm, t = thickness = 11mm, ρ = density of steel =7850 kg/m^3

$$\therefore \quad W_{base\ plates} = 2(0.3 \times 0.3 \times 0.011 \times 7850) = 15.543kg$$

Note that the weight of hinges, bolt and nuts may be regarded as negligible compared to the weight of main components.

Therefore, the total weight on the foundation = $W_{tower\ and\ turbine} + W_{base\ pipe} + W_{base\ plates}$

= 79.413 + 2.847 + 15.543 = 97.803 kg

The equivalent mass of concrete to overcome 97.803 kg is the foundation of the tower. Although the tight of foundation by the ground soil is also a factor of safety, but it is recommended to use a factor of safety of 6 to 8 for non-rotating (static) wind turbine equipment (ETB, 2016).

Therefore, taking the highest value of the range of 8 for better safety of the tower, we are to cast a concrete foundation of 8×97.803 = 782.424 kg which is enough to withstand the push from the wind speed of the site on the turbine machine.

The equivalent volume of concrete to weigh 782.424 kg is given by:

$$\text{Volume of concrete} = \frac{Mass\ of\ Concrete}{Density\ of\ Concrete}$$

The density of concrete varies according to richness of the mixture and the type of cement used; but concrete with normal strength properties of typical Portland cement has a density between 2240-2400 kg/m^3. However, this project use the lowest value of 2240 kg/m^3 as the density of normal weight concrete.

$$\therefore\ V_{Concrete} = \frac{782.424}{2240} = 0.349m^3$$

We can see that from the detail drawing of tower construction parts, the base pipe is 1.5m inside the concrete foundation.

$$Surface\ Area\ of\ Foundation = \frac{Volume}{Height} = \frac{0.349}{1.5} = 0.233m^2$$

But, the concrete wrap round the base pipe of 155.4mm diameter

Therefore, top face area of foundation = Area of Concrete + Area of Pipe

$$\therefore \ A_{Foundation} = 0.233 + \pi \frac{0.1554^2}{4} = 0.252m^2$$

Most concrete foundations for tubular structures have square top surface area,

$$\therefore \ Each\ Side = \sqrt{0.252} = 0.5m = 50cm\ long$$

3.10.0 Guy-wire Selection

It is an additional factor of safety to use the guy-wire to stabilize the swinging of the tower, especially during the heavy wind blow. It's calculated above (page 53-54) in the tower design analysis, that the total force acting on the tower (i.e due to axial force of wind on rotor and weight of the wind generator), is F = 710.941N, which is also the same load acting on the guy-wire. But;

$$Stress\ on\ the\ wire = \frac{Load\ on\ the\ wire}{Area\ of\ the\ wire}$$

Therefore; Load on the wire = Area of the wire × Allowable stress of wire material

Where; Load on the wire = 710.941N

Allowable stress of steel in tension and compression = 52.5 MPa

Area of the wire $=\pi \frac{d^2}{4}$, in which "d" also is the diameter of the wire

$$710.941 = \pi \frac{d^2}{4} \times 52.5$$

$$\therefore \ d = \sqrt{\frac{710.941 \times 4}{\pi \times 52.5 \times 10^6}} = 0.00415m = 4.15mm$$

Therefore, the thickness of the guy-wire selected is 5mm diameter.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1.0 Results

Table 4.1 Results

S/N	COMPONENT OF THE TOWER	RESULT
1	Diameter of upper steel pipe tower material	51mm
2	Diameter of middle steel pipe tower material	73mm
3	Diameter of lower steel pipe tower material	89mm
4	Stiffness of the weak section of the tower	8633 kN/m
5	Natural frequency of the tower	191 Hz
6	Overturning moments on jack in lifting the tower	6730.818 Nm
7	Force required to lift the tower at fulcrum	20,192.5N
8	Calculated size of the jack recommended to lift the tower	2,575 kg
9	Diameter of hinge rod material	12mm
10	Thickness of base plate material	11mm
11	Number of bolts required for the tower	4
12	Size of bolts required to hold the tower	M14
13	Calculated volume of concrete foundation required for the base	$0.349m^3$
14	Guy-wire diameter	5mm
15	Highest peak wind speed measured for the site	56km/h
16	Average daily energy consumption measured for the site	72.963kWh
17	Average capacity of daily energy supply of the turbine installed	120kWh

18	Average wind speed measured during the turbine commissioning	9km/h
19	A/C voltage output measured during the turbine commissioning	50.2V
20	D/C voltage output measured from the rectifier on commissioning	54.4V

4.1.1 Working Drawings

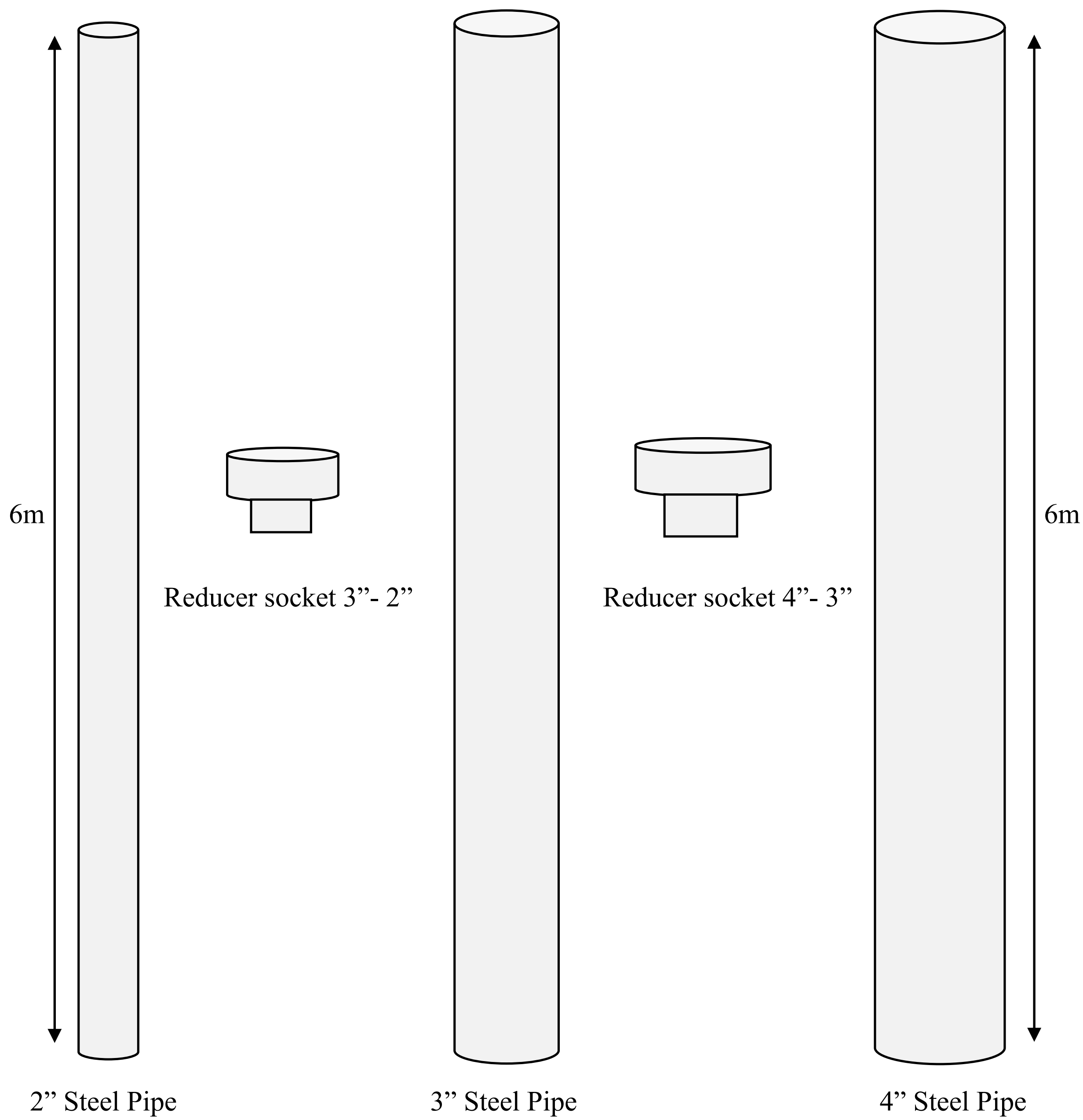


Fig. 4.1 Construction Pipes and Reducer Joints

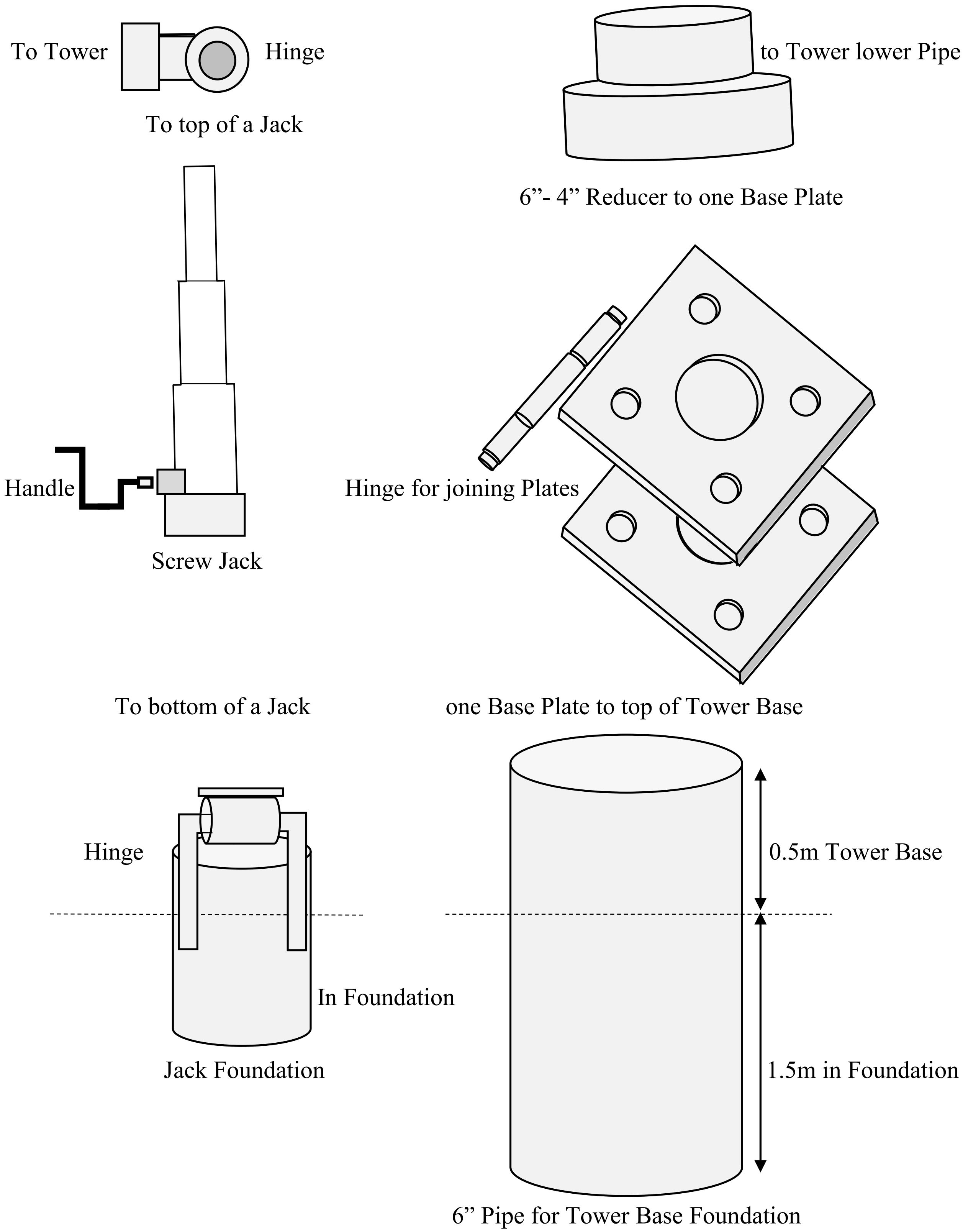


Fig. 4.2 Other Construction Parts

4.1.2 Assembly Drawing

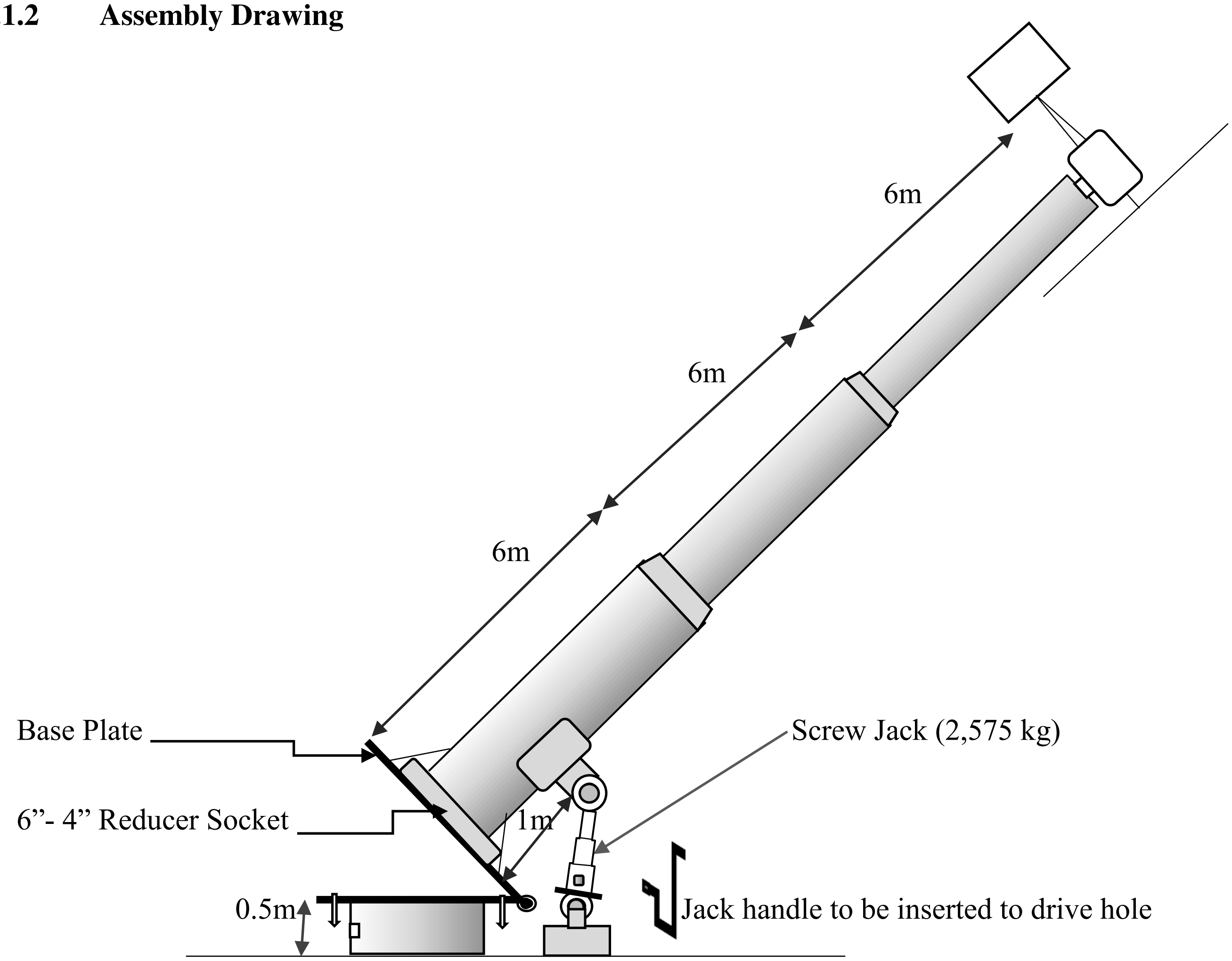


Fig. 4.3 Assembly Drawing of a Self-Erecting Tower

4.2.0 Discussion of Results

From Table 4.1, it can be seen, that the calculated diameter of pipes in designing the tower are increasing toward the base, this is to conform with the standard tubular steel towers, that are formed in conical shapes, and this is to increase the stability of the tower. While the force required to lift the assembly of the tower is calculated to be 20192.5N, the capacity of the jack required to lift the tower exceeds this value. This is to ensure that the jack does not fail in lifting the tower, which may cause the damage of the tower during erecting-up or in bringing down the tower. The size of the jack selected is the one which by utilizing 80 percent of its recommended capacity can lift the tower up and bring it down safely and is calculated to be 2575 kg, with the fulcrum at 1m from the pivot.

The hinge rod where the fulcrum is located is where the tower was supported, and the hinge rod at the pivot is where the tower rotates, each of these rods are 12mm in diameter. While the base plates that are located in between the lower reducer socket and the base pipe of the tower were found to be 11mm thick. Also, the number of bolts to tight the tower to the base is 4, as it is recommended to use 4 bolts for coupling of materials of diameter above 40mm up to 100mm in design of bolts. And the size of bolts to use, for the calculated value of core diameter which correspond to table of standard dimensions of screw thread is M14 according to IS: 4218.

The highest peak wind speed of 56km/h measured for the site is an important parameter for this kind of structural design. And the average daily energy needs for the site is calculated from the records of daily power consumption of the site, and was found to be 72.963kWh, which means there is a need to generate a minimum of this amount daily for the site. But with the 48V 1600W wind turbine installed on the tower constructed for this dissertation, an estimated average daily energy supply of up to 120kWh for the site can be generated.

Figure 4.1 shows the construction pipes each with uniform cross-section and of different diameters, also reducer sockets of the corresponding pipes were used in joining the pipes before welding.

Other construction parts are shown in Fig. 4.2, which include the hinges, the base plates, the tower base foundation pipe, the jack base foundation pipe and the screw jack selected.

The jack lifts the tower at position 1m from the pivot (see Fig. 4.3). However, to lift a tower from a fulcrum of 1m from the pivot must use a jack that extend to a length above 1m in height, while, most of the available hydraulic jacks have shorter extension in length, screw jacks have longer extension than hydraulic jacks but mostly shorter than the stated length for light weight lifting such as this calculated size. The electric jacks extend longer enough to serve this purpose even for this calculated size, but almost not available in our markets except that of satellite dish control which is also not available in larger sizes to this calculated value. Hence, an appropriate size of a screw jack was selected, and the construction attachment of the jack to the tower was achieved by applying the trigonometric ratio of a scalene right angle triangle, with the jack at hypotenuse, tower at the vertical side, while the horizontal base is the distance between the tower and the jack base.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1.0 Conclusion

i. In the determination of the energy needs of this research site, the average weekly power consumption, reflects only consumptions of months which are among the windy months but with less energy demand, due to low hot weather in October and high cold weather in December, while the major energy needs for residential area in Nigeria is the cooling energy, not the heating energy. But for the average daily consumption of 72.963kWh, which reflects some consumptions of energy in some periods, in which although it is not among the hottest months in northern Nigeria, but it is within the period of usual consumption of cooling energy. Therefore, this value was considered to be the approximate daily energy need for the residence of the construction site. And the 48V, 1600W wind turbine installed on this tower, constructed for this dissertation can feed a 5kW (or greater) power inverter, which in one complete day and night can supply (5kW × 24h = 120kWh), which is enough compared to daily energy needs of 72.963kWh for the residence of the site of this research work. This also gives light to the need of this research work in the site.

ii. The tower designed in this research work consists of three steel pipes of different diameters calculated to be 51mm which correspond to 2 inch from the standard pipes, 73mm which is approximately 3 inch pipe, and 89mm which is rounded up to correspond with 4 inch pipe. The pipes are connected using steel reducer sockets, and then the joints welded to obtain a permanent solid tower. The assembly of the tower required a calculated force of 20192.5N to be lifted, and therefore to be a factor of safety, the size of the jack selected is the one which by utilizing a maximum of 80 percent of its recommended capacity can erect the tower up and bring it down safely. The size of the jack was calculated to be 2575 kg. The self-erecting design was achieved in designing a tower that can be erected-up by changing the angle of inclination of tower from a certain angle above zero degree to the horizontal to a maximum angle of 90 degrees to the horizontal.

iii. The tower was constructed using the available materials in Kano markets, the assembly of the parts was done at the installation site, and the self-erection mechanism was tested. However, the 2inch pipe was improved in stiffness by reducing it in length during the commisioning of turbine, which reduced the tower height to 16m. The idea employed in this dissertation eliminates the inconveniencies associated with the mobile cranes access to the installation site, and the turbine machine can easily be brought down for lubrication and repair services, without the need of any supporting machine. This research work therefore encourages the use of available renewable energy sources in generating electricity for domestic use, in order to achieve a free polluted and energy sufficient environment.

5.2.0 Recommendations

i. It is recommended that, in the future research, developers will use larger turbines (greater than 1600W) on taller towers (greater than 16m), investigate the effect of forcing frequency due to wind and turbine, and to use electric jack that requires less effort to operate for this type of self-erecting tower. This is because of the need to refocus attention on renewable energy resources such as wind, and to adopt a better energy utilization method and research for ways to improve the green energy generation, in order to obtain a free polluted environment with sufficient power generation to enhance the productivity in the country.

ii. Further research work to focus on the performance analysis of the unit. In addition, it is useful to investigate the possibility of using twin turbine on one supporting tower.

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APPENDICES

A. Pictures of the self-Erecting Tower Constructed for this Dissertation

Plate A_{I}. Construction pipes

Plate A_{II}. Tower base

Plate A_{III}. Erecting mechanism

Plate A_{IV}. Self-erecting part after commisioning

Plate A_{V}. Finished dissertation construction

B. 10 Years Wind Speed Data for Kano area (m/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	9.1	9.3	9.3	8.0	11.0	10.2	9.7	9.1	7.5	6.7	6.8	8.0
2002	10.4	8.7	8.3	9.3	8.9	12.0	10.0	8.0	7.6	6.1	5.6	7.7
2003	6.9	6.6	8.0	9.1	8.4	9.6	9.1	7.6	6.4	5.6	6.4	6.7
2004	6.4	8.5	8.9	7.3	11.9	10.7	7.8	7.2	6.9	5.5	6.4	5.6
2005	9.0	7.5	6.9	7.1	8.1	9.9	8.7	7.7	7.2	6.0	6.9	7.0
2006	7.5	7.5	7.5	7.7	5.1	7.7	5.1	7.7	7.2	7.5	7.7	8.0
2007	5.3	6.9	6.9	5.1	8.0	7.7	7.7	7.5	6.7	6.7	5.1	8.0
2008	5.3	5.0	5.3	4.6	5.3	5.1	5.0	4.6	7.2	6.9	5.1	7.5
2009	7.7	6.9	7.7	7.7	8.0	5.1	8.0	5.1	7.2	8.0	7.7	8.0
2010	8.0	7.2	5.3	7.5	8.0	7.7	5.3	5.1	6.9	X	X	X

Source: **Nigerian Metrological Agency (NIMET Kano Office)**