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DESIGN AND FABRICATION OF VERTICAL PISTON PUMP USING HELICAL WIND TURBINE

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ABSTRACT

Since the industrial revolution the main sources of energy has been oil, natural gas, nuclear energy, wood and coal. However, all these sources are limited and are the main cause of pollution and this has led to development and more focus on sustainable energy supply with minimum pollution effects. Hence research and analysis has shown that wind energy, solar energy and biomass are the most prominent solutions to the above problems because they are eco-friendly and readily available in nature.

Wind energy can be generated using windmills that provide mechanical energy that is used directly on machinery e.g., water pumps, grinders or wind turbines that provide electrical energy, but our main objective for this project was to design a windmill for pumping water and therefore our scope will be limited to a windmill for water pumping water.

The windmill is designed to provide water for irrigation and the region in question is the Taita/ Taveta region which is a semi-arid region of low height tree coverage. This region also has mean wind speeds of 2.3Meters/Second (m/s) – 2.4m/s and a water table of about 300 meters (m) deep.

Based on this data the windmill needs to be of a height of 12 meters with a rotor diameter of 6 meters and a blade area of 2.7m^2, and the pump of choice is a piston pump. The windmill which will be able to pump an average 4m^3 of water per a day which means our windmill will serve 4 farms approximately every day. This is going by the by the assumption that each small-scale farmer in the Taita/ Taveta county has about 1/4 acres of land set aside for agriculture only and of that half of it is for horticulture and is served by a 1000litre tank at the least.

The total cost for construction of the windmill comes to 138,170 Kenya shillings.

Key Words: Windmills, Pump and Piston Pump

Introduction to Wind Energy

In Africa today the biggest issues being tackled by most countries is poverty and famine especially in the rural areas. For most countries which include Kenya the biggest income earner is agriculture, which has taken a major blow over the past year due inaccessibility to sufficient water; seasonal or no rainfall, most areas are located very far from water bodies like rivers, streams and lakes, very deep-water tables and drought.

To address these problems many methods have been employed and are expensive and take a toll on the farmer's pocket. We have come up with a design of a windmill that can be cost effective and could serve a small village.

Research on Wind Speeds in Kenya

Characteristics of the Winds over Kenya

Kenya's location within the equatorial region does not favor stronger winds like those experienced in the extra-tropical regions, which are usually strong and persist over a long period of time. Nevertheless, there are however many locations in Kenya that possess relatively strong and persistent wind speeds with considerable wind power potential throughout the year.

Various studies have shown that complex topographical features and the varying nature of the surfaces and the existence of large inland lakes found in Kenya have marked influence in modifying the horizontal and vertical wind speed profiles thus making many locations to possess substantial wind energy potentials. The mesoscale circulations (Land/Sea breeze) generated by these large water bodies are known to have significant influence on both the wind flow and weather patterns of the surrounding areas.

Other studies have also shown that the topographical features around Marsabit and Turkana regions have marked influence on the wind flow patterns over the region. A low-level jet known as the Turkana Jet has been observed over this region and is attributed to the orographic channeling effects of the surface wind speeds by the mountain ridges around this region. This venturi effect results in very strong and persistent winds over the Marsabit area

LITERATURE REVIEW

Wind Energy: A Review Paper BY Gyancity Journal of Engineering:

Atul Kumar (M S College), Muhammad Zafar Ullah Khan, Bishwajeet Pandey (University of Management & Gyancity Research Lab), examined the outline of wind innovation, where the approach depends on standards and down to earth executions. Wind vitality is the second biggest wellspring of sustainable power source after hydropower. It is incredibly reasonable, yet it is discontinuous. Even though the abuse of twist goes back a few centuries, the cutting-edge wind vitality industry started amid the oil emergency of the seventies. Most these days wind turbines are onshore; however, others are fabricated seaward, more often than not in wind ranches. Since wind vitality is discontinuous, it must be upheld by different wellsprings of power. Wind vitality can be productive as a rule. However, it has not yet accomplished full matrix equality with fossil vitality sources.

Performance analysis of wind turbine systems under different parameters: By International Journal of Environmental Engineering:

Salih Mohammed Salih (University of Anbar) and Mohammed Qasim Taha (University of Anbar) In this paper, simulation models are used to study the performance of small power systems based on different weather parameters. The results are extracted using Matlab software program for analyzing the performance of two wind turbines: Whisper-500 3.2KW and NY-WSR1204 600W which have the same type of permanent magnetic alternators (three phase and 16 poles). Different parameters can affect on the performance of wind turbines which are: the wind speed air density, air pressure, temperature and the length of blades for wind generators. The mathematical results related the previous mentioned parameters are analyzed in order to determine the sensitivity of input power on the output of wind generators. 1. Introduction The basic goal of calculating effect of air's parameters in mechanical power (that later become electrical output power) is to show the generating sensitivity of wind generator to air characteristics variation at any wind speed value. Then create database for air effect of mechanical power to use it in practical tests, installation, electrical generation, usefulness of wind station with air's parameters of its location and compare the economic profit to electrical wind station installation with its costs and losses. In the last years MATLAB/Simulink has become the most used software for modeling and simulation of wind systems. Wind turbine systems are an example of such dynamic systems, containing subsystems with different ranges of the time constants: wind, turbine, generator, power electronics, transformer and grid. In 2008, the United States became the nation with the largest wind power generation infrastructure. As wind turbine power generation proliferates, designs are needed which are both efficient and minimally disruptive to surrounding communities, particularly in terms of additions to background noise. Design optimization is therefore needed to resolve the conflicting considerations of maximum power production and minimum noise generation. Horizontal Axis Wind Turbines (HAWTs) have become the predominant configuration for harnessing wind power, exemplified in the General Electric 1.5sle wind turbine, a model rated at 1.5MW. The wind turbine rotor is the mechanism which interacts directly with the wind in order to convert it into energy, and is also the main contributor to wind turbine noise. Therefore, the present work will focus on optimization of the aerodynamic and aero acoustic properties of the wind turbine rotor. The main improvement over that work is the incorporation of a variable airfoil shape across the rotor and fixed y-coordinates of the Bezier curve control points.

HISTORICAL DEVELOPMENT OF WIND POWER: By Renewable and Efficient Electric Power Systems:

Gilbert M. Masters from ISBN researched about Wind utilized as a source of power for thousands of years for such tasks as propelling sailing ships, grinding grain, pumping water, and powering factory machinery. The world’s first wind turbine used to generate electricity was built by a Dane, Poul la Cour, in 1891. It is especially interesting to note that La Cour used the electricity generated by his turbines to electrolyze water, producing hydrogen for gas lights in the local schoolhouse. In that regard we could say that he was 100 years ahead of his time since the vision that many have for the twenty-first century includes photovoltaic and wind power systems making hydrogen by electrolysis to generate electric power in fuel cells. In the United States the first wind-electric systems were built in the late 1890s; by the 1930s and 1940s, hundreds of thousands of small-capacities, wind electric systems were in use in rural areas not yet served by the electricity grid. In 1941 one of the largest wind-powered systems ever built went into operation at Grandpa’s Knob in Vermont. Designed to produce 1250 kW from a 175-ft-diameter, two-bladed prop, the unit had withstood winds as high as 115 miles per hour before it catastrophically failed in 1945 in a modest 25- mph wind (one of its 8-ton blades broke loose and was hurled 750 feet away).

Stress analysis and Design Optimization of Piston, Slipper assembly in an Axial Piston Pump: By Journal of Scientific and Industrial Research:

Kishan Choudhuri (National Institute of Technology, Agartala), S. Chakraborty (National Institute of Technology, Agartala), Prasun Chakraborti (National Institute of Technology, Agartala) The amount of research carried out on piston assemblies of axial piston pump is a good indication of the problems which have been encountered. Fortunately, this is one branch of engineering where research is usually well ahead of production failures. A representative domain for the high development of the axial piston pumps manufacturing is the aeronautics. In this industrial branch, light hydraulic transmissions that operate in very safe conditions are required. The mass reduction must be done according to an optimal design of the machine's geometry, taking into account the static and dynamic stress and deflection states of the mechanical components. In this paper, a steady state stress analysis and also an optimization of the piston slipper assembly has been carried out by using ANSYS software. Optimization is done using Sub-problem approximation method where the main objective is to minimize the volume of the piston and slipper. Dimensions of the assembly are taken from SPV 22 axial piston pump, made by ZTS Company. This optimization technique minimizes the volume of the piston and also slipper. The paper concludes with the Comparison of the piston and slipper dimensions before and after optimization.

Axial Piston Pumps, New Trends and Development: Published by Nova Science USA:

J. M. Bergada (Universität Politècnica de Catalunya), Sushil Kumar (Bharat Institute of Engineering and Technology), J. Watton (Cardiff University) Researched about Axial piston pump main components. From 1, it is to be noticed that relative movement appears between pistons and barrel, slippers and swash plate, barrel and port plate and piston-slipper spherical journal. The pump operating mechanism is as follows; as the cylinder block (barrel) rotates, the exposed ends of the pistons (slippers) are constrained to follow the surface of the swash plate plane. Since the swash plate plane is at an angle to the axis of rotation, the pistons must reciprocate axially as they proceed about the cylinder block axis. The axial motion of the pistons is sinusoidal. During the rising portion of the piston's reciprocating cycle, the piston moves towards the port plate, during this period, the fluid trapped between the buried end of the piston and the valve plate is vented to the pump's discharge port. When a piston is positioned at the top reciprocating cycle (top death center, TDC), the connection between the piston-cylinder chamber and the pump's discharge port is closed, shortly thereafter, piston-cylinder chamber is connected to pump's inlet port. The piston moves away from the port plate, thereby increasing the volume of piston-cylinder chamber, as this occurs, fluid enters the chamber from the pumps inlet to fill the void. This process continues until the piston reaches the bottom of the reciprocation cycle (bottom death center, BDC). At BDC, the connection between the piston-cylinder chamber and the inlet port is closed, shortly thereafter, the chamber becomes open to the discharge port again and the pumping cycle starts over.

Investigation on the Radial Micro-motion about Piston of Axial Piston Pump: By CHINESE JOURNAL OF MECHANICAL ENGINEERING

The limit working parameters and service life of axial piston pump are determined by the carrying ability and lubrication characteristic of its key friction pairs. Therefore, the design and optimization of the key friction pairs are always a key and difficult problem in the research on axial piston pump. In the traditional research on piston/cylinder pair, the assembly relationship of piston and cylinder bore is simplified into ideal cylindrical pair, which cannot be used to analyse the influences of radial micro-motion of piston on the distribution characteristics of oil-film thickness and pressure in details. In this paper, based on the lubrication theory of the oil film, a numerical simulation model is built, taking the influences of roughness, elastic deformation of piston and pressure-viscosity effect into consideration. With the simulation model, the dynamic characteristics of the radial micro-motion and pressure distribution are analysed, and the relationships between radial micro-motion and carrying ability, lubrication condition, and abrasion are discussed. Furthermore, a model pump for pressure distribution measurement of oil film between piston and cylinder bore is designed. The comparison of simulation and experimental results of pressure distribution shows that the simulation model has high accuracy. The experiment and simulation results demonstrate that the pressure distribution has peak values that are much higher than the boundary pressure in the piston chamber due to the radial micro-motion, and the abrasion of piston takes place mainly on the hand close to piston ball. In addition, improvement of manufacturing roundness and straightness of piston and cylinder bore is helpful to improve the carrying ability of piston/cylinder pair. The proposed research provides references for designing piston/cylinder pair, and helps to prolong the service life of axial piston pump.

DESIGN OF WINDMILL

Rotor

The process of designing wind turbine blades is closely connected with the development of airfoils. Traditionally wind turbine blades have been based on aviation airfoils designed for plane wings flying at completely different flow regimes than the turbine blades. Later on, some research institutes and universities developed wind turbine specific airfoil shapes, tailored to the performance requirements of wind turbines.

The developments however of wind turbine designs have been rapid and current wind turbines are larger than ever before with rotor diameters in excess of 120m. These rotors are required to perform quietly and efficiently with low aerodynamic loads at turbulent and rough atmospheric conditions. Furthermore, the aerodynamic performance of wind turbines should be constant through time despite the gradual contamination of the blades which constantly operate in rough conditions.

High rotor efficiency is desirable for increased wind energy extraction and should be maximized within the limits of affordable production. Energy (*P*) carried by moving air is expressed as a sum of its kinetic energy:

$P = \frac{1}{2} \rho A_S V^3$ …………………………… ***Equation: 1***

Where: V = *Air Velocity*

A_S = *Swept area*

ρ = *Air Density*

The energy extraction is maintained in a flow process through the reduction of kinetic energy and subsequent velocity of the wind. The magnitude of energy harnessed is a function of the reduction in air speed over the turbine. 100% extraction would imply zero final velocity and therefore zero flow. The zero-flow scenario cannot be achieved hence all the winds kinetic energy may not be utilized. This principle is widely accepted and indicates that wind turbine efficiency cannot exceed 59.3%. This parameter is commonly known as the power coefficient C_P, where max C_P= 0.593 referred to as the Betz limit. The *Betz theorem* assumes constant linear velocity.

According to *Newton's third law of motion*; for every action, there is equal and opposite reaction. Therefore, the decelerating force on the wind is equal to the thrust force which the wind applies to the rotor. In designing the rotor, the main goal is to make sure that the thrust produced is able to produce Betz' optimum deceleration.

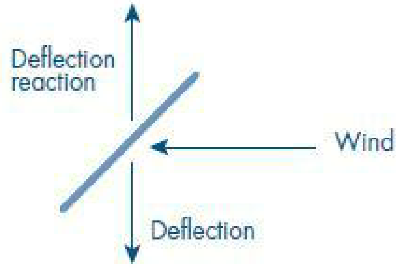


Fig: Illustration of the reaction force that causes thrust

Therefore, any rotational forces such as wake rotation, turbulence caused by drag or vortex shedding (tip losses) will further reduce the maximum efficiency. Efficiency losses are generally reduced by.

1. Avoiding low tip speed ratios which increase wake rotation
2. Selecting aero foils which have a high lift to drag ratio
3. Specialized tip geometries

Blade Plan Shape and Quantity

The ideal plan form of a HAWT rotor blade is defined using the BEM method by calculating the chord length according to Betz limit, local air velocities and aero foil lift.

Several theories exist for calculating the optimum chord length which range in Complexity, with the simplest theory based on the Betz optimization:

$C_{opt} = (2/N)\,(8/9C_L)\,(V_{wd}/\lambda V_r)$ ……………………..**Equation 2**

$V_r = (V_{wd2} + V_{w2})^{(1/2)}$

Where:R= Blade radius

N = Number of blades

C_L = *Lift coefficient*

V_W = *Wind speed*

V_{wd} = *Design speed*

C_{opt} = *Optimum Chord Length*

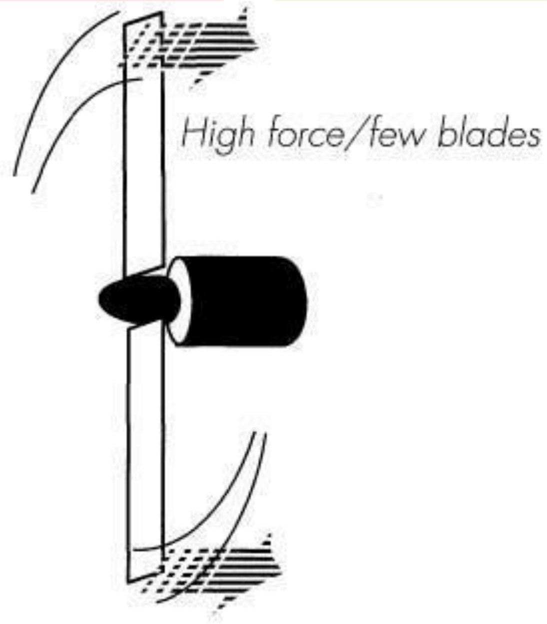
λ = *Local tip speed ratio*

Vr = Local airvelocity (m/s)

Table: Typical choices for the tip speed ratio and blade number for pump and generator

S.NO	No. of Blades Functions ratio	Tip speed
1	6-20	Slow pumps
2	4-6	Faster pumps
3	3-6	Dutch 4-bladed
4	2-4	Slow generators
5	2-3	Generators
6	1-2	Fastest Possible

Typical choices for the tip speed ratio and blade number for pump and generator.



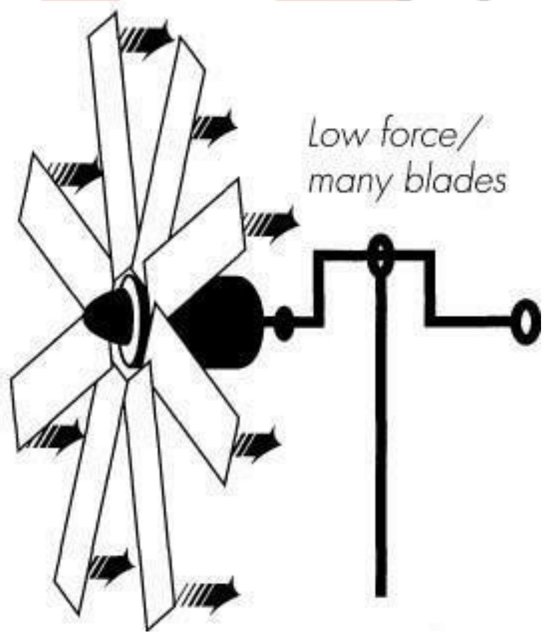


Fig. (a) Generator - High Speed and low torque **Fig. (b) Pump - Low Speed and high torque**

For blades with tip speed ratios of five to six utilizing aero foil sections with negligible drag and tip losses, Betz's momentum theory gives a good approximation. In instances of low tip speeds, high drag aero foil sections and blade sections around the hub, this method could be considered inaccurate. In such cases, wake and drag losses should be accounted for. The Betz method gives the basic shape of the modern wind turbine blade (Figure 2). However, in practice more advanced methods of optimization are often used.

The Aero foils

In the design of the cross-section (aero foil) of the blades, there are some key considerations and specifications that should also be taken into account to ensure maximum thrust and lift. The following figures show these important specifications.

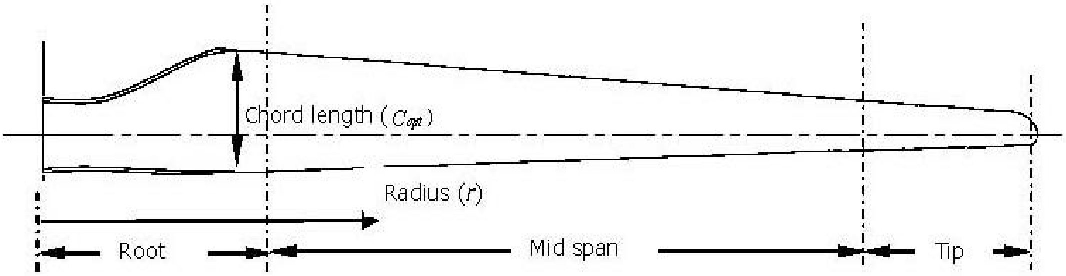


Fig.: Peter J. Schubel and Richard J. Crossley, 'Wind Turbine Blade Design', Energie

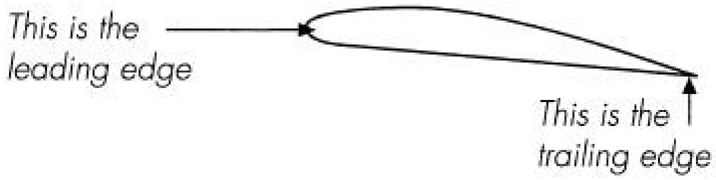


Fig.: Illustration of the leading and trailing edges

The other important specification is the **Angle of attack (α)**. This is the angle between the chord line and the relative air (or wind) movement. It is illustrated in the figure below.

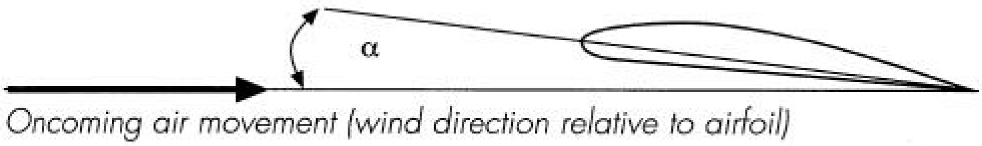
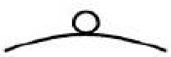


Fig.: Illustration of the angle of attack

Table : Data for some common blade cross-sections

Section	**Sketch**	**Drag/ Lift Ratio**	**Optimum angle of attack**	**Lift coefficient (C_L)**
Flat plate		0.1	5_0	0.8
Curved Plate (10%curvature)		0.02	40^0	1.25
Curved plate with tube on concave side		0.003	4^0	1.1
Curved plate with tube on convex side		0.2	14^0	1.25
Aero foil		0.01	4^0	0.8

Rotor solidity

Solidity of a windmill loosely refers to the proportion of a windmill rotors' swept area that is filled with solid blades (Solidity is the ratio of total rotor plan form area to total swept area). Solidity is represented mathematically as:

$\sigma_{rotor} = NA_B/A_S$ …………………………………………… ***Equation .3***

Where: σ_{rotor} *= Rotor solidity*

N = Number of Blades

A_B *= Area of one blade* (M^2)

A_s *= Swept Area* (M^2)

Most of the HAWT Windmills that are used on wind pumps are multi-bladed rotors they are usually of high solidity due to the fact that a large proportion of the swept area is 'solid' with blades.

If the rotor solidity is 0.10; this is considered as low solidity which means that the wind turbine in question has high speed and low torque.

If the rotor solidity is >0.80; this is considered as high solidity which means that the wind turbine in question is of low speed and high torque.

Rotor Efficiency

Our rotor has an efficiency of 70% which suggests that 30% of the total power produced is lost due to various losses.

Therefore, to calculate the actual power a mathematical expression shown below is used,

Output power (watts) *= Input power (watts) ÷ Efficiency (%) × 100* …………… ***Equation .4***

Theory:

Betz Theorem:

Power is extracted from the wind by decelerating it. This deceleration is as much as a third of the upstream velocity. This translates to 59.3%. Any further deceleration of the wind will divert the wind away from the rotor.

Newton's third law of motion:

For every action there is an equal and opposite reaction.

Power coefficient C_P:

The power coefficient is the ratio of the actual power output (H_W) to the theoretical power in the wind

Power = Force × Velocity;, *Force = Rate of change of momentum;*

But; *Momentum = Mass* × Velocity;

For a fluid of density (ρ), flows through a cross-sectional area of *A*, the mass flow rate $\dot{m}$

Is given by:

$\dot{m}$ρAV

Average Force = ½ρAV2

$H_T = ½\ \rho A V^3$

Therefore; $C_P = H_W/H_T$………………**Eq.5**

Swept Area A_S:

This is the section of air that encloses the wind turbine or windmill in its movement and interacts with the rotors to produce the rotation motion. For a Horizontal Axis Wind Turbine (HAWT), the swept area is circular in shape. On the other hand, for a Vertical Axis Wind Turbine (VAWT) with straight blade, the swept area is Rectangular in shape. The swept area for the HAWT is calculated by:

A_S = ¼ ^{2}………………………**Eq.6**

Where: A_S= *Swept Area* (m^2)

D = Rotor Diameter (m)

NOTE: The rotor radius is the distance from the tip of one blade to the center. The diameter is twice this length.

Tip Speed Ratio, λ:

- The tip speed ratio defined as the relationship between rotor blade velocity and relative wind velocity at radius R when rotating at ω radians per second to the speed of the wind V m/s i.e., Tip Speed ratio is ratio of the speed of the windmill rotor tip:
- The tip speed ratio is represented mathematically by:

$\lambda = \omega R/ V_w$…………………………………………… **Eq.7**

$\lambda = 4/N$ …………………………………… **Eq.8**

Where: V_W= *Wind speed*

R = Radius

ω = Rotational velocity (rad/s)

λ = Tip speed ratio

N= Number of blades

Calculation

P = ½ ρASV3

Where: P = Power

ρ = 1.1629 Kg/ M3

Vmax = 7.2 M/S

V_{mean} = 5.025 M/S

V_{min} = 2.85 M/S

A_S = ¼π× 6^2=**28.274334 M^2**

P_{max}= ½ × 28.274334 × 7.2^3× 1.1629=**6136.2387 watts**

P_{mean}= ½ × 28.274334 × 5.025^3× 1.1629= **2085.99353 watts**

P_{min}= ½ × 28.274334 × 2.85^3× 1.1629= **380.5742 watts**

$\lambda = \omega R / V_W$ Where: V_W = 5.025 M/S

$N = 4\pi / \lambda$ R = 3 M

ω = 7.2 ÷ 3 = 2.4 (rad/s)

λ = Tip speed ratio

N= Number of blades

λ = 2.4 × 3 ÷ 5.025 =**1.4328**

N = 4π ÷ 1.4328= **9 blades**

$C_{opt} = (2/N)\ (8/9C_L)\ (V_{wd}/ \lambda V_r)$

$V_r = (V_{wd}^2 + V_w^2)^{(1/2)}$

Where: R = 3 M

N = 9 Blades

C_L = 1.25

V_W = 5.025 M/S

V_{wd} = 7.2 M/S

λ = 1.432

V_r = Local resultant air velocity

C_{opt} = Optimum Chord length

$V_r = (7.2^2 + 5.025^2)^{(1/2)}$= 8.78013 M/S

C_{opt}= (2π × 3÷ 9) (8 ÷ [9 × 1.25]) (7.2 ÷ [1.4328 × 8.78013])=**0.9 M**

$\sigma_{rotor} = NA_B/A_S$

Where: σ_{rotor} = Rotor solidity

N = 9

A_B= 3 × 0.9 = 2.7 M^2

A_s = 28.274334 M^2

σ_{rotor} = 9 × 2.7 ÷ 28.274334= **0.8**

CONCLUSION

The windmill is designed to operate and in the Taita/ Taveta region which is a semi-arid region of low height tree coverage. This region also has mean wind speeds of 2.3 Meters/Second (M/S) – 2.4 M/S and a water table of about 300 meters (M) deep.

Thus, the windmill is of height 12 meters and has a 9-blade rotor; each blade has a length of 3 and a chord length of 0.9 meters and a 10% curvature giving the rotor a diameter of 6 meters. Each blade has an area of 2.7 square meters giving the rotor a sweeping area of 28.27 square meters. The windmill has two tail vanes: the larger tail vane is used for yawing and the smaller tail vane which is a ¼ the size of the larger tail vane is used for braking. The windmill has a solidity of 0.86.

The windmill operates a piston pump which will pump an average 4 cubic meters of water per a day which requires an operation power of 415.53 watts.

The total cost for construction of the windmill comes to 138,170 Kenya shillings.

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