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Palm tree inspired blade design for horizontal axis wind turbines

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ABSTRACT

Our Invention Palm tree inspired blade design for horizontal axis wind turbines is this present invention provides a palm tree inspired blade for horizontal axis wind turbines, where in the turbine tower bends 50 to 80 degrees in stormy conditions without snapping to generate optimal power, as compared to the conventional horizontal axis wind turbines. Due to such chord length and airfoil twist resembling a palm tree leaf blade shape proposes an optimum blade design for the wind turbine in stormy weather conditions. The usage of 'B-spline curves' gives the entire blade system sheer strength and malleability of the tower to act like the palm tree stem inclement to withstand the stormy weather conditions without snapping. This bio-memetic concept of palm tree inspired blade design can improve the aerodynamic performance of the horizontal axis wind turbine blade system even in stormy weather conditions, without producing a lower maximum power co-efficient; hence maintaining the higher lift co-efficient even at crucial stormy weather velocities, without snapping or breaking the wind turbine controls.

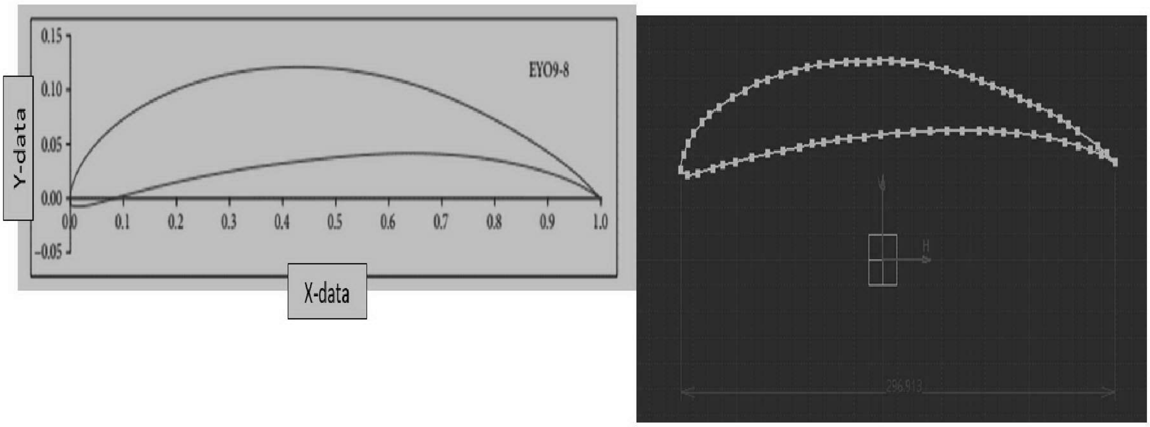

Fig. 1 Standard airfoil shape of EY09-8 [PRIOR ART]

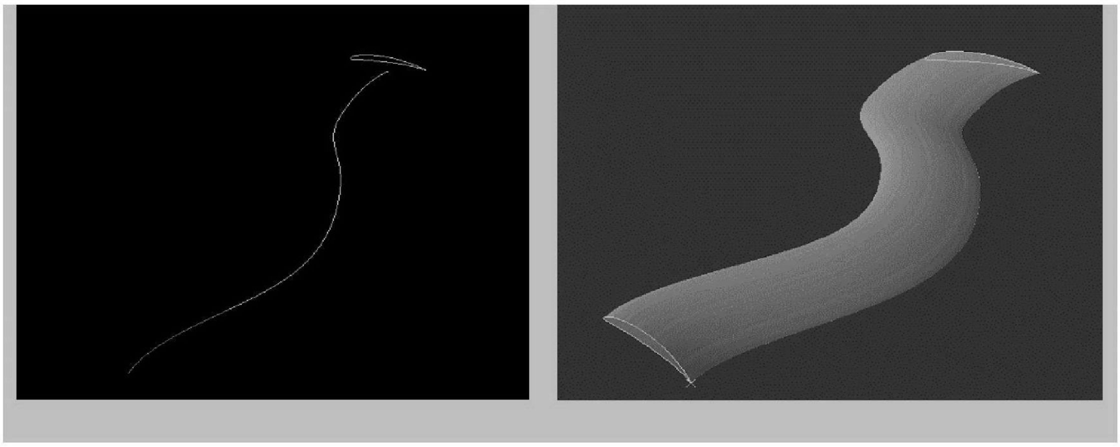

Fig. 2 B-Spline curve approximation and sweep generation for the palm-leaf blade with the blade twist

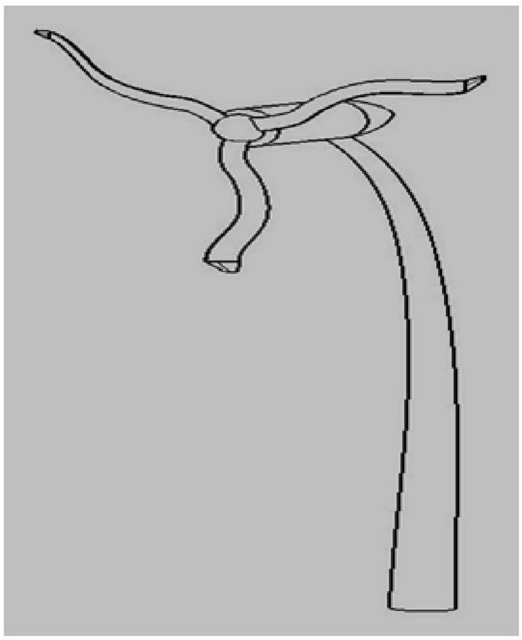

Fig. 3 Three bladed palm-leaf horizontal axis wind turbine with central hub.

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Palm tree inspired blade design for horizontal axis wind turbines

FIELD OF THE INVENTION

Our Invention is related to is Palm tree inspired blade design for horizontal axis wind turbines.

BACKGROUND OF THE INVENTION

Horizontal axis wind turbines are well known, the windmill being a most exemplary example. The principle of operation of a windmill has been expanded from pumping water or grinding to the generation of electricity. In use, at least a pair of turbine blades are mounted symmetrically about a rotating turbine hub. In response to an incident wind, the hub is caused to rotate. The hub is connected either directly or indirectly to an. electrical generator shaft (rotor) such that rotation of the shaft generates an electrical output from the generator.

Wind turbine blade design is commonly based on blade element theory (BET), whether by manufacturers of large or small turbine blades. In the blade element theory, a turbine blade is longitudinally divided into a number of elements and each element is assumed to behave as an aerofoil section at the same velocity and angle of attack.

Once this is done, the lift and drag coefficients for the aerofoil can then be used to determine the torque acting on each element. The sum of the torque on all of the blade elements provides a total torque from which a total power output is derived. Reference is made to the "Wind Energy Handbook", Burton et al (John Wiley & Sons) 2001, the disclosure of which is incorporated herein in its entirety by cross- reference. An extensive description of blade element theory is provided by Burton et al. and it will be understood that this teaches the determination of the power output and optimization of the blade shape for maximizing the generated power in given wind conditions.

Most large wind turbine (for example 2 OkW+) blades have a circular or substantially circular blade root to allow the most secure connection to the wind turbine hub. The blade section gradually transforms to the circular or substantially circular root shape as the blade length decreases and the hub approaches. Unfortunately, such blade designs and arrangements cause an overly significant decrease in starting performance when used on relatively small turbine blades.

A wind turbine blade is configured such that the lift force from the blade airfoil is always normal, or nearly normal, to the shaft torque. This condition maximizes energy conversion. This objective may be achieved by a) having the airfoil chord always aligned to the actual wind direction (subject only to small angle of attack variations), and b) slowing the turbine rotation rate so that no blade twist is needed. As a result, blade tip speed due to shaft rotation is less than the wind speed, and preferably much less. This low tip speed eliminates any hazard to birds. The lift force from the blade airfoil directly drives the torque on the shaft, so the control problem simplifies to adjusting the blade angle of attack to keep the lift constant across varying wind speeds.

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Throughout history, civilization has yearned for better and more efficient sources of power generation. Fossil fuels have not always locally available and have been expensive to transport over long distances. Nuclear power has produced unwanted radioactive waste and carries potential for apocalyptic accidents. Solar power's promise has been dimmed by the high cost of equipment necessary to utilize the sun's energy. Hydroelectric power generation requires flowing water and, often, disruption of normal paths of water. Seemingly, the wind is the only readily available and safe source of power.

Though developed centuries ago, wind-powered devices are thus still a favoured source of power generation today. The windmill, once used to grind grain, has been adapted to produce electricity. Windmills have evolved into wind turbines wherein the wind's power no longer turns stone wheels atop grain, but rather passes magnets alongside wire coils to generate electricity. In wind turbines, the wind's force pushes the blades of a wheel which act as the rotors of a generator.

Over time, wind turbines have been developed to work more efficiently in compensating for many of the natural obstacles impeding consistent energy recovery from the wind. For example, shifts in wind direction can stop a fixed wind turbine; thus, wind turbines have been constructed with various rotational methods so that the wind will strike the blade in the optimum fashion. Further, wind turbines have been developed whereby fluctuations in wind velocity leave the wind turbine relatively unaffected in both structural integrity and power generation potential.

Horizontal axis wind turbine generators have proven very effective in producing electricity from the wind. Typically, they consist of a nacelle mounted atop a tall tower. The nacelle houses a transmission to increase a rotor's rotational speed to the speed of an electrical generator; some means of power smoothing is necessary to compensate for cyclic fluctuation and wind gusts. The nacelle also incorporates a strong shaft to carry a large rotor hub and blades. Turning in a horizontal plane, the nacelle adjusts to the direction of the wind current to face the rotor into the oncoming wind. Horizontal axis wind turbines are not without their problems, however. The transmission requires regular maintenance and repair; a major expense in horizontal axis wind turbine design is the transmission.

Furthermore, the main shaft must withstand not only the load of the rotor hub and blades, but also the load from oscillations and wind gusts. Additionally, expenses are incurred in reinforcing the tower structure supporting the heavy nacelle. Another problem with horizontal axis wind turbines is maximizing rotor diameter and the number of rotor blades. Horizontal wind turbine generators usually have a rotor diameter of at least 20 meters, and they are designed with only two or three blades.

As a general rule, if a wind turbine has a large number of blades, the rotor's solidity is increased, rotation speed is slower, and less noise is produced. Horizontal axis wind turbines have employed few blades, however, because the design and construction of conventional blades is expensive. Moreover, the increased rotor diameter of horizontal axis wind turbines makes blade control and structural integrity difficult at high wind speeds.

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PRIOR ART SEARCH

Osei, E. Y. *et al.* (2020) 'Development of High Performance Airfoils for Application in Small Wind Turbine Power Generation', *Journal of Energy*. Edited by A. Zidansek, 2020, p. 9710189. doi: 10.1155/2020/9710189.

Piegl, L.A. and Tiller, W., The NURBS Book, 2^{nd} Edition, Springer, New York, pp. 81-116 (1997).

OBJECTIVES OF THE INVENTION

1. The objective of the invention is to create a bio-memetic horizontal axis wind turbine blade design inspired by palm tree.
2. The other objective of the invention is to propose a method to design a three bladed palm leaf shaped blade system which will be placed in stormy weather conditions or stormy weather velocities to produce maximum power coefficient and lift coefficient without snapping or breaking the wind turbine controls;
3. The other objective of the invention is to enable the designed bio-memetic palm leaf shaped blade to provide a better lift-to-drag ratio to enhance the maximum power coefficient, as well as generate more power and make use of the available energy from the stormy weather conditions or higher wind velocities;

SUMMARY OF THE INVENTION

Therefore, the palm-tree based three bladed wind turbine design and analysis method can be explained as follows:

In this present invention, there is provided a blade for the horizontal axis wind turbine which bio-mimics the palm tree leaf for the blade structure and palm-tree stem for the tower design of the disclosed invention. This representative palm-leaf horizontal axis wind turbine blade aims to improve the aerodynamic performance of the wind turbines even in stormy weather conditions i.e. higher wind velocities, when compared to the conventional wind turbines of the same size.

Firstly, a high performing airfoil is chosen to connect the circular section of the hub with the blade root airfoil, after which a B-Spline curve is inserted to avoid pre-bending (undesired curvature variations) whilst maintaining the high tolerance levels for the design quality. The airfoil markers are then placed at every 10% of the overall length of the blade before lofting or creating a sweep to make the 2D surface models into 3D solid model. Furthermore, this invention is subjected to various multi-disciplinary optimization CFD and FEA virtual environment tests to determine the baseline model to compare the aerodynamic performance with an equivalent three bladed wind turbine system.

This three bladed palm-leaf horizontal axis wind turbine blade system aims to maintain higher lift and maximum power coefficients at higher angles of attack or stall points as well as higher wind velocities that to those without palm-leaf shaped wind turbines.

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Therefore, this invention aims to provide better lift-to-drag ratio i.e. it might enhance the maximum power coefficient to help this turbine generate maximum power and also make use of more energy available from the wind.

It might also generate higher lift which can be very effective in the startup of the wind turbine system as well operate more smoothly than the fixed pitch wind turbines due to bio-memetic characteristics of the palm-tree being designed in this blade system, to bend over 50 degrees to 80 degrees in stormy weather conditions without snapping or breaking. The cylindrical approach of the wind tower design in this invention provides the supportive compressive strength and flexibility for inclement in stormy weather conditions. The sheer strength and malleability of this turbine tower is designed to withstand the harsh stormy weather conditions.

Finally, this method attempts

1. To present a three bladed horizontal axis wind turbine system designed through the bio-mimicry of a palm tree to generate higher maximum power coefficient even in the stormy weather conditions;
2. The palm-leaf wind turbine blade system aims to generate power at higher and lower velocities and therefore become more economically feasible for energy production for rural as well as small-scale areas for energy production through the renewable energy source i.e. The Wind.

According to a first aspect of the present invention there is provided a wind turbine blade configured to be mounted to a wind turbine hub configured to be mounted for rotation in a hub plane of rotation so as to generate electricity, the blade extending lengthwise between a hub mounting root end and a blade tip end, and extending a blade width between a leading edge and trailing edge, such that when mounted to the hub the blade is twisted at the root end by an angle of between 19° to 21 ° relative to the plane of rotation of the hub and wherein the blade is twisted at a tip end to rotate in a plane parallel to the plane of rotation of the hub to within ±1 °.

According to a second aspect of the present invention there is provided a wind turbine including a turbine hub configured to be rotatably mounted for rotation in a hub plane of rotation so as to inductively generate electricity, and two or more wind turbine blades each according to the first aspect of the invention and being mounted symmetrically about the hub.

According to a third aspect of the invention there is provided a wind turbine blade configured to be mounted to a wind turbine hub configured to be mounted for rotation in a hub plane of rotation so as to generate electricity, the blade extending lengthwise between a hub mounting root end and a blade tip end, and extending a blade width between a leading edge and trailing edge, such that when mounted to the hub the blade is twisted by an angle of between -1° to 25° about a blade longitudinal axis extending lengthwise along the blade relative to the plane of rotation of the hub and wherein the blade tip end is configured to rotate in a plane parallel to the plane of rotation of the hub to within ±1°.

According to another aspect of the invention there is provided a wind turbine blade configured to be mounted to a wind turbine hub configured to be mounted for rotation in a hub plane of rotation so as to generate electricity, the blade extending lengthwise between a hub mounting root end and a blade tip end, and extending a blade width between a leading edge and trailing edge, such that when mounted to the hub the blade is twisted at the root end by an angle of between 19" to 21 ° relative to the plane of rotation of the hub wherein the turbine blade is twisted by an angle of between -1 ° to 25° about a blade longitudinal axis extending lengthwise along the blade.

It can therefore be seen that there is provided a wind turbine blade and a horizontal axis wind turbine employing the blades 1 which each advantageously optimise the starting characteristics of a 2kW to 1 OkW horizontal axis wind turbine generator and also optimise the power extracted from the horizontal axis wind turbine generator at a nominal operating rotations speed.

Existing wind turbine designs look very much like aircraft propellers. Underlying this resemblance is the apparent assumption that the wind turbine problem extracting energy from the wind—is the dual of the aircraft propulsion problem. Further to this assumption, existing wind turbines rotate fairly rapidly, with blade tip speeds around 200 miles per hour. Noise from the tip vortex is a necessary result. The fast moving rotor blades also pose a distinct hazard to birds and other flying creatures.

On closer examination, however, the assumptions underlying the foregoing design approach appear to be open to question. In particular, aircraft propellers are designed to convert torque from the engine into a forward-directed lift force. One byproduct of this process is “propeller wash,” a mass transfer of air from ahead of the propeller to behind it. This transfer of air appears as a wind flowing in a direction opposite to the lift force to someone standing behind the propeller of a stationary airplane.

The dual relationship considers this problem in reverse: that air motion past a stationary propeller should produce a torque on the propeller shaft, and a lift force in a direction opposite to the wind direction. Conventional wind turbines demonstrate that this approach is workable. Whether it is optimal is a different question. The high tip speed requires the blade to be twisted (airfoil chord significantly misaligned to the wind direction) so that it is not physically aimed in the direction of the wind.

A horizontal axis wind turbine, according to the present invention, comprises a rotor-supporting framework, a multi-vaned rotor, an electricity- generating stator, and a rotation track. The supporting framework is constructed with a plurality of triangular sub-units. The rotor has a plurality of vanes projecting from a central hub rotatably mounted on the supporting framework. The vanes have adjustable pitch and are encircled by a rim having a plurality of magnets. Wind induces rotation of the rim. The stator is essentially stationary and is mounted on supports that attach the stator to the framework opposite the rim.

The supports on which the stator is mounted adjust to ensure a constant distance between the rim and the stator, regardless of movement of the rim. The attraction between the rotor rim magnets and the stator maintains the stator in alignment with the rotor. The stator is able to move into alignment with the rotor because the supports flex but remain parallel to the rotor axis. This is a major feature of the present invention. As magnets on the rotating rim pass by the stator, electricity is generated. The framework is mounted on the rotation track so that the framework can continually be adjusted to maximize wind-induced rotation of the rotor.

BRIEF DESCRIPTION OF THE DIAGRAM

DESCRIPTION OF THE INVENTION

In order to generate the bio-mimicked shape of palm leaf, a high efficiency airfoil EYO9-8 was chosen as it is one of the most efficient airfoils for wind turbines applications (Osei *et al.*, 2020). The required geometrical parameters for the selected airfoil at the 2D level to generate the palm-leaf blade are chord length, twist angle, and the airfoil centre which is relative to the centre of the blade. The points were plotted and the spline was drawn through all of them to form a closed contour. Fig. 1 shows the standard airfoil EY09-8 from which the blade surface was generated.

To avoid the unnecessary curvature variations, and broken continuity B-Spline curve are introduced at the blade root section. A B-Spline curve of degree p is defined as follows (Piegl and Tiller, 1997):

$$\mathrm{C(u)}=\sum_{i=0}^{\mathrm{n}} n_{i,p}(u)P_i$$

Eqn. 1 [PRIOR ART]

where, P_i are the control points, and $n_{i,p}$ are the B-Spline basis functions which are defined over the knot vector by:

$$U=\left\{\underbrace{0,\ldots,0}_{p+1},u_{p+1},\ldots,u_{m-p-1},\underbrace{1,\ldots,1}_{p+1}\right\}$$

Eqn. 2 [PRIOR ART]

Thus by, using the chord-length parameterisation and knot-vector generation mentioned in the Equations 1 and 2; the palm-leaf blade root section starts with a circular curve to fit the purpose of the design ensuring the tolerance fitting and the quality is maintained at

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each radial section. This further avoids the pre-bending of the 3D model of the blade, and doesn't generate complicated 3D curves. The B-Spline curve approximation as demonstrated in the Fig. 2 has the desired continuity for the leading edge and the trailing edge, therefore the curvature variations result in maintaining the better lift coefficients further beyond the stall point to those without palm-leaf shaped horizontal axis wind turbine blade systems.

Having generated the sweep of the palm-leaf blade, the next task was to model the palm-leaf blade into a circular pattern with the addition of the central hub to make it a three bladed palm-leaf horizontal axis wind turbine as shown in the Fig. 3. The addition of the central hub ensures the uniform mounting surface, which makes it easy for the blades to easily adapt to any angle of attack or higher wind velocities in stormy conditions. It should also be noted that when such palm-leaf horizontal axis wind turbine in a flow velocity and rotating at an axial angular velocity, this blade may be able to produce greater power than a threshold of power, as this design aims to produce even in stormy weather condition, leaving alone the standard wind normal weather conditions.

The non-conventional structure gives the palm tree its flexibility and makes it supremely adaptable for hurricanes. Adapting such a natural quality to bio-mimic to design a three bladed wind turbine blade would improve the aerodynamic performance of the wind turbine blades even in stormy conditions with low maintenance, as well as without snapping or breaking the blades.

The cylinder approach provides great strength to support weight (compressive strength) which means that the palm-leaf turbine blade system can bend over 50 degrees to 80 degrees without snapping or breaking. As the sheer strength and malleability of the palm tree stems are engineered for such inclement weather, the palm-leaves have a central spine support to withstand the harsh weather conditions.

Therefore, the palm-leaf turbine may generate higher power coefficients as well as lift coefficients across various lower and higher cut-in velocities, and will not affect the overall turbine performance (Subject to various multi-disciplinary optimisation Computational Fluid Dynamics [CFD] and Finite Element Analysis [FEA] virtual environment tests to establish the baseline model, for the comparison with like-for-like three bladed horizontal axis turbine blade system overall power coefficient and lift coefficients performance).

It will now become apparent that from the above descriptions that the palm-leaf blade employs bio-mimicry in substantially mimicking the palm-tree. Specifically, the blade shape is primarily characterised as a palm-leaf wind turbine blade, as will be appreciated with the further multi-disciplinary optimisation CFD and FEA tests, to identify the 'optimal palm-leaf wind turbine blade', for further manufacturing purposes.

Fig. 5 shows the inner view of the palm-leaf wind turbine blade, and the exemplary airfoil markers, which also act as the blade width will have the 'optimal width' in between '2.5m to 6m' which should be considered for illustrative purposes only. As seen from the above photo, each airfoil marker is defined by a percentage length along the length of the blade at airfoil marker 100%. The airfoil leading edge and trailing edge are already defined in the description of the Fig. 1, above. Where the overall length of the blade (L) will be in between '20m to 70m' making it available to generate at small scale as well as large scale power generation.

Where the Blade hub height (B_{hh}) will be in between '65m to 80m', the Blade tower height (B_{th}) will be in between '55m to 70m', the Blade hub diameter (B_{hd}) will be in between '2m to 5m, and the Tower bend angle (T_b) will be in between '50 degrees to 80 degrees'. For the purposes of promoting an understanding of the design principles of palm-tree based three bladed horizontal axis wind turbine system, it will nevertheless be understood that no limitation of the scope of the disclosure is subjected to further alterations or modifications of the inventive features described in the Fig. 6, or any extra feature additions of the principles or the palm-leaf blade illustrated here in this invention which one would normally occur to one skilled in the relevant art and having possession of this disclosure, are definitely to be considered within the scope of this invention.

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WE CLAIM

1. Our Invention Palm tree inspired blade design for horizontal axis wind turbines is this present invention provides a palm tree inspired blade for horizontal axis wind turbines, where in the turbine tower bends 50 to 80 degrees in stormy conditions without snapping to generate optimal power, as compared to the conventional horizontal axis wind turbines. Due to such chord length and airfoil twist resembling a palm tree leaf blade shape proposes an optimum blade design for the wind turbine in stormy weather conditions. The usage of 'B-spline curves' gives the entire blade system sheer strength and malleability of the tower to act like the palm tree stem inclement to withstand the stormy weather conditions without snapping. This bio-memetic concept of palm tree inspired blade design can improve the aerodynamic performance of the horizontal axis wind turbine blade system even in stormy weather conditions, without producing a lower maximum power co-efficient; hence maintaining the higher lift co-efficient even at crucial stormy weather velocities, without snapping or breaking the wind turbine controls.
2. According to claim1# the invention is to a palm tree inspired blade for horizontal axis wind turbines, where in the turbine tower bends 50 to 80 degrees in stormy conditions without snapping to generate optimal power, as compared to the conventional horizontal axis wind turbines.
3. According to claim1,2# the invention is to a Due to such chord length and airfoil twist resembling a palm tree leaf blade shape proposes an optimum blade design for the wind turbine in stormy weather conditions. The usage of 'B-spline curves' gives the entire blade system sheer strength and malleability of the tower to act like the palm tree stem inclement to withstand the stormy weather conditions without snapping.
4. According to claim1,2,3# the invention is to a bio-memetic concept of palm tree inspired blade design can improve the aerodynamic performance of the horizontal axis wind turbine blade system even in stormy weather conditions, without producing a lower maximum power co-efficient; hence maintaining the higher lift co-efficient even at crucial stormy weather velocities, without snapping or breaking the wind turbine controls.
5. According to claim1,2,3# the invention is to a create a bio-memetic horizontal axis wind turbine blade design inspired by palm tree.
6. According to claim1,2,4# the invention is to a propose a method to design a three bladed palm leaf shaped blade system which will be placed in stormy weather

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conditions or stormy weather velocities to produce maximum power coefficient and lift coefficient without snapping or breaking the wind turbine controls;

7. According to claim1,3,4# the invention is to an enable the designed bio-memetic palm leaf shaped blade to provide a better lift-to-drag ratio to enhance the maximum power coefficient, as well as generate more power and make use of the available energy from the stormy weather conditions or higher wind velocities;

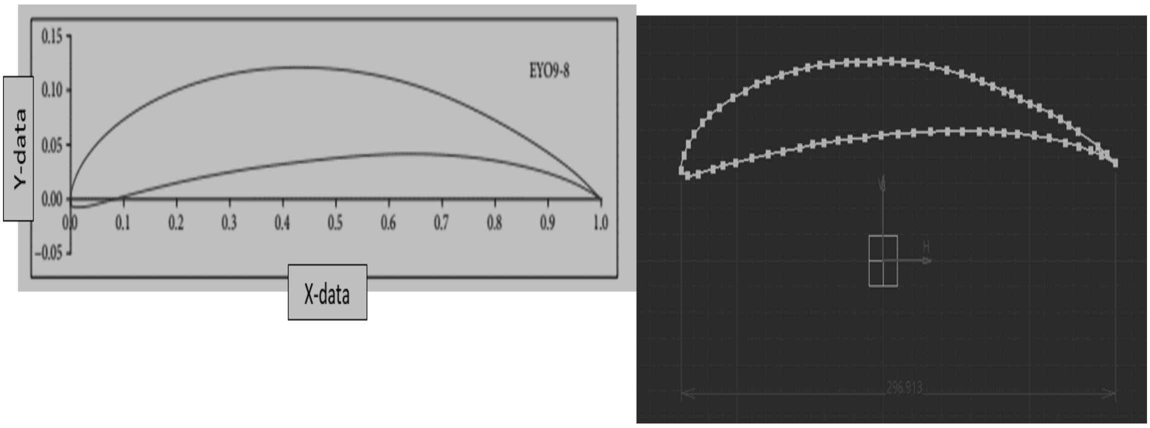

Fig. 1 Standard airfoil shape of EY09-8 [PRIOR ART]

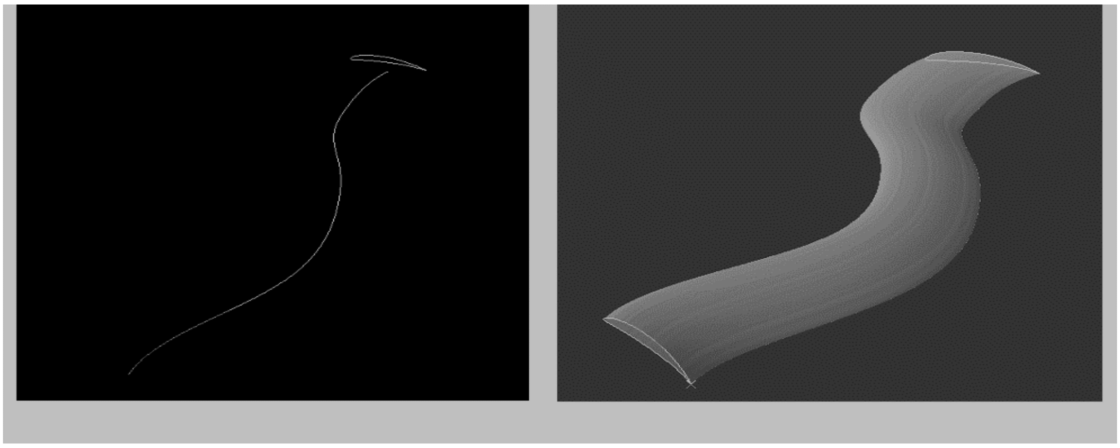

Fig. 2 B-Spline curve approximation and sweep generation for the palm-leaf blade with the blade twist

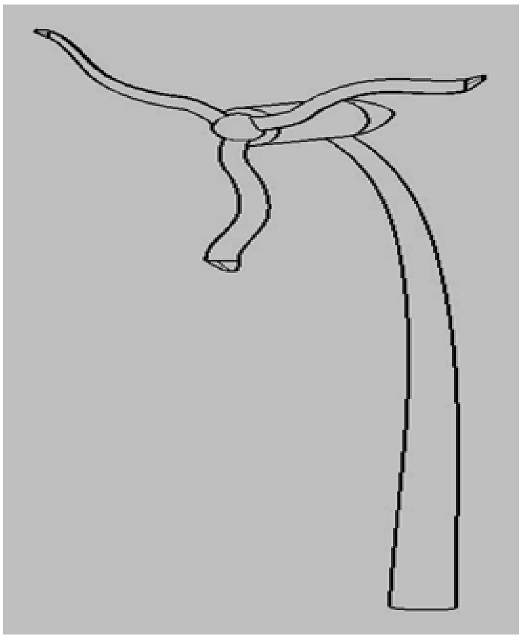

Fig. 3 Three bladed palm-leaf horizontal axis wind turbine with central hub.

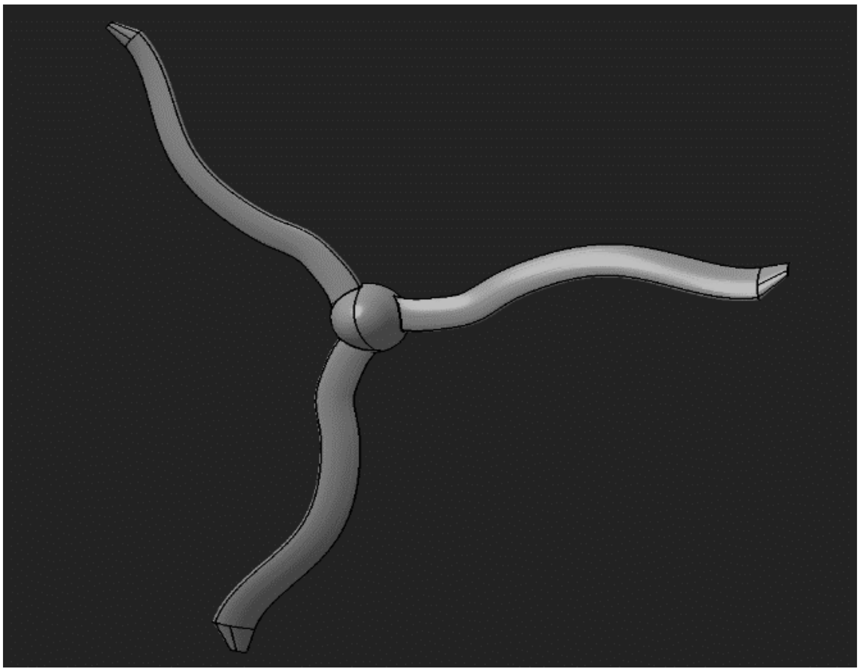

Fig. 4 Three bladed palm-tree based horizontal axis wind turbine with a generator

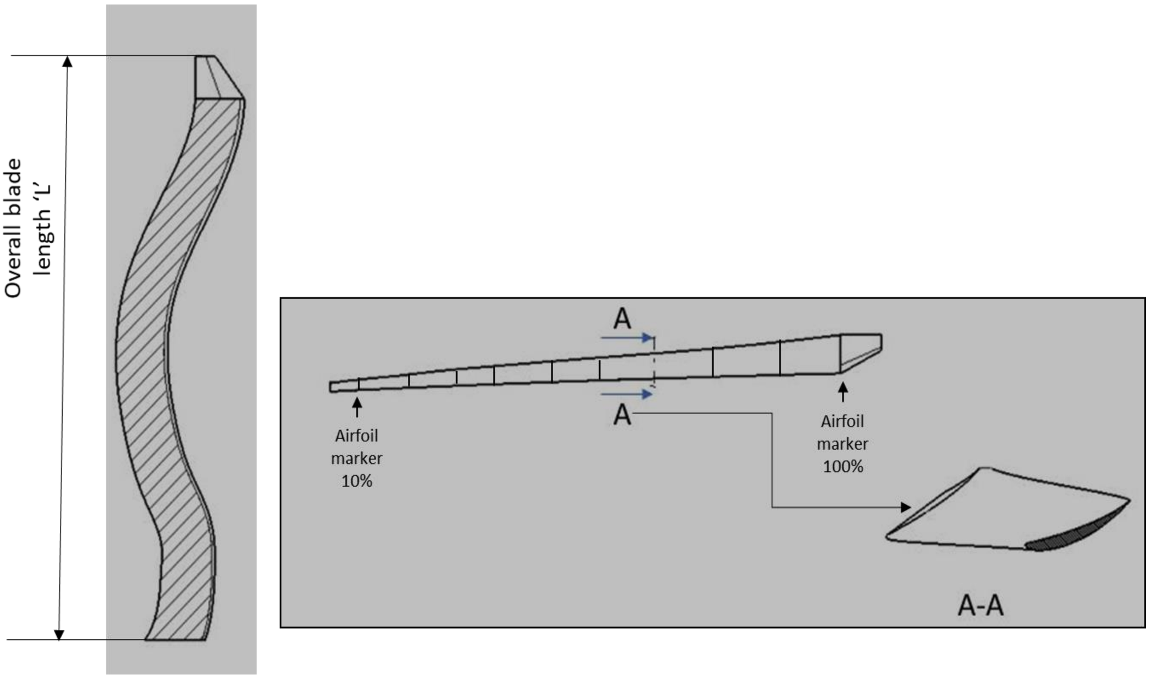

Fig. 5 Palm-leaf turbine blade with airfoil markers along with airfoil cross-sectional view

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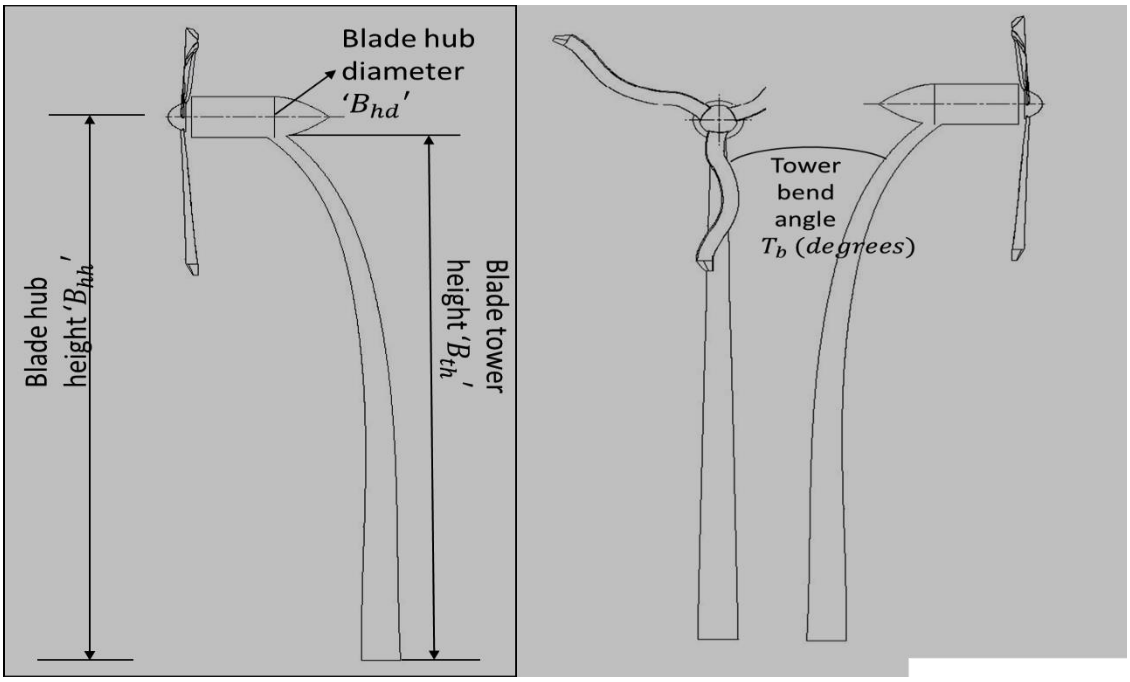

Fig. 6 Palm-leaf turbine other design parameters