Innovative and cost effective design of small-size micro wind turbines for low-speed regions, suitable for use in Egyptian villages

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***Abstract*– Wind energy has proven to be an important source of clean and renewable energy. In order to take advantage of wind turbines, the design of aerodynamic-efficient blade is required not only to improve the performance and reliability of wind turbines, but also to operate these turbines in a safe condition. This project focuses on designing an efficient small-size wind-turbine that can operate efficiently in low wind speed regions as the situation in north Egypt. The design objectives include: cost-effective manufacturing and assembly of the turbine's components, select the size, shape and orientation of rotor blades for maximum induced power, minimize startup friction.**

In this project, a manually pitch-controlled small-size rotor diameter of wind turbine has been designed, constructed and tested for aerodynamic performance. The present report covers four main tasks. First, careful design of number of flat blades with different size and shapes & make a simulation for each blade on Blade to outline the characteristic of each blade. Second, a pitch control system is to control the pitch angle manually by a moving mechanism implemented to the hub. Third, design the main body of the turbine, & test the numerous blade designs at different pitch angles and record the result of each blade to decide the best pitch angle for each blade and the next stage is to compare the blades with each other to choose the optimal design. Fourth, to enhance the per performance of the turbine is by reducing the friction losses generated due to the ball bearing, so we design a magnetic bearing by which we can eliminate the friction losses in the turbine, so in this stage, design & test a magnetic bearing & compare its performance with the ball bearing and record the results.

The idea behind choosing flat blade is the target regions for this technology are locations where people have limited access to tools or supplies. In addition, the area must have access to a reasonable wind resource and access to certain key materials. These materials can be easily produce the blades if the original blades was deformed or broken. The Flat blades are less common than other designs but offer significant benefits, especially in low income or remote areas.

Benefits of Flat Blades are Easy to produce & Simple design & Less equipment and time is required during construction & Easier to ensure blades are a consistent shape and size

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KEYWORDS : SMALL-SIZE WIND TURBINE , DIFFERENT SHAPES OF FLAT PLATE , WIND TURBINE MODEL WITH PERMANENT MAGNET BEARING ,Q BLADE SIMULATION ,PITCH CONTROL .

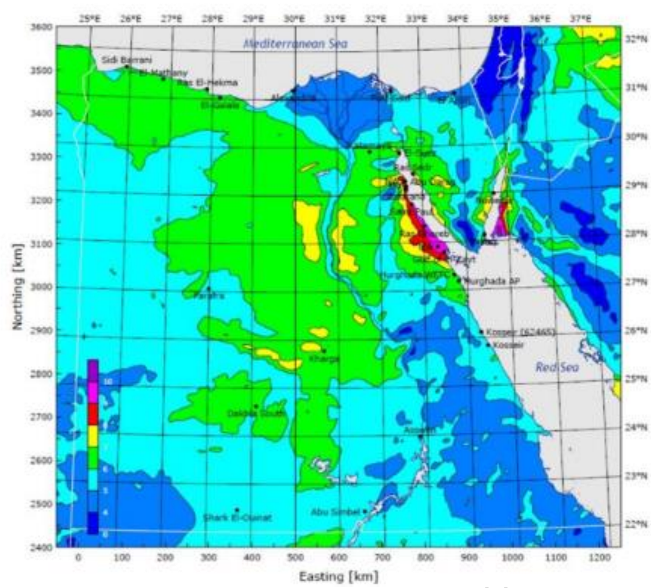


FIG (1) WIND ATLAS FOR EGYPT[15]

I. INTRODUCTION :

Wind energy is one of the fastest growing and cost effective means of generating electricity. The wind energy is observed as an essential and powerful energy resource for the socio-economic development. In the middle east and despite the presence of promising areas of the high wind speed - but the vast majority of other areas where the wind speed ranges between 4 and 6 [m/s] . Therefore, it is suggested that wind power would be more profitably used for local and small-scale

applications. In consequence, it is proposed that the small-size wind turbines (WT) can demonstrate the innovative solution for the wind energy conversion for low speed regions. In the other side, such turbines that operating at low wind speeds regularly face poor performance because of the low solidity ratio of commercial wind rotors and resistive torque caused by friction. Furthermore, the separation bubbles on blades, which are formed due to operating at low Reynolds number, increase the pressure drag and consequently, degrade the overall aerodynamic performance. This paper suggests possible improvements of structural and aero-dynamical design of small-size WT. The investigation aims to construct a computational method to optimize the shape-geometry of small WT blades for the multiple objectives of rapid starting, efficient power extraction, low noise, less friction and minimal mass. The reason of diversity of the wind turbine designs is basically the need to extract the maximum possible energy available in the wind[3].

Nomenclature :

c	Chord length
$\mathbf{C_L}$	Lift coefficient
$\mathbf{C_D}$	Drag coefficient
$\mathbf{C_p}$	Pressure coefficient
$\mathbf{C_P}$	Power coefficient
α	Angle of attack
s	Thurst force
M b	Bending moment
Ω	Rotational velocity of rotor
A	Swept area
λ	Tip speed ratio TSR
P	Extracted power
β	Blade pitch angle

Wind turbine classification :

Wind turbines come in different sizes and types, depending on generated power capacity and the rotor design deployed. Small wind turbines with output capacities below 100 kW are used primarily for residences, telecommunications dishes, and irrigation water pumping applications. Large -scale wind turbines have high power ratings over1 MW as shown in Table 1[10]

	Rotor diameter r [m]	**Swept Area [m^2]**	**Standard power rating [kW]**

Small scale	Micro	0.5	1.25	0.2	1.2	0.004	0.25
	Mini	1.25	3	1.2	7.1	0.25	1.4
	Household	3	10	7	79	1.4	16
Small commercia		10	20	79	314	25	100
Medium commercial		20	50	314	1963	100	1000
Large commercial		50	100	1963	7845	1000	3000

Blade pitch control :

Large scale wind turbines can vary their blade pitch. The altering of blade angle can be used to maximize the lift force on the blades at different wind speeds. The blade angle can also be changed to minimize lift and drag during gales or stormy conditions for safety operation. Small scale wind turbines do not have such mechanisms to adjust the blade angle. They normally apply brakes and completely stop at high wind speeds.

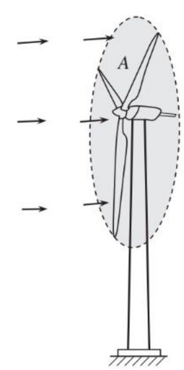
In this paper, flat element is used for small size wind turbine and an efficient experimental procedure is developed as well as the aerodynamic loads. For small size wind turbine, flat element is used to model the blade structure with variable pitch angle, which we adopt the flat blade design to our test blades for our project .

Power Available in the Moving Wind :

Available energy in wind is basically the kinetic energy of moving air. Blades of the wind turbines receive this kinetic energy, which is then transformed in to mechanical or electrical forms. Generally, the kinetic energy accompanied with a stream of air having mass, m, and moving with a velocity ,V, is given by

$$E_k = \frac{1}{2} m v^2 \qquad (1)$$

When wind passes through a wind turbine and drives blades to rotate, the corresponding wind mass flowrate is



$$\dot{m} = \rho A V \qquad (2)$$

the available power in wind Pw can be expressed as

$$P_W = \frac{1}{2} \rho A v^3 \qquad (3)$$

Blade swept area :

the blade swept area can be calculated from the formula:

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$$A = \pi[(L+r)^2 - r^2] = \pi L(L + 2r) \quad (4)$$

where **L** is the length of wind blades and **r** is the radius of the hub .

Power Absorption by a Turbine :

The wind turbine can absorb a portion of the available wind power determined in the previous section. This value of power depends on the type of turbine, the efficiency, and other conditions in the operation of a turbine. This coefficient must, obviously, be smaller than one. It is called power coefficient Cp. So the power which the wind turbine can extract from wind can be expressed as[16]

$$P_W = \frac{1}{2} \rho \, C_p \, A \, V^3 \quad (5)$$

To provide more electrical energy from wind turbine :

- Developing innovative techniques
- Decreasing wind turbine costs
- Optimizing manufacturing processes and enhancing manufacturing operations
- Improving wind turbine performance and efficiency
- Reducing operating and maintenance costs

The current major in the development of wind turbines are towards higher power, higher efficiency and reliability, and lower cost .

Benefits of Flat Blades

Flat blades are less common than other designs but offer significant benefits, especially in low income or remote areas. The following is a list of benefits offered by utilizing flat blades:

- Easy to produce
- Simple design
- Less equipment and time is required during construction
- Easier to ensure blades are a consistent shape and size

Q blade HAWT Simulation :

flat plate airfoils whose coordinates are imported and plotted in Q- blade. Black coloured dotted curve shows[1]

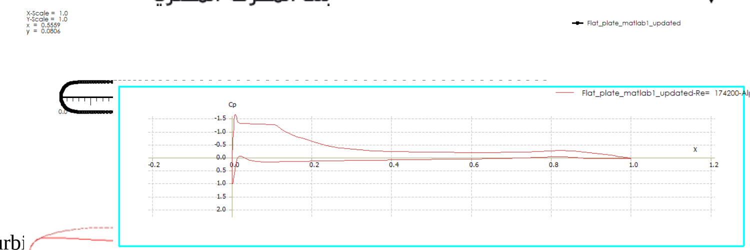

fig (2) Air moving to wind turbi

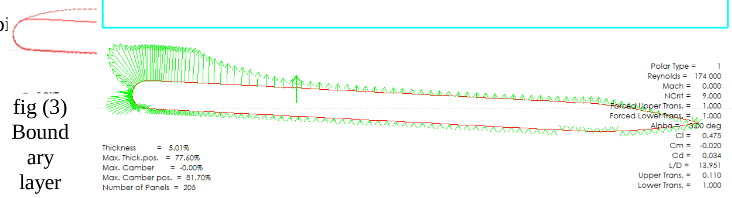

fig (3) Boundary layer around flat plate

fig (4) Pressure distribution around flat plate

Lift and Drag for flat plate Airfoils:

Lift on body is force on body in a directional normal to flow direction.
Drag on body is force on body in direction parallel to flow direction.

A graph of lift coefficient is plotted against angle of attack for flat plate airfoils as shown in Fig. below.

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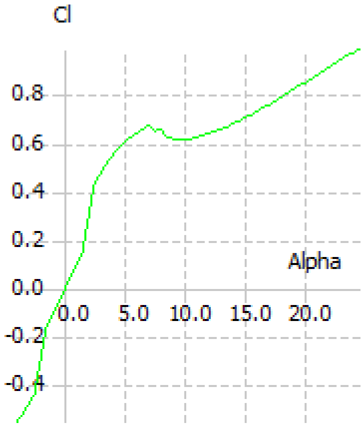
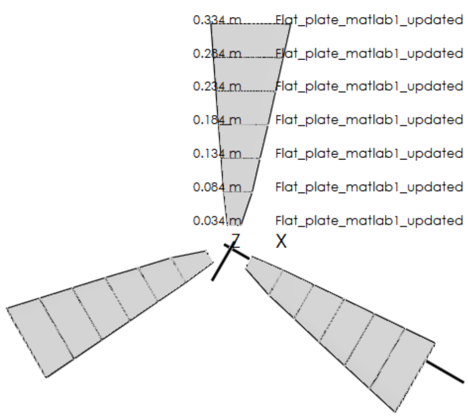


fig (5) lift coefficient against angle of attack

fig (6) Design of blade in Q-Blade

lift to drag ratio versus angle of attack for flat plate airfoils.



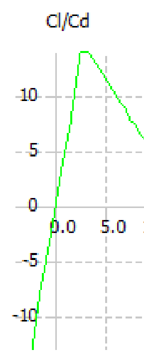


fig (5) lift to drag ratio versus angle of attack

Turbine BEM Simulation For Blade 1 :

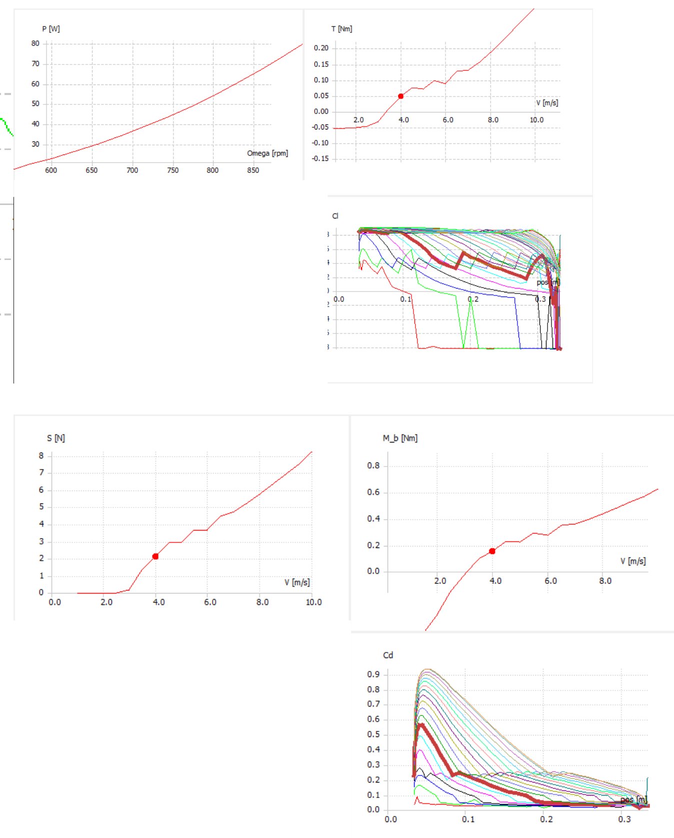


fig (7) thurst force-bending moment-drag coefficient &velocty

HAWT Rotor Blade Design :

BLADE 1 ((solidarity ratio = 0.17)):

	Position (mm)	Chord (mm)	Foil
1.	0	0.02	Flat_plate_matlab1
2.	0.05	0.04268	Flat_plate_matlab1
3.	0.10	0.058	Flat_plate_matlab1
4.	0.15	0.074	Flat_plate_matlab1
5.	0.2	0.089	Flat_plate_matlab1
6.	0.25	0.104	Flat_plate_matlab1
7.	0.30	0.119	Flat_plate_matlab1

Table -2 Q-Blade Parameter

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fig(8)SHAPES OF BLADE USED

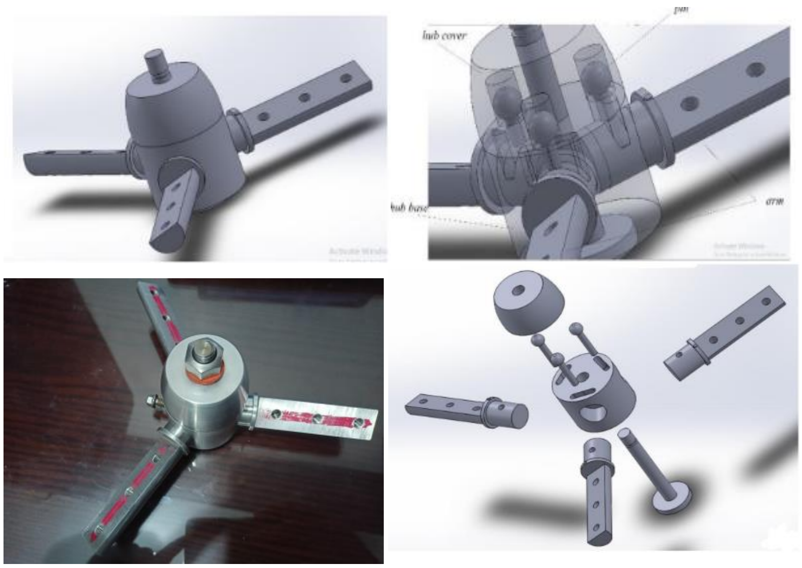
fig(9)The main components of the wind turbine model

All measurements actions were achieved by using Arduino uno board, Ut363s digital anemometer and Omron Rotary Encoder E6B2

Hub pitching mechanism :

While trying to meet the goals of our project, which is to achieve the maximum power output of the turbine in low air speed regions, we had to design a new hub to allow us to control and change the pitch angle of the blades. And

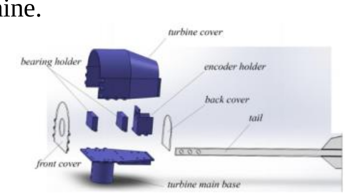
following are some Figs that shows the hub .The hub was designed by SolidWorks software according to the purpose of our project, then it was machined by the lathe and milling machine .



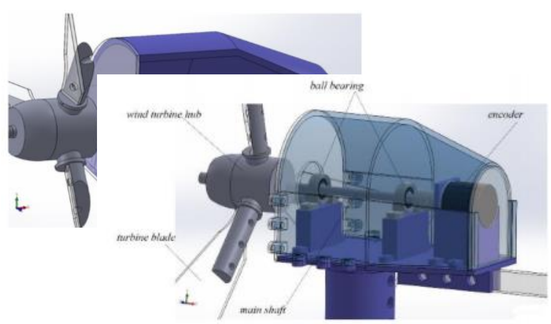
fig(10)pitching mechanism and exploded view of Hub

Turbine main body :

While trying to meet the goals of our project, which is to achieve the most cost effective design, we had to design the body to be as much compact & material saving as possible, And we also took in consideration the different heights of the many components that should be contained in the main frame, so we choose of the following design for the turbine. The hub was designed by SolidWorks software according to the purpose of our project, then it was produced by the 3d printing machine.



fig(11)exploded view of turbine main body



fig(12)assembly view of the turbine components

EXPERIMENTAL SET-UP AND DATA PROCESSING :

the specifications and main components of the small wind turbine model under study as well as the pitch angle control system and the instrumentations of the experimental set-up are discussed in details.

A horizontal axis small wind turbine of rotor diameter 70 cm was designed and constructed to test the performance of pitch angle control technique on the model in a wind tunnel. The wind turbine has a pitching mechanism actuated manually.

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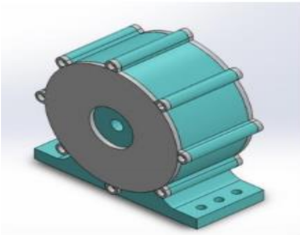
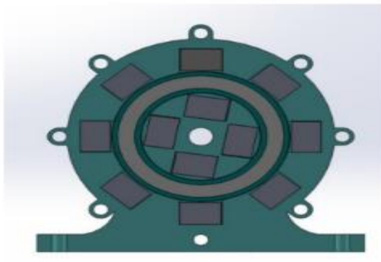
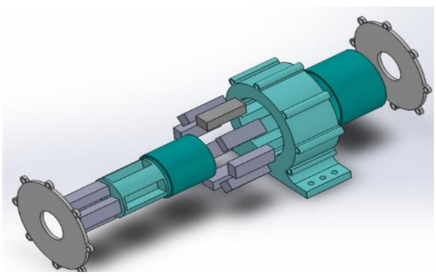




Electromagnetic Bearing :

In the beginning, we tried to design an electromagnetic bearing to reduce the friction losses generated due to the rotating motion of the shaft to generate the maximum rotating speed under the low speed of airflow on the blades. And below are some Figs of it

fig(13)electromagnetic bearing first design



The components used to build the electromagnetic bearing:

For each bearing we used:

1- Four electric magnets.
2- Two L-298 dual driver.
3- One Arduino uno board.
4- One 12V power supply.
5- Wires to connect the components.

Permanent Magnet Bearing :

After the attempt with the electromagnetic bearing, we designed a bearing model with permanent magnets used in it. And following we will show the design and the configuration of the bearing in the turbine model.

fig (14) Permanent Magnet bearing design and position in the turbine

fig(15)Permanent Magnet bearing design and position in the turbine

The components used to build the permanent magnetic bearing:

1- The body, casing, and cover of the bearing which was designed by using SolidWorks software and was printed by a 3D printer.

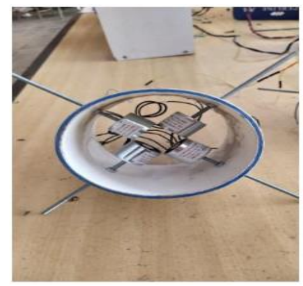
2- 12 permanent Neodymium magnets used in the bearing to generate the magnetic flux.

fig(16)exploded view Permanent Magnet Bearing

MEASUREMENTS AND RESULTS :

Wind Turbine Model optimal blade design.

The first step of our project is to find the optimal blade design,



so we put in test five different blade design and acquire their results at different pitch angles (5^o , 10^o , 15^o , 20^o , 25^o , 30^o) so we can find the optimal pitch angle for each blade, then compare the five blades with each other at their optimal state to find the best blade among them.

the wind turbine testing procedure can be listed as following:

1. Run the wind fan and wait to make sure that the air is steady.
2. Measure wind velocity by Ut363s digital anemometer & make sure that it fixed at 4 m/s.
3. Set the wind turbine model on the desired pitch angle.
4. Measure the rotation speed (rpm) for the model by the rotary encoder.
5. Change the pitch angle for the model.
6. Repeat steps 3 to 6.
7. Plot the relation between rpm of rotor at different pitch angles & time for a specified blade.
8. Change the blade with different design.
9. Repeat steps 3 to 9.

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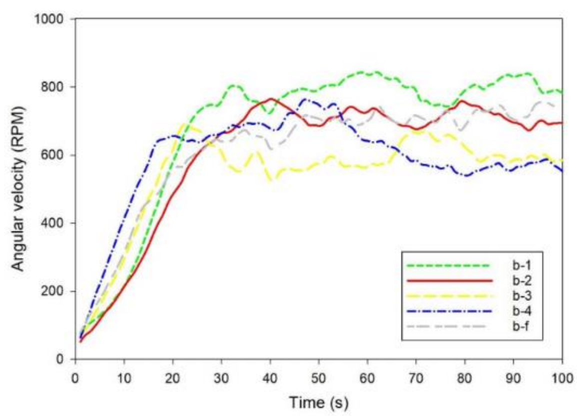
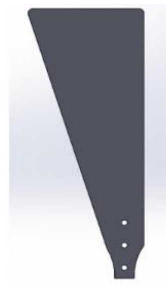
Blade (b-1) ((solidarity ratio = 0.17)) :

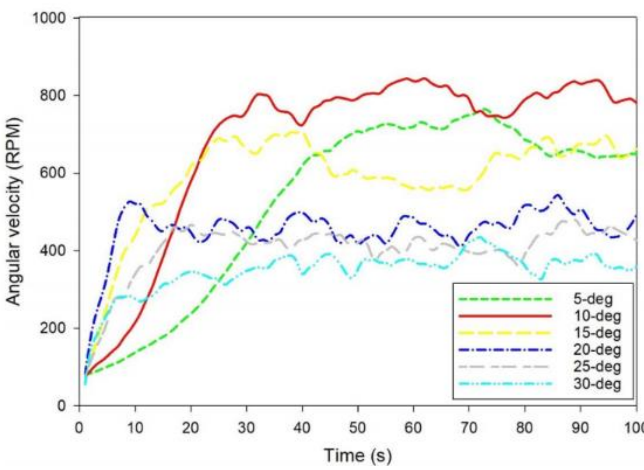




fig(17)the design & the dimensions of the blade b-1

the optimal blade design.

From the previous results gathered we can drive a comparison between the blade to deicide the optimal design.



fig(18)the experimental results of the blade b-1

- From the experimental results acquired from the encoder, we found that the optimal pitch angle for this blade is 10^o

From the experimental results acquired from the encoder, we found that the optimal pitch angle for **all blades** is 10^o .

fig(19)the comparison between the blades

From the expermintal results acquired from the encoder, we found that the optimal blade design is blade b-1 with pitch angle at 10^o .

Wind Turbine Model with Permanent Magnet bearing :

The second step of our project is to find how we can enhance the turbine efficiency, so we decide to replace the ball bearing with Permanent Magnet bearing because of a considerable portion of the energy is lost due to friction in the ball bearing.

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So we choose the optimal blade (b-1) for both cases to ensure that the only factor that will affect the system is the ficition.

fig(20)the comparison between normal ball bearing & Permanent Magnet bearing

from the Fig above we can clearly see how much the efficiency increased with the removel of the normal ball bearing.

Economical study :

Material of the hub

For the entire hub we used aluminum expect for the pins we made it from stainless steel.

The estimated cost for hub

due to the manufacturing & the machining costs can be varied from one manufacturer to another, we put an average for the cost of the material & the machining cost to be 2000LE.

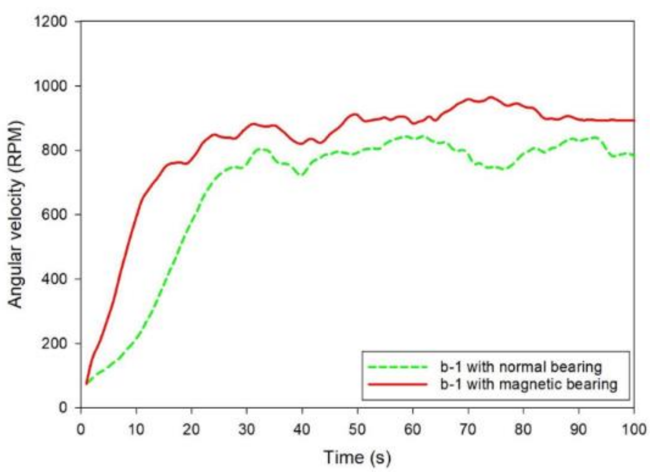
The blades :

Material of the blades:

For the blades, we made it from acrylic sheet.

The estimated cost of blades :

Because in our project we need five sets of blades of different shapes & sizes we consumed the whole acrylic sheet, in in reality the turbine will only require one set of blades so we can



say that the set of blades will cast 120 LE.

Turbine main body :

Material of the blades

For the Turbine main body, due to its complex shape we decided to use 3d-printer to produce the desired parts.
And for the tail & front & back cover we decided to made it from acrylic sheet & use the laser cutter machine.

The estimated cost of main body :

because the overall weight of the different parts is almost 500 gram, it will cost roughly 1000LE .

Table-3

Nameofcomponent	No of components	Total cost
The hub	1	2000 LE
The blades	3	120 LE
The 3D printed parts	1	1000 LE
The ball bearing	2	90 LE
total		3210 LE

Conclusions :

The major findings and conclusions of the present work are summarized as follows:

1. Since the turbine blades are flat blades, the factors that affect the performance of the turbine are manly the pitch angle & the size of the blade & its shape.
2. Pitch angle control technique is quite simple & easy to manufacture & easy to use, and all is required for its use is the angular scale.
3. The wind turbine model under study considered a flexible testing model, which can be used to test another shapes & sizes of different blades and study their performance.
4. We can use the Permanent Magnet bearing to increase the efficiency of the turbine sufficiently.
5. Since the turbine blades are flat blades, it provide an economic solution because it is very easy to manufacture & don't require the complex calculation nor the manufacturing complexibility of blades with profile, all you need to manufacturea sheet of material and its dimensions.

REFERENCES :

1. Nada, A.A., Al-Shahrani, A.S. Dynamic modelling and experimental validation of small-size wind turbine using flexible multibody approach. Int. J. Dynam. Control 5, 721–732 (2017). https://doi.org/10.1007/s40435-016-0241-2
2. Bayoumy, AH, Nada, AA, & Megahed, SM. "Modeling Slope Discontinuity of Large Size Wind-Turbine Blade Using Absolute Nodal Coordinate Formulation." Proceedings of the ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 6: 1st Biennial International Conference on Dynamics for Design; 14th International Conference on Advanced Vehicle Technologies.

Funding was received from Academy of Scientific Research and Technology (ASRT) to sponsor research, travel and participating.

Chicago, Illinois, USA. August 12–15, 2012. pp. 105-114. ASME. https://doi.org/10.1115/DETC2012-70467

3. Ayman A. Nada, Ali S. Al-Shahrani, Shape Optimization of Low Speed Wind Turbine Blades using Flexible Multibody Approach, Energy Procedia, Volume 134, 2017, Pages 577-587, https://doi.org/10.1016/j.egypro.2017.09.567.
4. A. Hemami, Wind Turbine Technology, 1st edition, Cengage Learning, USA, ISBN: 978-1-4354-8646-1, 2012.
5. J. Twidell and T. Weir, Renewable Energy Resources, 1st edition, Taylor & Francis, USA and Canada, ISBN: 9-78-0-419- 25320-4, 2006.
6. T. Foley, K. Thornton, and Hinrichs-rahlwes, Renewables 2015 Global Status Report, Paris, ISBN:978-3-9815934-6-4, 2015.
7. D. Burtraw and A. Krupnick, The True Cost of Electric Power, Paris, p. 17, 2012.
8. A.R.jha, Wind Turbine Technology, 1st edition, Taylor & Francis, USA and Canada, ISBN: 978-1-4398-1507-6, 2011.
9. http://www.pluginindia.com/whatiswindenergy.html [Accessed in January 2016].
10. A. Tummala, R. K. Velamati, D. K. Sinha, V. Indraja, and V. H. Krishna, “A review on small scale wind turbines,” Renew. Sustain. Energy Rev., vol. 56, pp. 1351–1371, 2016.
11. Z. Wu and H. Wang, “Research on Active Yaw Mechanism of Small Wind Turbines,” Energy Procedia, vol. 16, pp. 53–57, 2012.
12. D. Wood, Small Wind Turbines Analysis,Design and Application. 1st edition, springer, ISBN: 978-1-84996-174-5, 2011.
13. E. Hau, Wind Turbines: Fundamentals, Technologies, Application, Economics, 2nd edition, springer, ISBN: 978-3- 540- 24240-6, 2006.
14. H. Geng and G. Yang, “Linear and Nonlinear Schemes Applied to Pitch Control of Wind Turbines,” Sci. World J., vol. 2014, pp. 1–9, 2014.
15. [12] N. G. Mortensen, J. C. Hansen, J. Badger, B. H. Jørgensen, C. B. Hasager, U. S. Paulsen, O. F. Hansen, K. Enevoldsen, and Yousef, “Wind Atlas for Egypt: Measurements, micro- and mesoscale modelling,” 2006 European Wind Energy Conference and Exhibition, pp. 1-10, 2006.
16. Ayman A. Nada · Ali S. Al-Shahrani, “Dynamic modelling and experimental validation of small-size wind turbine using flexible multibody approach,” 2006 European Wind Energy Conference and Exhibition, pp. 1-10, 2006. International Journal of Dynamics and Control / Published online: 26 March 2016
17. Rohith Kamath, Vivek Venkobarao and C.K. Subramaniam, “Design and Analysis of a Permanent Magnetic Bearing for Vertical Axis Small Wind Turbine,” 1st International Conference on Power Engineering, Computing and CONtrol, PECCON-2017, 2-4 March 2017, VIT University, Chennai Campus

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