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THE DESIGN OF A MODULAR WIND TURBINE MEANT FOR HOUSES AND OFFICE BUILDINGS

Abstract: *This paper describes a new wind turbine design which can be implemented for home, office and public buildings. Also, this article presents specific steps taken by the designer to develop the product. A honeycomb design has been implemented for modularity reasons. Certain measures have been taken to ensure the quality of the design including, but not limited to: an emphasis on design principles, product development and shapes described by and found in nature.*

Key words: *industrial design, wind turbines, ergonomics, computer-aided industrial design, eco-design.*

INTRODUCTION

Nowadays the energy sector is getting bigger and bigger with the addition of renewable energy power plants that keep being added to the system. The recently added automation layer guarantees a better, more optimized National Energy System.

The energy market has evolved in recent years and also regulatory measures have been taken to aid the evolution of the energy trade. More and more companies have concentrated their focus on renewable rather than on conventional energy power plants. The industry has added extended power plants to supply the energy needs of factories and big companies.

Numerous wind farms have been created and also solar plants have arisen. In recent years the home energy sector has evolved as well and now some houses come with a wind turbine installed that can use wind energy to provide some of the house's energy needs.

According to The European Wind Energy Association and Global Wind Statistics the wind energy capacity has seen an exponential growth over the years beginning with the year 1980 and the present moment. With a optimistic forecast in future years. Below are a few statistics about global wind energy growth [6], [7], [8].

Table 1

Evolution of wind energy capacity worldwide over the years

Period	Installed capacity
[years]	[MW]
1980	10
1985	1020
1990	1930
1995	4780
2000	17400
2005	49091
2010	197039
2015	369597
2020	712081
2030	1479767

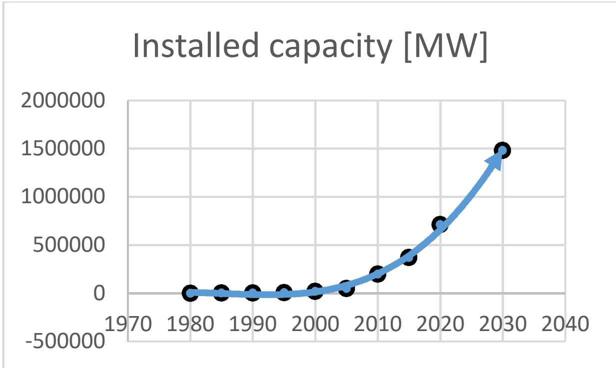

Fig. 1 Evolution of wind capacity

2. INDUSTRIAL SCALE AND SMALL SCALE WIND TURBINE DESIGN

2.1 Wind turbine components

The large scale wind turbine design has come a long way since the early days. Now offshore wind turbines can generate up to 7 MW of power and onshore ones can generate 5 MW easily. The effort is to generate a shape that can convert as much wind energy as possible and to limit the mechanical and electrical losses around all the equipment that make up the wind turbine.

Recent automation advances can optimize the wind turbine further with implementation of equipment and code that tells the wind turbine how to react to changing parameters.

In most cases a wind turbine has the following basic components:

- Rotor which is composed of blades, a hydraulic system that handles the pitch control of the blades;
- Nacelle houses the shaft that connects the blades and generator, a gear box, the generator itself and a few other motors that are used for the yaw functionality;
- Pole is two times higher than the diameter of the rotor and on which the nacelle rests;
- Foundation is very important because it handles the weight of all of the above

The placement of the components is as seen in Figure 2.

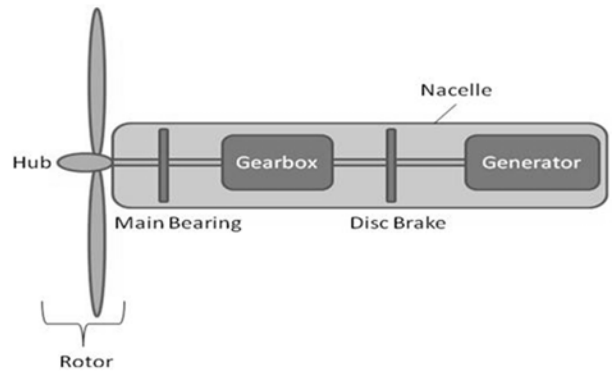

Fig. 2 Basic components of a wind turbine [1]

2.2 Wind turbine optimal blade number

The number of blades varies and wind turbines with up to 6 or more blades can be found in power plants. The number of blades determines how much of the wind power is converted into mechanical and then electrical energy.

As the number grows, the energy conversion increases but at a certain number the increase doesn't make economic sense because the increase is to small compared to the investment.

Fig. 3 Wind turbines with different number of blades [2]

As seen in Figure 3 the wind turbine can be used with a varied number of blades. Increases in number of blades however does not make economic sense and so the majority of wind turbine power plants found all over the world are equipped with 3 blade rotors which implies that the 3 blade rotor design makes the most economic sense and also ensures high technical performance of wind turbines.

2.3 Wind turbine scale

As far as dimensions go, for wind turbines used in power plants all over the world, a typical height can range as seen in Table 2 which applies for Vestas, range of models.

Table 2

Vestas large scale wind turbines [3]

Model	Power [MW]	Tower Height [m]	Rotor diameter [m]
Vestas V136	3.45	149	136
Vestas V90	3	105	90
Vestas V110	2	125	110

And as a comparison here are the dimensions for wind turbines used in small homes all over the world, a typical height can range as seen in Table 3 which applies for Aeolos, range of models.

Table 3

Aeolos small scale wind turbines [4]

Model	Power [kW]	Rotor diameter [m]
Aeolos-H 500W	0.5	2.7
Aeolos-H 1kW	1	3.2
Aeolos-H 5kw	5	6.4
Aeolos-H 50kw	50	18

3. DESIGN PROCESS FOR A SMALL SCALE WIND TURBINE

3.1 Main principles in technical systems

The design process starts with the steps needed to obtain electrical power as seen in table 4 below.

Table 4

Steps taken to convert wind energy to electrical energy

Faze of conversion	Explination
The conversion of wind energy into mechanical energy	The wind's energy is turning the rotor blades. The rotation of the blades is proportional to the wind speed. The blades turn the shaft of the turbine.
Mechanical energy step-up process	The shaft of the wind turbine is connected to the gearbox where the amplification takes place. Rotation speed reaches the electrical generator's nominal RPM.
The conversion of mechanical energy into electrical energy	The mechanical energy from the shaft is transfered on to the generator shaft and electrical energy is generated.

3.2 Criteria list for the wind turbine

A criteria list has been generated as seen below in order to determine the needs for the device in question.

Needs of the product:

- Optimum wind power absorption;
- Interactivity with other turbines in the same range;
- Light but durable blade material;
- Telescopically tower;
- Technical features;
- Motion transmission to the generator shaft;
- Optimize conversion in real time;
- Safety in the use of the device;
- Braking at high wind speeds;
- Resistance to high loads;
- Short-circuit protection.

4. BLADE DESIGN IMPLEMENTATION

The profile of the blade has a 2D cross section optimized to balance aerodynamic forces which are unevenly scattered all over the blade. In Figure 4a and 4b you can see the geometry of the blade profile.

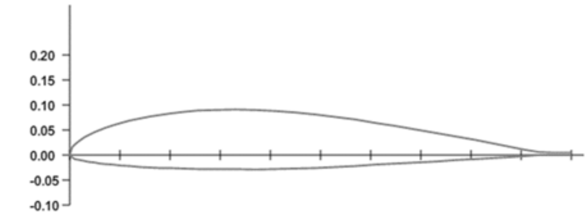

Fig 4 a) Airplane wing profile [5]

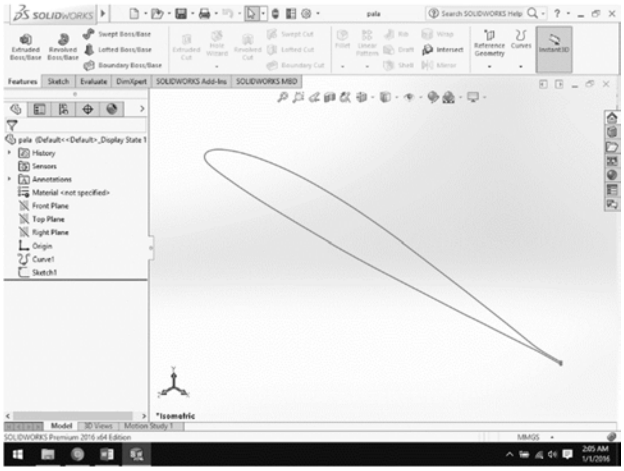

Fig 4 b) Wind turbine blade profile

The blade itself has been generated by drafting 2 wind blade profiles on 2 parallel planes one being the tip and the other being the base of the wind turbine blade.

The curvature of the wind turbine blade is in effect due to the offsetting of the tip profile by 10 degrees and a 0.27 scale of the tip profile in regards to the base profile of the blade. As seen in Figure 4 and 5 the blade generated following these guidelines is aerodynamic and follows the optimal path. The SolidWorks software has been used in order to generate the geometry.

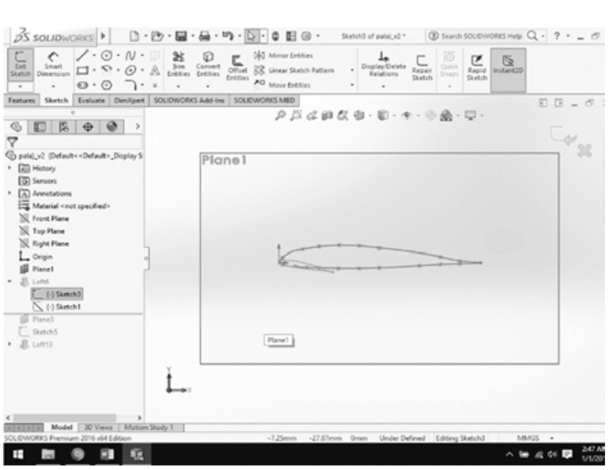

Fig. 5 Offset tip and base wind turbine blade profiles

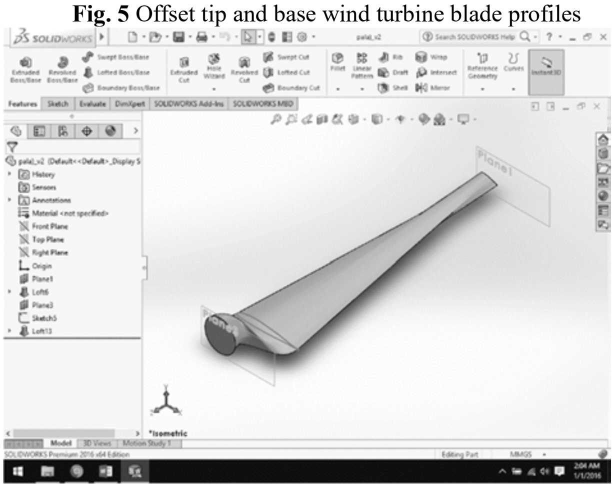

Fig. 6 Wind turbine blade

5. OVERALL DESIGN OF WIND TURBINE

The wind turbine si made up of several parts and the design is so that the assembly is done with ease and minimal effort. As seen in Figure 6 the list of parts it as follows in table 5.

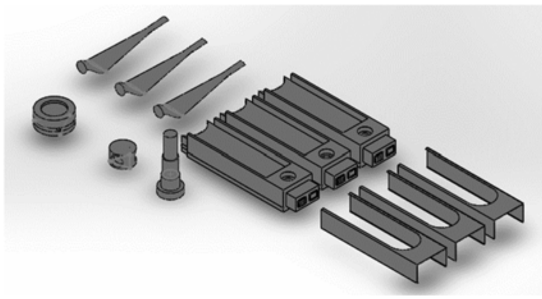

Fig. 7 Parts that make up the wind turbine

Table 5

Parts of wind turbine

Part	Amount
Wind turbine blade	3
Wind turbine base plate	3
Wind turbine base plate cover	3
Three hole joint base	1
Tower	1
Nacelle	1

The parts have been modeled using the SolidWorks software and were built separately as parts and joined together in an assembly.

The wind turbine assembly can be seen in Figure 13 and in Figure 14 are underlined the most important basic components of the wind turbine.

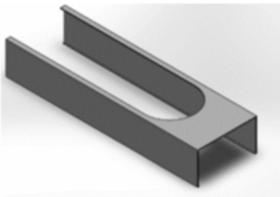

Fig. 8 Base plates cover design

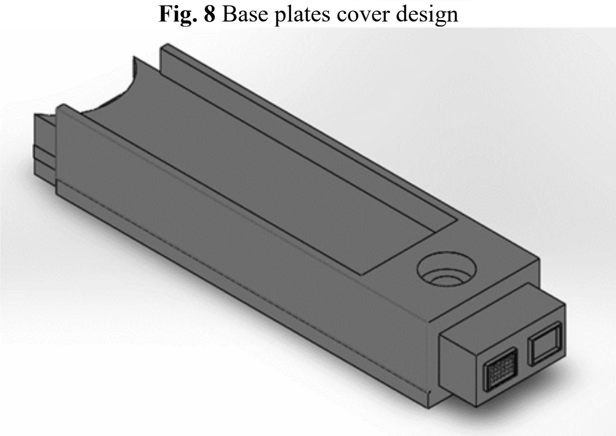

Fig. 9 Full base assembly with plate

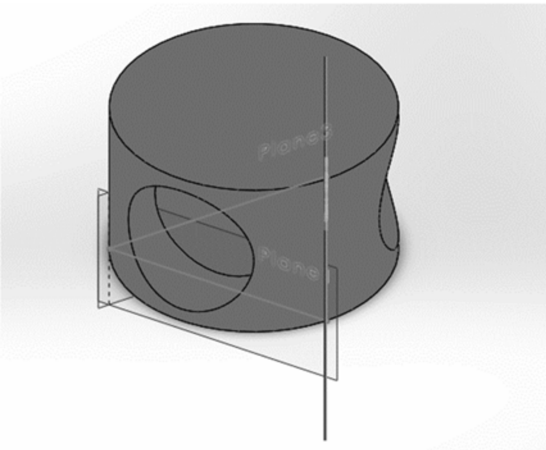

Fig. 10 Nacelle design

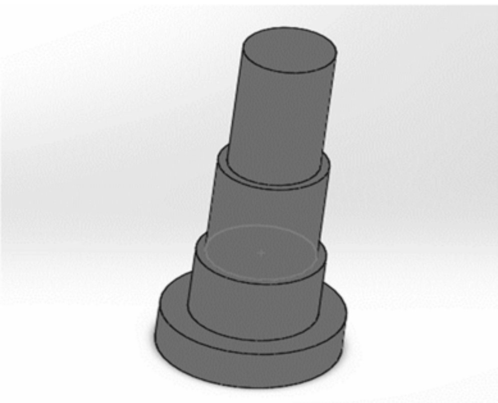

Fig. 11 Wind turbine tower design

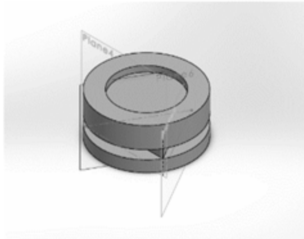

Fig. 12 Circular base joint design

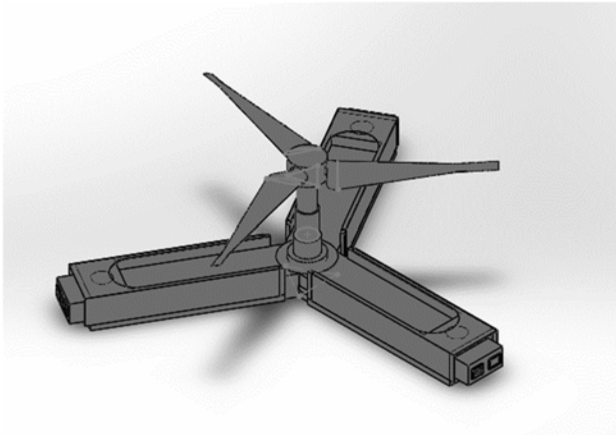

Fig. 13 Wind turbine design

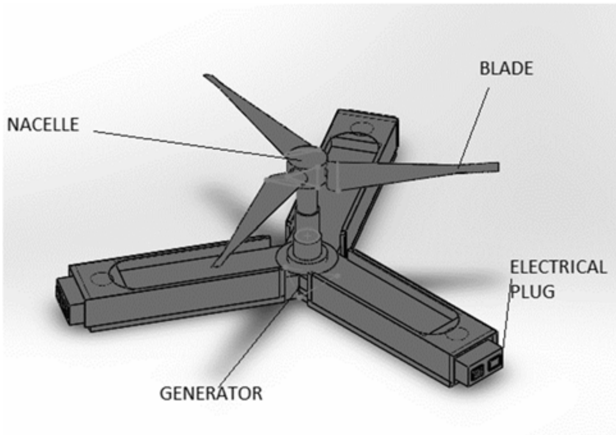

Fig. 14 Main components of the wind turbine

6. MODULAR DESIGN FEATURES AND INTEGRATION OF ECO-DESIGN IN THE PRODUCT DEVELOPMENT PROCESS

In a wind turbine design modularity principles aren't taken into account or are taken too little to make any subtle changes to the design so the end result is illustrated in Figure 15 made with the Neplan software.

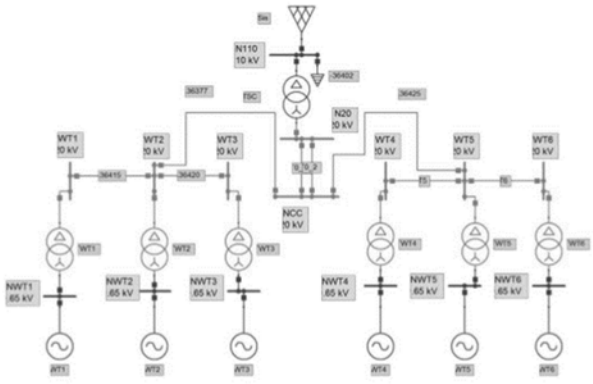

Fig. 15 Non-modular wind turbines joined together

In Figure 15 the solution proposed implies that the electrical calculations are done in the matter that the conductors and wires can handle the load.

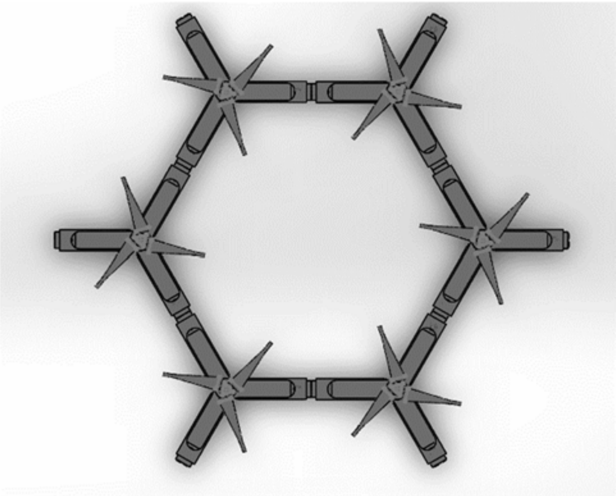

Fig. 16 Modular wind turbine design

7. POWER GENERATION AND YEARLY ENERGY ESTIMATES

We need to consider the density of air to be $\rho = 1.225$ and the total swept area of the rotor $S = 0.8$ m^2. By solving the following set of equations and by taking into account a yearly working duration of 2000 hours we can estimate the total annual amount of energy produced by the turbine at different wind speeds.

The dynamic pressure generated by the wind on the wind turbine's blades:

$$P_d = \rho \frac{v^2}{2} \tag{1}$$

Total swept area of the wind turbine's rotor:

$$S = \frac{\pi D^2}{4} \tag{2}$$

The force resulted because of the pressure:

$$F = P_d \times S \tag{3}$$

The electrical power that can be generated by the wind turbine:

$$Pe = \rho S \frac{v^3}{2} \tag{4}$$

The amount of energy generated in one year:

$$E = P \times t \tag{5}$$

The results generated by solving the above system of equations are displayed in table 6 and illustrate the total power generated in a year, at various speeds and the resulting energy taking into account the total number of hours in a year that the turbine is working which has been chosen to be 2000 h/year.

Table 6

Total annual energy production

Wind speed	P_d	F	P_e	E
[m/s]	[Pa]	[N]	[W]	[kWh]
1	0.6	0.5	0.5	1
2	2.5	2	3.9	7.8
3	5.5	4.4	13.2	26.5
4	9.8	7.8	31.4	62.7
5	15.3	12.3	61.3	122.5
10	61.3	49	490	980
15	137.8	110.3	1653.8	3307.5
20	245	196	3920	7840

8. CONCLUSIONS

Wind energy will be part of the renewable sources of energy a long time and thus making room for improvement and innovation as the market evolves.

The blade design used for the manufacturing of the wind turbine blade is a profile design for airplanes and has aerodynamic properties which suit wind turbines as well.

The telescopic tower permits the wind turbine blades to subtract in difficult weather conditions and make sure the equipment is safe.

The honeycomb design of the modular solution offers an effort free and easy to install installation with a reduced rate of difficulty when it comes to maintenance.

The wind turbine design mentioned above has multiple applications in the home and office building sector providing green energy for the building on which it is installed.

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