Small power wind turbine (Type DARRIEUS)

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Abstract: *This presentation focuses on the calculation for small vertical axis wind turbines (VAWT) for an urban application. The fixed-pitch straight – bladed vertical axis wind turbine (SB-VAWT) is one of the simplest types of wind turbine and accepts wind from any angle (no yaw system). This turbine is useful for moderate wind speeds (3 - 6 m/s). A case study is presented based upon the use of well documented symmetrical NACA 0012 turbine blade profile. We describe a solution for VAWT. To perform a linear static analysis in the structure, the commercial finite element analysis code ANSYS is used because of its flexibility for handling information in files written in a more or less free format.*

Key Words: *Wind action, Vertical Axis Wind Turbine, Darrieus rotor, numerical modelling, stress analysis, glass fiber reinforced polyester, finite element commercial package ANSYS*

1. INTRODUCTION

1.1 Preliminary considerations

VAWTs have several advantages which currently begin to be valued. Most VAWTs have a low cut-in speed so that they produce at least a little electricity in low wind speed. Vertical axis windmills have a feature that is particularly attractive - they accept wind from any horizontal direction and do not need the complicated head mechanisms of conventional horizontal axis windmills.

Many VAWTs have a tip speed ratio of only 2 to 3 which equates to some useful power production but with less noise generation [15]. Darrieus wind turbines have difficulty in self-starting in most normal wind regimes.

However, evidence shows that a Darrieus turbine using fixed geometry symmetrical airfoils can self-start in the field during atmospheric gusting.

Evidence shows that a lightly loaded VAWTs equipped with symmetrical NACA 0012 airfoils will self-start in wind speeds under 3 m/s. Their aerodynamics is more complicated than that of horizontal axis wind turbines due the dependence of all kinematic parameters on the blade polar position reported to wind direction.

The suitability of the wind turbines for low wind speed regime is its ability to extract power at that low speed. Therefore, the lowest wind speed at which the wind starts to produce power is of much interest.

The low rotational speed of VAWT rotor implies that the machine will be quieter than the high-rotational speed of HAWT, thereby being potentially suitable for applications closer to population centers.

Also, simplicity is the main advantage with this wind turbine concept.

1.2 Nomenclature

Airfoil section	NACA 0012
C	the blade chord (= 200 mm)
C_L	the lift coefficient
C_D	the drag coefficient
H	blade span (= 3.6 m)
N_b	number of blades (= 5)
R	radius (= 3 m)
V	wind speed

2. SHORT DESCRIPTION OF THE WIND TURBINE

This type of turbine consists of five blades mounted vertically on a rotating shaft (fig. 2). It is shown [8] that a lightly loaded three (or more) - bladed rotor always has the potential to self start under steady wind conditions, whereas the starting of a two-bladed device is dependent upon its initial starting orientation. The shaft is held in place by two bearings that allow the free rotation and torque transmission but no lateral or axial movement. Ten aluminum arms which support the five blades are joined to this shaft. The blades are made of fiber-glass coated foam and are the key driving component of the turbine.

The investigated structure is a guyed tower build from a lot of pipes attached to the ground by four guy cables (see fig. 1). For VAWTs – optimal blades are untwisted and they have a uniform cross section making them relatively easy to manufacture. One of the most important design parameters for cost effective VAWT is the selection of blade material. Available prospective materials are shortlisted. Comparisons are made between the available materials based on their mechanical properties and cost. Finally, we selected glass fiber reinforced polyester. The guyed tower is held upright with guy cables which stretch from the tower to their anchors in the ground some distance (10 m) away from the base to the tower. A guyed tower is the least expensive system.

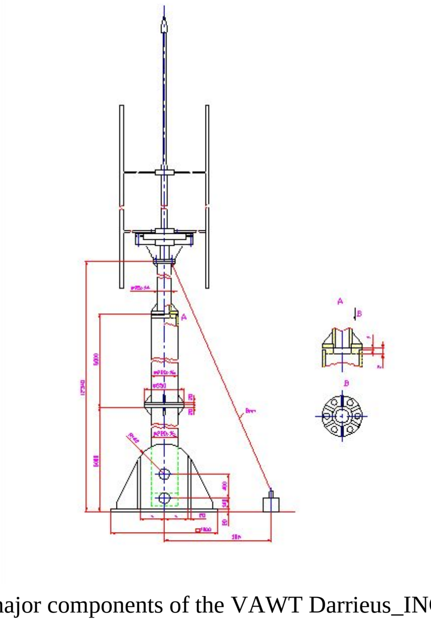

Fig. 1 The major components of the VAWT Darrieus_INCAS_2011

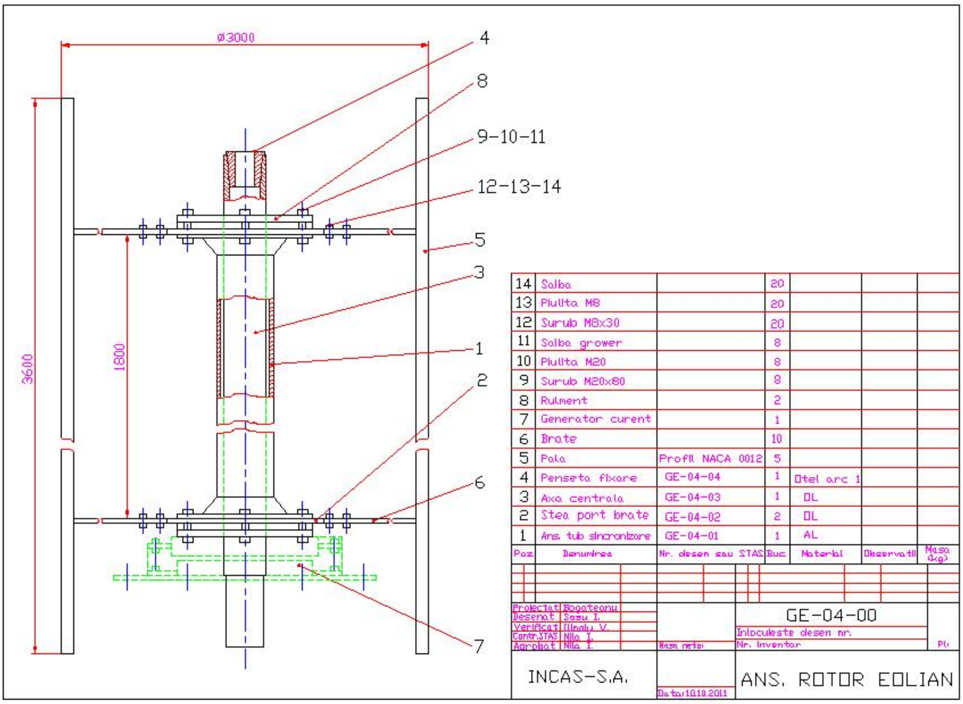

Fig. 2 The rotor geometry. The blades rotate about the vertical axis [1]

3. MODELLING

In the FEM model created for the ANSYS run we used the following finite elements: PIPE16 (for tower), BEAM4 (for blade and arms), LINK 10 (for guy cables) and MASS21 for lumped masses. The sketch of the model is shown in Figure 3. Extensive FE model simplifications had been applied in the analysis processes to check the validity of results.

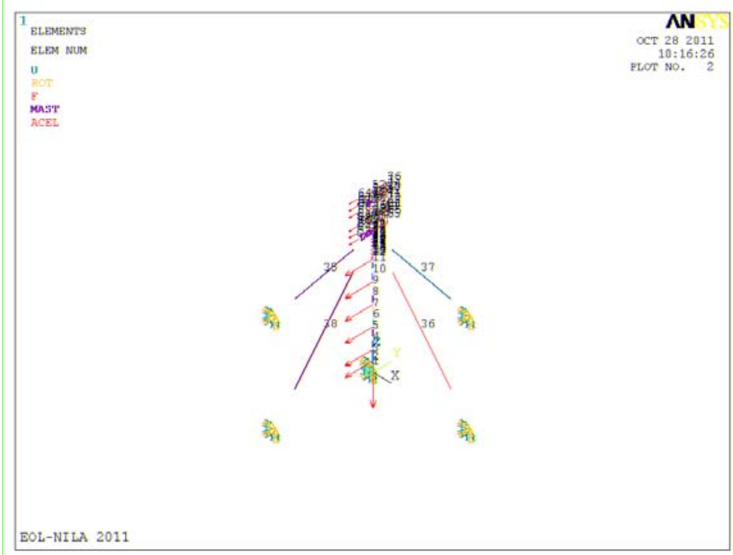

Fig. 3 Discretization model and applied loads

Wind load calculations were based by assuming solid frontal areas of the blades and the tower structure. The Darrieus rotor can be analyzed in an elementary way by assuming that each section of a blade behaves as an airfoil in a two-dimensional flow field. (See fig. 4)

The lift force due the wind is given by:

$$L = \frac{1}{2} C_L \, \rho S v^2 \tag{1}$$

where :

	L	lift force
	C_L	lift coefficient
	ρ	air density
	S	blade area
	v	wind speed

and drag force (D) by:

$$D = \frac{1}{2} C_D \, \rho S v^2 \tag{2}$$

C_D drag coefficient

The aerodynamic loads were used as design loads because they produce the largest forces on the blade. Also, the von Mises theory is a conservative predictor of the failure.

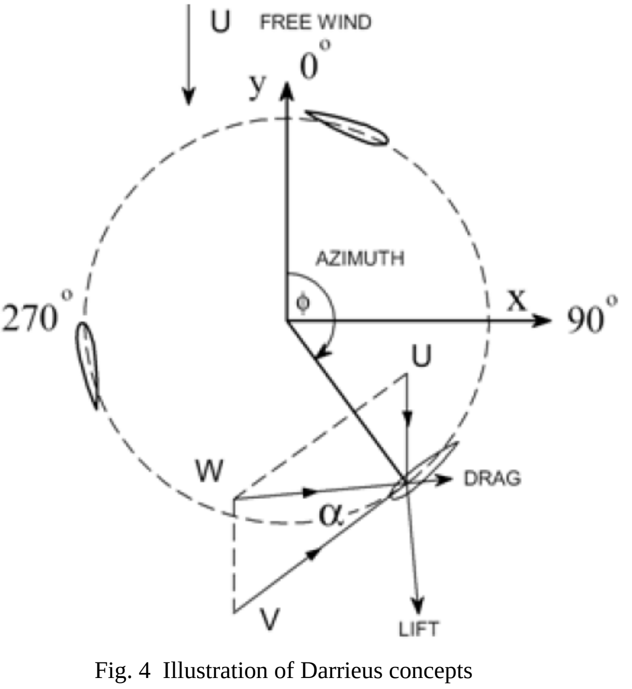

Fig. 4 Illustration of Darrieus concepts

The basic speed of the wind V -according to definition [16]- is the speed of a gust of 3 seconds, exceeded in average once in 50 years measured 10 m above ground, in open and flat area.

The Brazilian code NBR 6123/88 dealing with the analysis of structures excited by the wind is too hard for our country. We shall consider a wind of **30 m/s.** The cut-in wind speed is generally 3 m/s.

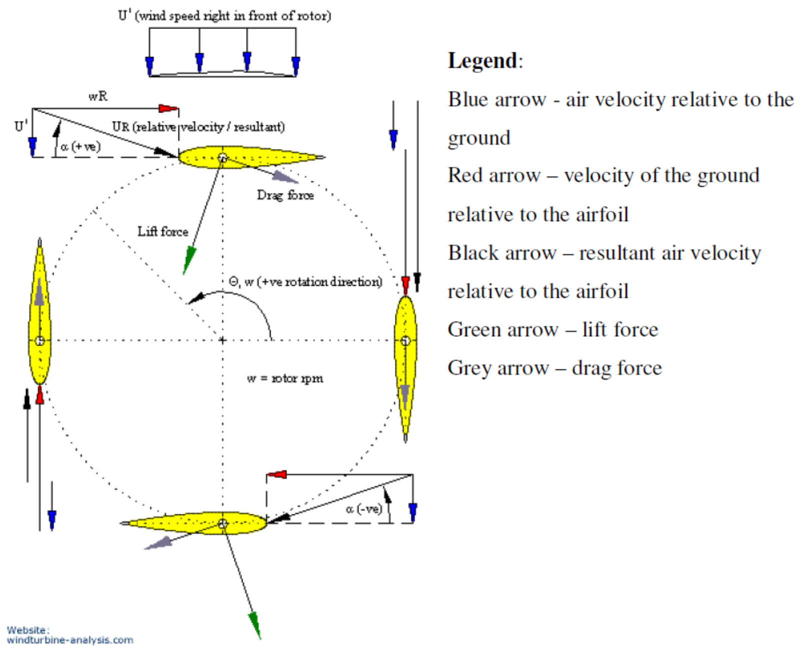

Fig. 5 Top view of forces on a Darrieus blade throughout 360 degrees of rotation [18]

In Figure 5 there is/Fig.5 shows / a top view of forces on a Darrieus blade through 360º of rotation (winturbine-analysis.com). The double arrow represents the air velocity relative to the ground; the red arrow-velocity of the Airfoil relative to the ground; the black arrow-resultant air velocity relative to the airfoil [18]

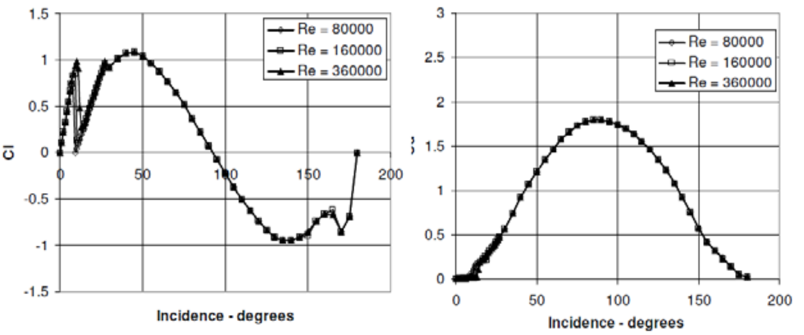

Fig. 6 NACA 0012 lift and drag coefficients at three Reynolds Number [8]

To analyze the blade forces and hence the torque and power of the machine it is necessary to know the lift and drag characteristics of its blades over the full incidence range (see fig. 6).

The loading regimes to which wind turbines are subject to are extremely complex requiring a special attention in their design, operation and maintenance. An understanding of the loadings on wind turbines is crucial to avoid their catastrophic failure. The difficulty in understanding the operational characteristics of the VAWT are centered on the fact that the blade ‘sees’ a flow of continuously changing velocity magnitude and direction (fig. 5).

Materials used: steel for tower and guy cable, E-glass-epoxy for blades and aluminum alloy for blade arms.[1].

4. NUMERICAL RESULTS

By using von Mises failure theory, the most critical value for the stresses in tower is:

MAXIMUM VALUES
ELEM 12
VALUE 68.329

Stress analysis for the blade and support arm:

Figure 7 shows the bending moment and shearing force diagrams for the blade.

The blade is a simply supported beam (on the support arms) and loaded with aerodynamic uniform distributed loads [9],[14].

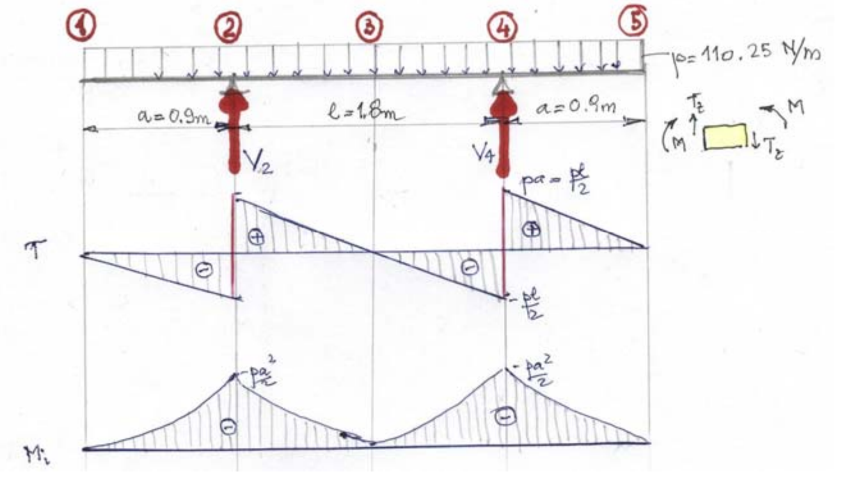

Fig. 7 Bending moment and shearing force diagrams

The reaction on the support is:

$$V_2 = p \bullet (a + l/2) = 110.25 \bullet 1.8 = 198.45\,N$$

The maximum stress in the support arm is:

$$\sigma_{brat} = \frac{V_2}{A_{brat}} = \frac{198.45}{240} = 0.83\,MPa$$

Bending moment for the blade is:

$$M_{\max} = \frac{p}{2}\left(\frac{l^2}{4} - a^2\right) = \frac{110.25}{2}\left(\frac{1.8^2}{4} - 0.9^2\right) = 44.65\,Nm$$

The maximum bend stress in the blade is:

$$\sigma_{\max} = \frac{Mz}{I} = \frac{44.65 \bullet 10^3 \bullet 10}{2 \bullet 10^4} = 22\,MPa$$

(Shear stress is too small and it was ignored).

Allowable stress. Margin of safety

Admissible stress: are taken minimum values for yielding stress for used materials

- ☞ tower (steel) $\sigma_a = 355\ MPa$
- ☞ guy cable $\sigma_a = 360\ MPa$
- ☞ rotor blade $\sigma_a = 150\ MPa$
- ☞ support arm $\sigma_a = 300\ MPa$

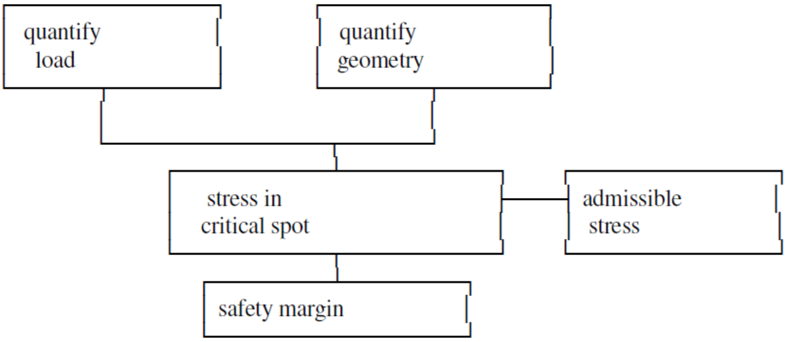

Fig. 8 Determination of the margin of safety

The minimum margin of safety are:

- Tower (pipe D=220 mm) $MS = \frac{\sigma_{02}}{\sigma_{ef}} - 1 = \frac{355}{68} - 1 = 4.22\ (> 2\ )$

- guy cable $MS = \frac{\sigma_{02}}{\sigma_{ef}} - 1 = \frac{360}{189} - 1 = 0.904 (> 0.25\ )$

- rotor blade $MS = \frac{\sigma_{02}}{\sigma_{ef}} - 1 = \frac{150}{22} - 1 = 5.81 (> 2)$

- support arm $MS = \frac{\sigma_{02}}{\sigma_{ef}} = \frac{300}{0.83} = 361.4\ (\ >> 2\ )$

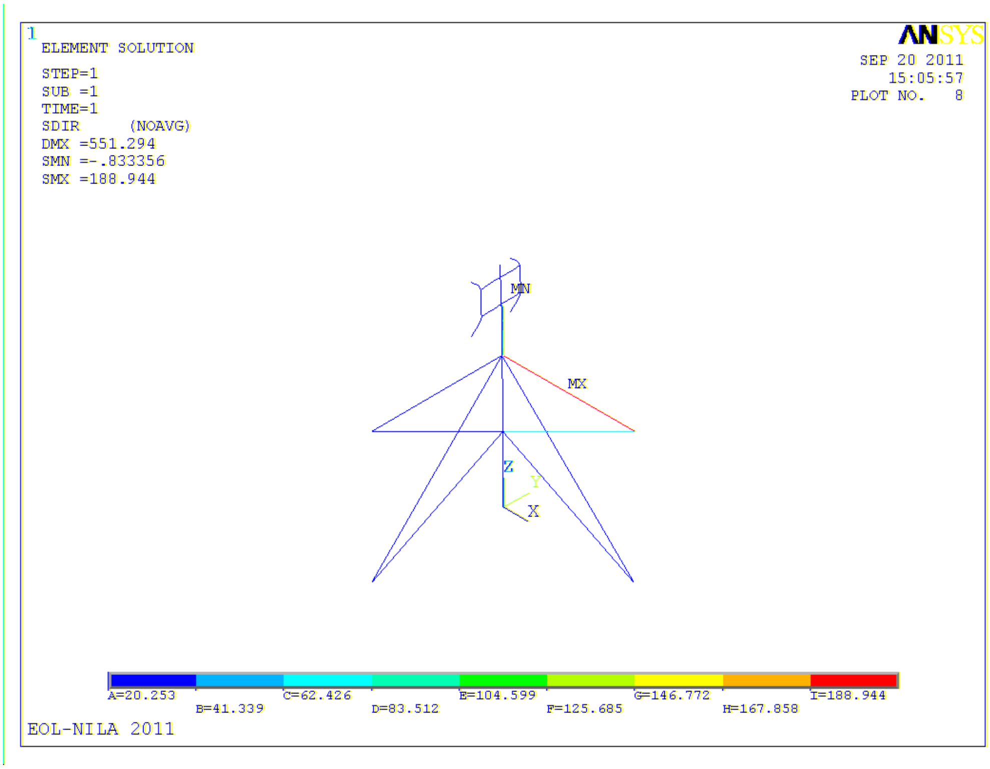

Fig. 7 The stresses in the structure

5. CONCLUSIONS

The project aim was to design a light weight, durable and economic wind turbine using commercially available parts and composite structural materials. Further to the design procedure outlined above there are still more design tasks required for a standard VAWT design project. These include the refined design, the prototype building, prototype testing (five years), wind turbine production.

This paper aims to ensure quality and safety for this kind of wind energy converter.

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