WIND TURBINE BLADE PLANFORM LINEARIZATION TO IMPROVE STRUCTURAL AND MANUFACTURING CHARACTERISTICS

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Abstract. *Optimum chord distribution for horizontal axle wind turbine (HAWT) gives complex blade plan forms that are not practical to build. Rectified leading and trailing edges are desirable for simplified manufacture process. Some authors suggest a linearization thought 0.5 to 0.9 r/R or 0.7 to 0.9 r/R. While good to reduce aerodynamic losses this linearization process implicates in small chords at blade root with structural penalties. In this paper an analysis of chord distribution includes structural effects, besides aerodynamic aspects. New linearized chord distribution criterion is proposed to keep good aerodynamic performance and match structural compromises.This alternative design approach was tested in a small wind turbine CEA WT-01 manufactured at the Centro de Estudos Aeronáuticos do Departamento de Engenharia Mecânica da UFMG.*

Keywords*: wind turbine, optimization, blade plan form, HAWT*

1. INTRODUCTION

The aerodynamic efficiency of a wind turbine demands a careful choice of some design parameters. Diameter, airfoils, rotational speed and chord and twist distribution, must be adjusted to ensure high efficiency in a large range of wind speed. Some predictive methods are used to evaluate torque and power produced by a rotor. The Blade Element Momentum (*BEM*) method developed by Glauert in 1930 (Ribeiro,2006) is based on momentum balance equations for individual annular stream tubes crossing the rotor and effectively works with the information about spanwise distributions. It is widely used in the wind energy industry and the analysis in this paper was performed with him.

2. METHODOLOGY

The procedure for determining the optimum blade shape is to adjust independently each blade radial station by continuously varying chord and twist angle to obtain maximum energy extraction. Gourieres (1980) and Burton *et al*. (2001) give a detailed view in this procedure.

This approach results in an optimum blade with nonlinear chord and twist angle distributions. It results in a very complicated blade shape which can be disadvantageous in manufacture, cost and structural strength and rigidity. If the constructive simplicity is a priority in the design, straight leading and trailing edges are desirable to allow a mold less manufacture.

To minimize losses in aerodynamic efficiency some authors recommend that the linearization of the chords can be done by taking the values from the optimum blade configuration at r=0,5R and r=0,9R (Kamal *et al*., 1995), or r=0,7R and r=0,9R (Burton *et al*., 2001). Figure 1 illustrates the blade chord distribution for a wind turbine with 7*m* diameter (R=3,5*m*) and a design tip speed ratio λ=7, using these criterion.

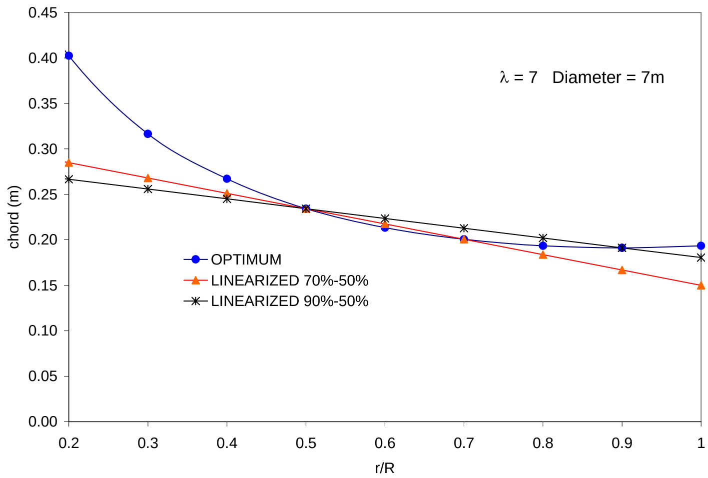

Figure 1. Optimum and linearized blade chord distribution for *a 7m* diameter, λ = *7* wind turbine

To compare the aerodynamic efficiency between linearized and optimum chord distributions a *Fortran* computational program $CEA_{\_ADAP}$, based in the *BEM* method was implemented. The curves of power coefficient C_P *versus* tip speed ratio λ for optimum and linearized chord distributions are plotted in Figure 2.

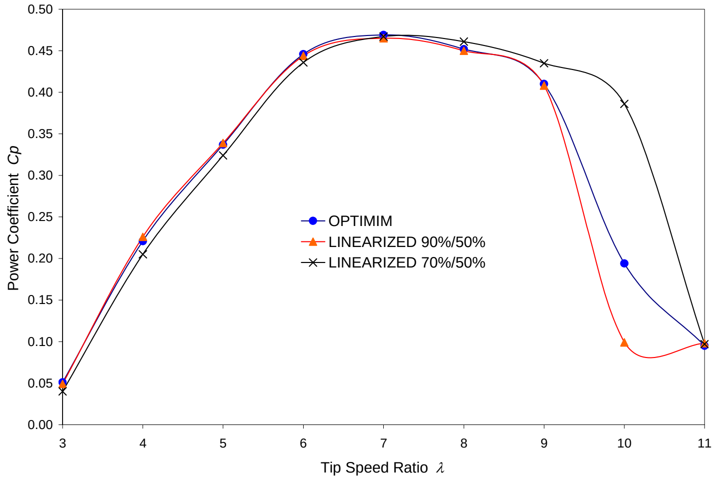

Figure 2. Variation of power coefficient with tip speed ratio for optimum and linearized chord distributions

As can be noticed in Figure 2, a very small loss in aerodynamic efficiency occurs when linearized chord distributions are adopted, mainly in the usual range of tip speed ratios. However, as can be observed in Fig. 1, the linearized distributions implies in small chords at root blades. These chords of small length do not offer adequate heights for the blade spar. Height is the most important parameter in a spar design since it has a cubic relation with the section moment of inertia. Manufacturers of large wind turbines have adopted airfoils of high thickness/chord ratio for use in the blade root region to solve this problem (Fuglsang *et* Back, 2004). In Fig. 3 *Riso* airfoils, example of this type of sections, are shown.

The adoption of these airfoils with high values of relative thickness is advantageous by structural point of view but it brings constructive difficulties. The complexity of blade geometry when using such profiles, mainly at root region of the blade, does not allow a mold less fabrication and demands more expensive manufacturing processes.

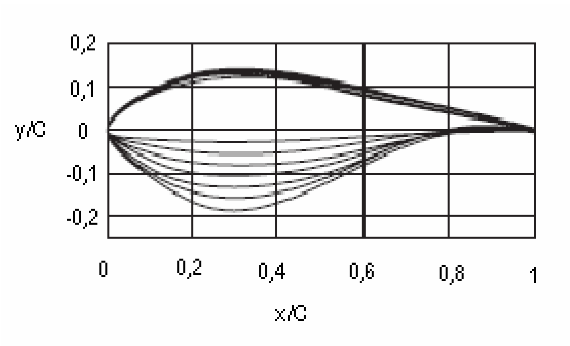

Figure 3. Airfoils *Riso* (Fuglsang *et* Back, 2004)

An alternative design was analyzed for the wind turbine *CEA WT-01*, a prototype designed and build in UFMG. In order to keep easiness of manufacture a linear distribution of chords where used. However a different criterion for linearization was tested. The choice of the root blade chord take in account structural demand and the tip blade chord was kept as in the optimum distribution. The chord length at root blade was defined to allow the use of a wood spar and an airfoil with 15% of relative thickness. This distribution is compared with the optimum distribution in the Figure 4.

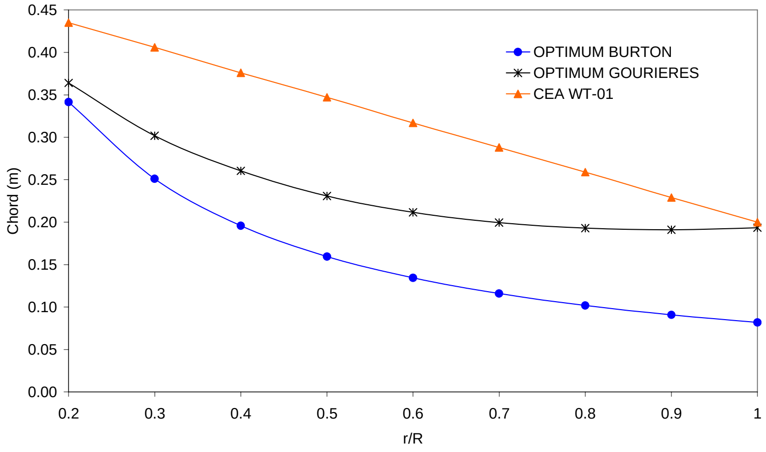

Figure 4. Blade chord distribution curves

3. RESULTS

Curves of power coefficient C_P *versus* tip speed ratio λ for Optimum and *CEA WT-01* blades using the $CEA_{\_ADAP}$ program are presented in Fig. 5.

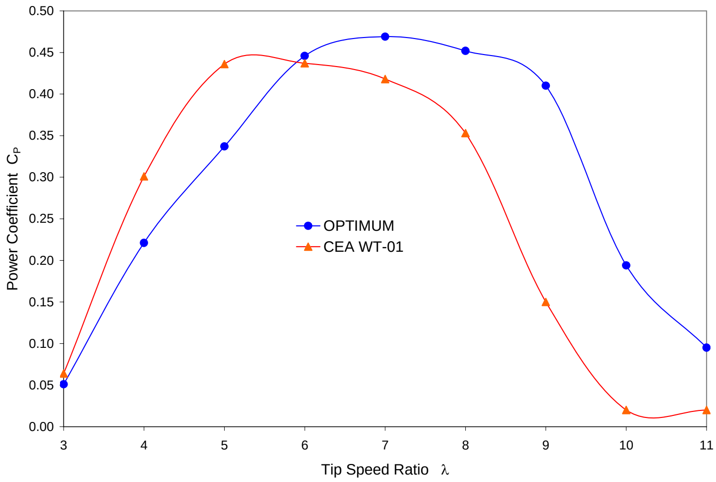

Figure 5. Variation of power coefficient C_P *versus* tip speed ratio λ for Optimum and *CEA WT-01* blades

An examination of Fig. 5 shows that the chord distribution that matches the structural criterion modifies in more sensible way the aerodynamic performance of the blade. It results in a bigger loss of efficiency for this configuration and also implies in a displacement in the optimum tip speed ratio λ value from 7 to 6. Since turbine *CEA WT-01* is designed to operate with a blade pitch control system the performance of the *CEA WT-01* turbine for some pitch angles β had been analyzed through the $CEA_{\_ADAP}$ program. Figure 6 presents these performance curves.

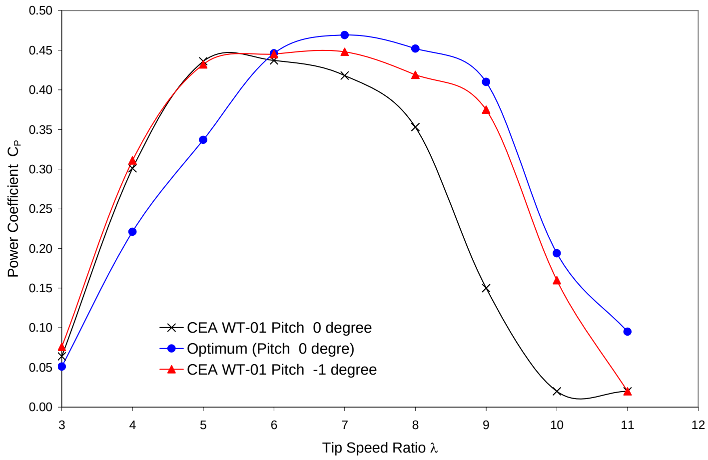

Figure 6. Variation of power coefficient C_P *versus* tip speed ratio λ for pitch angles β

It was verified that for a value of β = -1 the aerodynamic performance of the turbine is close to the optimum. Although to remain with maximum values smaller to the ones of the optimum curve it now has an advantageous widening of the plain region of the curve indicating good (and almost constant) values of *Cp* for a larger band of λ values. So it can consider that the annual average extraction of energy of this proposed configuration may be very close to the one expected for the optimum distribution.

In Figure 7 a picture of an early assembly of the *CEA WT-01* prototype shows the blades plan form with straight leading and trailing edges and glass fiber/epoxy hand lay-up laminates in the skin surfaces and the wood spars.

Figure 7. Rotor blades and hub of the *CEA WT-01* wind turbine

4. CONCLUSION

A proposed chord distribution criterion with new linearization parameters allows designing small wind turbines with very low cost and constructive simplicity and with only a few losses in aerodynamic efficiency. The increment over the available height on blade root sections allows the use of wood spars that are less expensive, easy to build and offer great fatigue strength.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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