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Dynamic Study of Wind Turbine Propeller Bearings

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Abstract

The increase in electricity outages due to the high price of fuel is pushing researchers to explore other alternatives to compensate for the use of fossil fuels. Wind energy, being the second most used New and Renewable Energy in the world after solar energy, remains a sustainable solution for the Sahelo-Saharan countries where the wind (inexhaustible source) is permanent.

This work presents a dynamic model of wind turbines, particularly those with a vertical axis, in order to optimize the loads on the bearings of the wind turbine while maximizing the power produced. Certainly, previous research has illustrated the maximum power produced by the wind rotor, this power leads to an increase in the motor torque from which the forces on the rotor bearings emanate, our model comes to resolve this problem, that is to say maximize power while especially minimizing the axial force on the rotor bearing which, in reality, is a source of degradation of said bearings.

Thus, we referred to two theories, the theory of axial flow and the theory of the blade element, the latter will take into account the one-dimensional and bidirectional theory of a wind rotor.

The dynamic model thus obtained is simulated by MATLAB/Simulink and we were able to determine the ideal angle of inclination of the blades allowing maximum power to be obtained while minimizing the forces on the wind rotor.

Keywords: Wind energy, Rotor Dynamics, Optimization

1. Introduction

Nowadays, with industrialization and technological developments, energy needs are increasing. Faced with this ever-increasing demand, industrialized countries have massively called on nuclear power plants because oil reserves are becoming exhausted day by day. However, this source of energy quickly presented safety aspects that were difficult to identify (high risk of accidents) and above all required a complex and expensive recycling process for its waste. Today, new questions about the viability of nuclear power are being raised, in particular because of the local warming of the temperature of river water used to cool the reactors (global warming problem).

The trend is to develop new sources of alternative electrical energy that are much more available but while preserving the environment (green energy) [1]. Among these sources, wind and solar energy are avenues to explore for countries that have wind and solar potential for a good period of the year [2]. The Sahelo-Saharan countries are among the countries with wind and sun potential that can be exploited to produce a significant quantity of electrical energy.

The proliferation of wind turbines and photovoltaic systems has led electrical engineering researchers to carry out investigations to improve the efficiency of electromechanical conversion and the quality of the energy supplied [3], [4]. It is in this context that our research will focus on wind turbines, in particular "the optimization of loads on the wind rotor while maximizing power".

Wind turbines remain one of the best alternatives to the problems of energy deficits in the Sahelo-Saharan countries, but they face constraints due to the lifespan of the rolling bearings [5]. Optimizing its loads will make it possible to increase the lifespan of its bearings and will also allow the popularization of this source of energy in both urban and rural areas.

Several research works have been done to determine the optimal parameters and the relationship between them for an optimal wind turbine design. This research is based on the blade element motion theory [3], [4], [6], [7]. This theory is the fundamental method to analyze the performance of the wind turbine in the general case. It is a combination of two theories mentioned above.

Propeller bearings are subjected to high mechanical loads, dynamic forces, and constant variations in environmental conditions. Their durability and performance are therefore of paramount importance for the overall efficiency of wind turbines and the profitability of wind energy.

Differently from the studies cited above, this study focuses on the dynamics of wind turbine propeller bearings.

2. Method

2-1 Theoretical study

Previous research allowed us to determine the maximum power produced by a wind turbine [3], [4], [6], [7], [8], [9], [10], [11]

$$P=2\pi\rho\Omega^2V(1-a)\,a'\int_0^R dr \qquad (1)$$

and even to formulate the forces on the blades [3], [4], [11], [12],

$$T=4a'(1+a')\,\rho\Omega^2\int dr\,(r^3) \qquad (2)$$

$$Ft=4\pi\rho\Omega a'V\int dr\,(r^2) \qquad (3)$$

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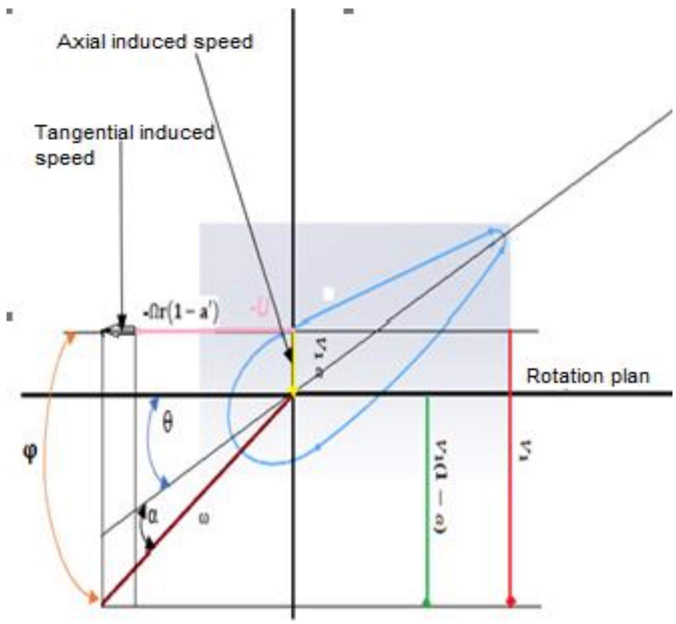

Figure.1: The disc speed field (axial-radial losses).

Where ω is the induced angular speed, and Ω the angular speed of the blades, thus the tangential speed of rotation of the air becomes:

$$w = \frac{v1(1-a)}{\sin\varphi} = \frac{\Omega r(1-a')}{\cos\varphi} \quad (4)$$

In our approach, we will use an aerodynamic zone between the head diameter and the root diameter of the blade, finally:

- - Maximize the power produced,
- - Minimize the forces on the blades.

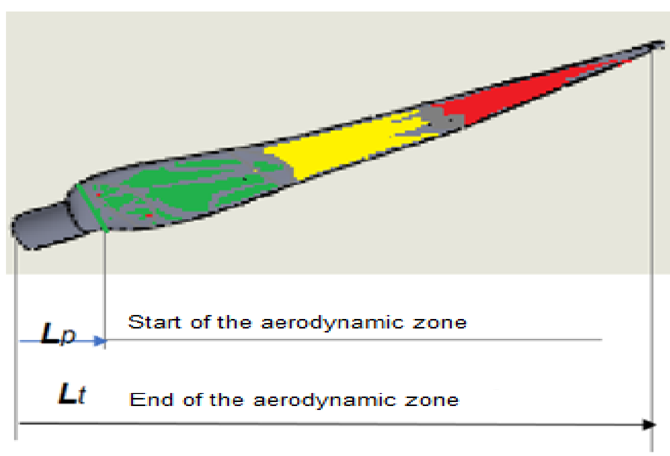

Figure 2: Geometric definition of a rotor in the plane

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According to this theory, the blade is a set of elements of thickness dr, where the aerodynamic interactions between them are negligible, the passage of air through the wind rotor creates a pressure difference between the two faces of the blade. blade (extrados-intrados).

The optimal extracted power is therefore;

$$\mathbf{P=2\pi\rho\Omega^2V(1\text{-}a)\ a'\int_{Lp}^{Lt} dr\ (r^3)} \qquad (5)$$

The axial thrust is obtained by integrating;

$$\mathbf{T=4a'(1+a')\ \rho\Omega^2\int dr(r^3)} \qquad (6)$$

The axial force will therefore be;

$$\mathbf{Fa=(a'+a'^2)\ \rho\Omega^2(L_t^4\text{-}L_p^4)} \qquad (7)$$

The tangential force is determined as follows;

$$\mathbf{F_t=2\pi\rho wV\int dr(r^2)\ avec\ w=2a'\Omega} \qquad (8)$$

We will have; $\mathbf{Ft=4\pi\rho\Omega a'V\int dr(r^2)}$ (9)

The tangential force will therefore be:

$$\mathbf{Ft=\frac{4}{3}\pi\rho\Omega a'V\ (L_t^3\text{-}L_p^3)} \qquad (10)$$

With $\frac{(1-3a)}{(4a-1')} = \mathbf{a'}$ (11)

2-2 Models obtained

A first model where the angular speed depends only on the wind speed and the aerodynamic radius is represented here by Matlab-Simulink

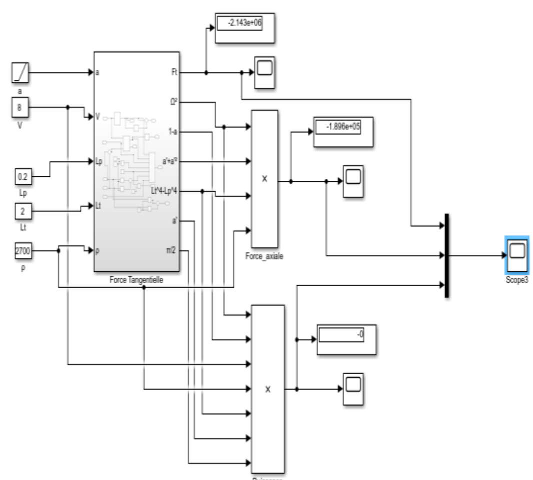

Figure 3-a: Model of P, T, Ft and a’ as a function of a with Simulink

Then a second model where the angular speed is a function of the angle of incidence of the blade is simulated by Simulink

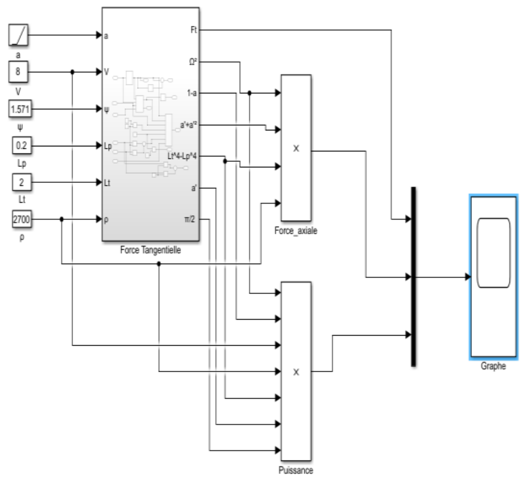

Figure 3-b: Model of P, T, Ft and a' as a function of a with Simulink

We represent the different models separately.

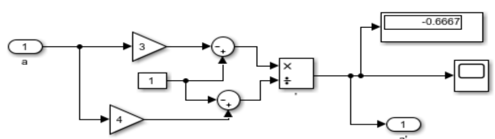

Figure 4: Model of a' as a function of a

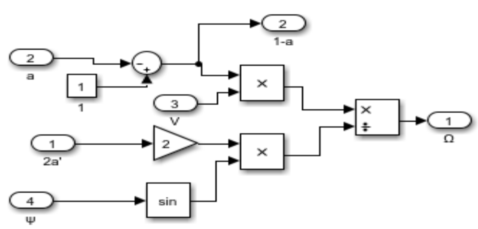

Figure 5: The model of angular speed as a function of the angle of incidence of the blade

3- Results

These models allowed us to arrive at the following results

For the simulation several values of φ were taken in order to choose the one which corresponds to the maximum power produced by the wind turbine.

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We will consider the Average Wind Speed (case of Mali where 4m/s≤V≤8m/s)

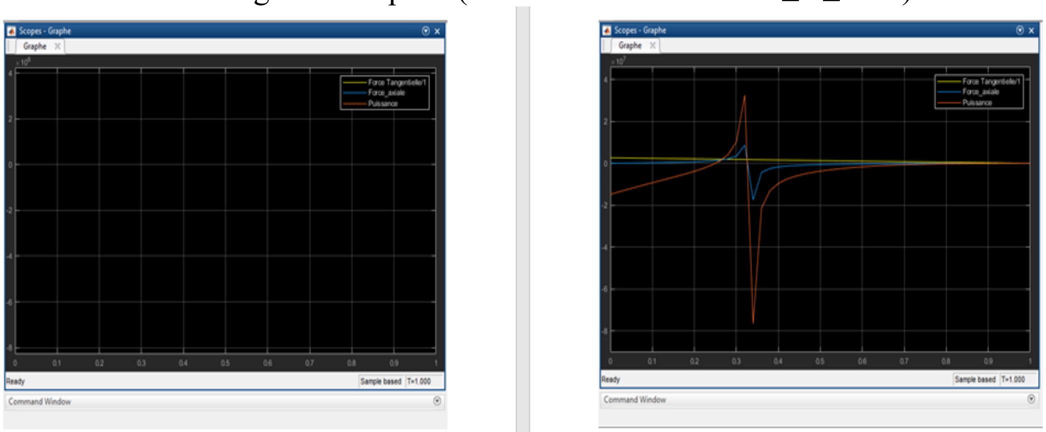

Figure 6-a: case where φ=0° Figure 6-b: case where φ=28°

Figure 6: Evolution of P, Ft and Fa as a function of φ

After choosing the ideal inclination angle for our blades, here are the results obtained

Model1

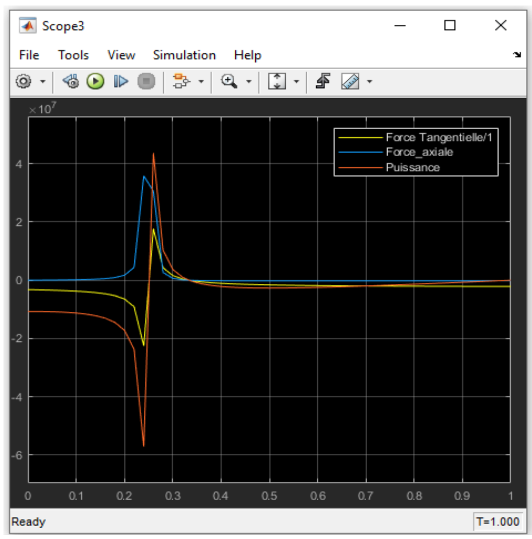

Figure 7-a: Curves of axial, tangential forces and optimal power as a function of a

Model 2

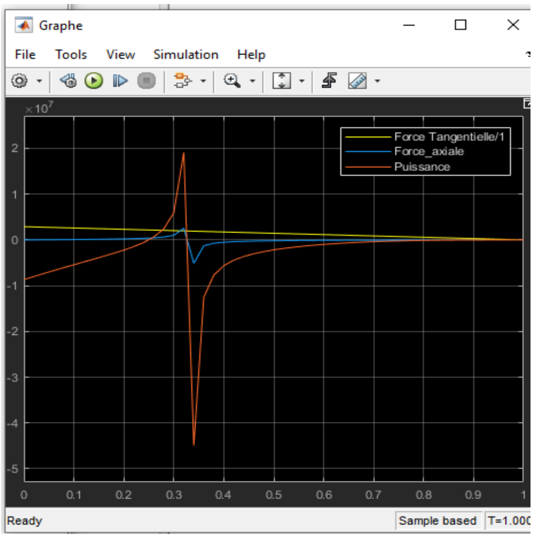

Figure 7-b: Curves of axial, tangential forces and optimal power as a function of a

Discussion

- The first model allowed us to obtain maximum power when the constant a is close to the value 0.26, which gives us a power constant Cp=0.569, a value very close to the ideal which is 0.596. although this model is very interesting, it reveals a strong axial action on the blade which will be reflected on the bearings and which can be a destructive factor.
- The second model maximizes the power when a is around the value 0.32, which gives us a power constant Cp=0.592. in addition to having a good power output, this model makes it possible to very considerably minimize both axial and tangential forces exerted on the bearings. So with this model we can considerably increase the lifespan of the rolling bearings which, today, still raises a lot of questions with wind turbines.

4- Conclusion

These simulated results with values comparable to the Sahelo-Saharan zone with an average wind of 5 m/s and by playing on the angle of incidence of the wind turbine blade and also the aerodynamic zone gives values of Cp more than satisfactory.

Dirigible blades may even be possible because a variation of the angle close to 0° makes it possible to cancel any force on the blade.

Thus, the blade can play an aerodynamic braking role, especially if it is accompanied by an adequate mechanical system.

Thus, in the years to come, wind turbines could be the best technology to overcome the energy deficit in these countries.

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