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Comparative study of Two and Three-Bladed Wind Turbine's performances, FAST as Framework

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***Abstract*— In this paper we compare dynamic behaviours of two and three bladed 5MW Wind Turbine.**

***Keywords*— Two-bladed wind turbine, Three-bladed wind turbine, 5MW-NREL wind turbine, FAST. Torque, Performance**

I. INTRODUCTION

Wind Energy has become lately, one of the most important sustainable resources one can investigate in order to get electricity [1].

Wind is a clean, economic and renewable energy source with a great availability in the environment. The main role of Wind turbines is to convert the kinetic energy available in the wind in order to get to produce electric energy [2].

Wind turbines are classified into two broad classes: Vertical Axis Wind Turbine (VAWT) and Horizontal Axis Wind Turbine (HAWT) [3] , former one being the most popular device for electricity generation for its higher efficiency due to high rotational speed.

In terms of modelling, wind turbines are complex mechanical systems exposed to uncontrolled wind profiles which make turbine design a challenging task [4].

Load Simulations are considered as a very important part in the Design Process of a Wind Turbine.

Before the assembly of Wind Turbine Components and its installation, one needs to build a numerical model besides of the test procedure.

Instead of testing real model Wind Turbines that cost Million euros per Megawatt, virtual prototypes are used and this charges less for the industries.

Several studies have been conducted in order to simulate behaviours of Wind Turbines, especially the three bladed model. However, the two bladed prototype have taken advantage of many attention. Numerous works have dealt with performance differences between both patterns [3] , [5] . There is huge number of software and frameworks that have been developed in this context. Among the tools of Simulation for load cases dedicated to Wind Turbines, there are : Bladed, Flex 5 [6], FAST [7], [8].

In this paper, we focus on the Class of HAWT and will compare the performance of two and three bladed Wind Turbine using FAST Simulation tool.

The prototype investigated for the simulation process is the 5MW NREL model given in [9]. The results show the change in torque coefficient, startup speed and power generation.

The paper is organised as follows. In the next section,we give the model development of the Wind Turbine. The section that follows presents the BEM Theory where we express the Torque, the Power and other characteristics relative to an element ring of the Blade. The section IV gives an overview of the FAST Framework. Finally in section V, we provide the simulation results, the 5MW NREL's model Wind Turbine is used and experiments are carried out under a steady wind of 18m/s.

II. MODEL DEVELOPMENT

A. The Wind Turbine Model

The following well-known algebraic equation (Eq. 1) gives the relation between wind speed and mechanical power extracted from the wind [10].

$$P_{wr} = (\frac{1}{2}) r Cp(l\ , q) A\, V_{wind}^{3} \qquad \text{(Eq.1)}$$

where *Pwr* is the power extracted from the wind in watts;

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ρ is the air density (kg/m^3);
C_p is the performance coefficient or power coefficient;
λ is the tip speed ratio ($\frac{V_t}{V_{wind}}$) , the ratio between blade tip speed V_t (m/s), and wind speed at hub height upstream of the rotor $V_{wind,}$ given by :

$$l = \frac{V_t}{V_{wind}} = h_{GB} \frac{2.R.w_r}{pV_{wind}} \quad \text{(Eq.2)}$$

p is the number of poles;
ω_r is the electric speed of the rotor;
θ is the pitch angle (in degree)
R is the radius of the turbine (Blade length) in m.
And A is the area covered by the wind turbine rotor (m^2).

B. The Blade Element Momentum Theory (BEM Theory)

In the blade element momentum (BEM) method the flow area swept by the rotor is divided into a number of concentric ring elements. The rings are considered separately under the assumption that there is no radial interference between the flows in one ring to the two neighbouring rings [11].

In this section, it is demonstrated by equations, how does the number of blades in a Wind Turbine influences the electric or aerodynamic parameters , be it the generated power, the rotor speed, the torque or others.

If we look at one blade element in the distance *r* from the rotor axis with the thickness dr, one Wind Turbine can be schematized as follows [11]:

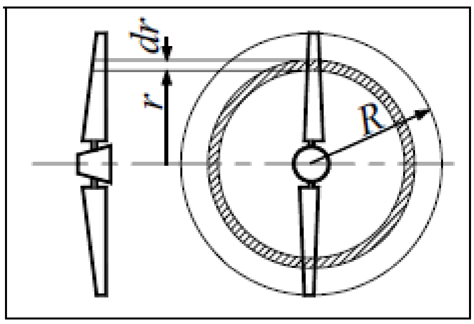

Fig.1: Blade section

R is the length of the Turbine.
Heneceforth; the next equations can be edited:
Power equations [12]
If we have B blades, the power produced is expressed such that

$$dP = B\frac{1}{2}rw^2cdrC_L\cos(g)rw \quad \text{[W]} \quad \text{(Eq.3)}$$

Where
dP is the Power produced on a ring element
B is the number of Blades
r is the air density (1.225 kg/m³)
w is the relative speed of the wind expressed such that:

$$w^2 = v^2 + u^2 \quad \text{(Eq.4)}$$

Where
- v is the axial wind speed in the rotor plane
- u is the tangential wind speed

(See Fig.2)
c is the chord length. r and the thickness dr are defined in the previous paragraph (see Fig.1).

C_L is the "Coefficient of Lift",
g is the angle of relative wind to rotor axis.
w is the angular speed of the rotor given by

$$w = 2pn \quad \text{[rad/s]} \quad \text{(Eq.5)}$$

where , n is the rotational speed of the rotor in round per second.

The blade, as shown on the Fig.2, is moving up wards, thus the wind speed, seen from the blade, is moving down wards with a speed of *u*.

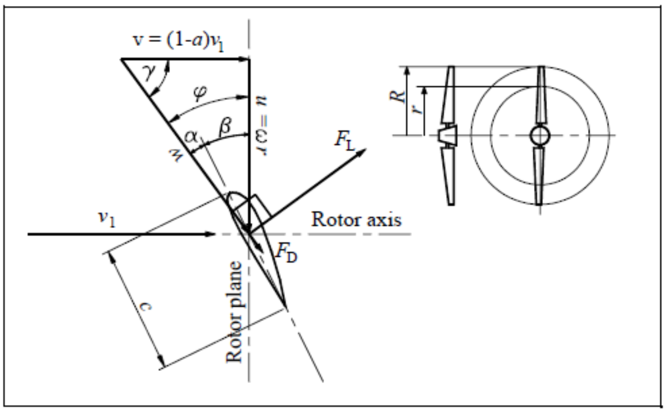

Fig.2: Velocities and angles on a chord Line

For more details about the notations on Fig.2, we mention:
- v_1 represents the wind speed upstream rotor (m/s)
- φ represents the angle of relative wind to rotor plane
- β represents the pitch angle of the blade

The angle of attack is given by : α=φ-β

F_L and F_D are respectively the Lift and the Drag Forces applied to the airfoil.

Torque equations
If we have B blades [12], the Torque equation in one ring is given by

$$dU = B(\frac{1}{2})rw^2cdrC_x \quad \text{[N.m]} \quad \text{(Eq.6)}$$

dU is the Torque on a ring element

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C_x is such that

$$C_x = C_L \sin(j) - C_D \cos(j) \quad [-] \qquad \text{(Eq.7)}$$

Where
C_L and C_D are respectively the “coefficient of Lift” and the “coefficient of Drag”.

φ is previously defined as the angle of relative wind to rotor plane.
The other elements of the equation are previously defined in the power expression.
For further details about these equations, see [2], [11], [13], [14].

III. Work description and Software USED

A. The FAST Framework

The FAST (Fatigue, Aerodynamics, Structures, and Turbulence) Code is a comprehensive aeroelastic simulator capable of predicting both the extreme and fatigue loads of two- and three-bladed horizontal- axis wind turbines (HAWTs) [15].

So Far, Jonkman have developed numerous versions of FAST. The one that is actually in use is the FAST V8.

The application in this paper, uses the design tool FAST with AeroDyn and ElastoDyn and ServoDyn—developed and verified by Jonkman and Buhl at NREL [7]—to create a model of a wind turbine concept. The time-domain simulation tool FAST can model the aero-hydro-servo-elastic response of a variety of onshore, besides of offshore floating wind turbines.

B. FAST Modules

There are several modules used in the design tool FAST such that : AeroDyn, HydroDyn, ServoDyn, ElastoDyn, SubDyn, MAP, IceFloe…

Each (see Fig.3) considers a specific part of the Wind Turbine, besides of its environment, either be it onshore farms or offshore ones.

In the present work, it is needed the use of the three modules, that we define next.

<u>Aerodyn Module</u>

The aerodynamics are calculated in the FAST module AeroDyn, which uses a state-of-the art blade element-momentum approach (BEM) with empirical corrections to calculate the rotor aerodynamics. The empirical corrections consider the losses caused by AeroDyn also is able to apply the generalized dynamic wake (GDW) theory to account for the effects of dynamic inflow [16].

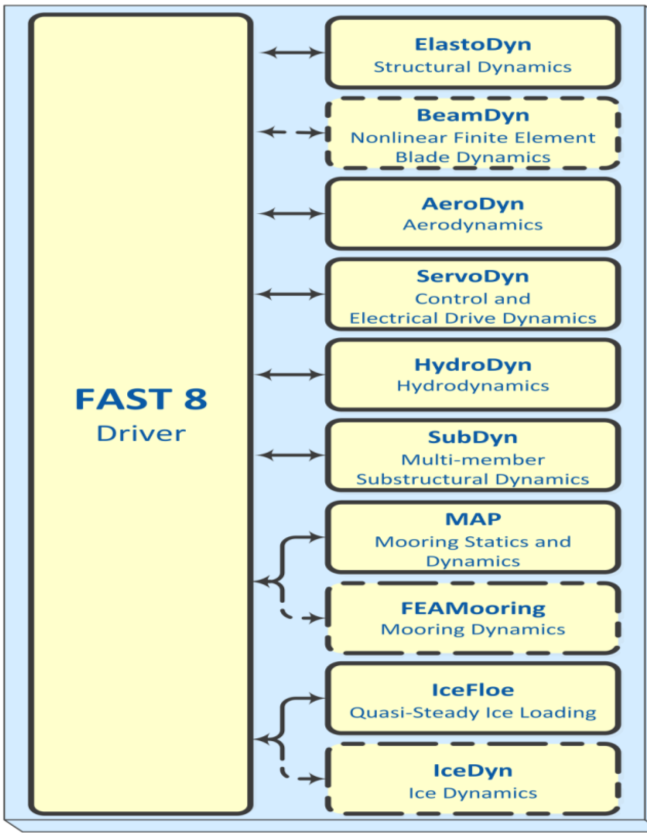

Fig. 3 FAST V8 [17]

<u>Elastodyn Module,</u> [18]

Is the Structural-Dynamic module for horizontal-axis wind turbines. It includes structural models of the rotor, drivetrain, nacelle, tower, & platform

<u>Servodyn Module</u> [19]

Is the Control and electrical-drive module for wind turbines and is used to be a fundamental part of FAST . It Includes control & electrical-drive models for blade pitch, generator torque, nacelle yaw, high-speed shaft (HSS) brake, & blade-tip brakes

IV. Numerical Simulations

A. NREL 5-MW Baseline Turbine Properties

The NREL 5-MW baseline wind turbine represents a typical state-of-the-art multi-megawatt turbine. This section gives an overview of its properties without providing details that are out of the scope of this work. An in-depth description of the turbine can be found in Jonkman [20], [21]. The baseline turbine’s properties presented in Table 1 are derived from publicly available data on the Multibrid M5000 and REpower 5-MW machines and from conceptual models used in the WindPACT, RECOFF, and DOWEC projects [16].

To perform a thorough loads analysis in the design code FAST, the floating wind turbine model was first created [16]..

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TABLE I
5MW-NREL WIND TURBINE SPECIFICATIONS

Property	**Specifications**
Related Power	5MW
Rotor Orientation	Upwind
Rotor Configuration	61.5m length
Rotor, hub diameter	126m, 3m
Hub height	90m
Wind Speed	
Cut- in Vin	3m/s
Rated	11.4 m/s
Cut-out Vout	25m/s
Cut-in rotor speed	6.9 rpm
Drivetrain concept	Geared
Gearbox ratio	97:1
Rated generator speed	1173.7 rpm
Generator efficiency	94.4 %
Rated tip- speed	80m/s
Overhang	5m
Shaft tilt	5°
Precone	2.5°
Rotor mass	110,000kg
Nacelle mass	240,000kg
Tower mass	347,460kg
Tower Diameter base	6m
Tower top diameter	3.87m
Structural Damping Ratio	0.47%
Control system	Variable speed generator torque and collective active pitch (PI)

The simulation examines the onshore wind turbine subject to a steady 18m/s wind without shear (see Fig.4). We consider both cases: Wind Turbine with two blades, then wind turbine with three blades.

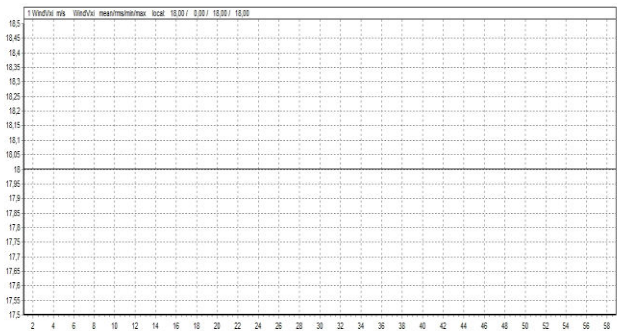

Fig. 4 Wind Profile : steady 18m/s without shear

B. *Two Bladed WT*

For this simulation, in the ElastoDyn Module file , we set specifically the Number of Blades in the Turbine Configuration *NumBl=2*.

Shapes of the Rotor speed, the Power and the Generator Torque, are depicted in Fig. 5

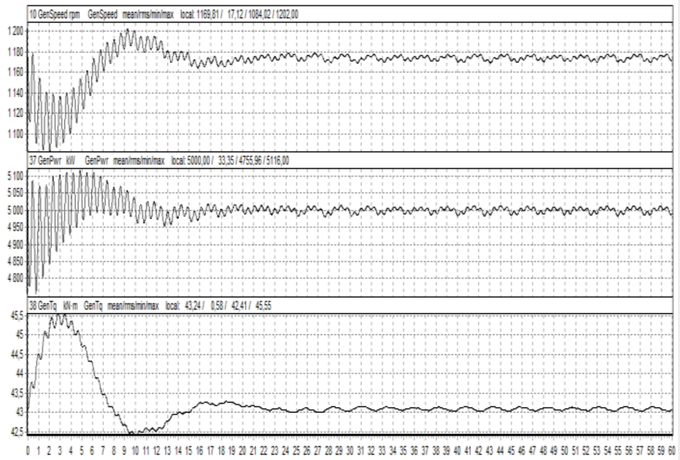

Fig. 5 A Two Bladed Wind Turbine performances (respectively the Generator Speed, the Generator Power and the Generator Torque)

C. *Three Bladed WT*

For this simulation, in the ElastoDyn Module file , we set specifically the Number of Blades in the Turbine Configuration *NumBl=3*.

Shapes of the Rotor speed, the Power and the Generator Torque, are depicted in Fig. 6

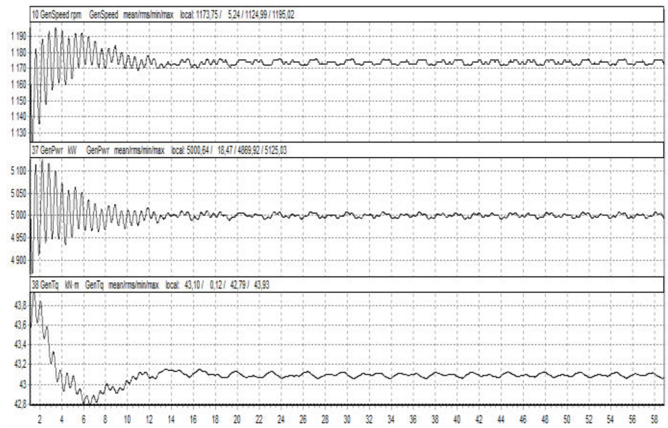

Fig. 6 A three Bladed Wind Turbine performances (respectively the Generator Speed, the Generator Power and the Generator Torque)

Based on Figures 5 and 6, we notice the differences between Two and Three Bladed Wind turbines. In Fig.5, it is clear that the startup speed of a WT with Two Blades is lower than the one with three blades. There is experimental evidence that for smaller scale turbines or at higher speeds, adding more blades can actually increase efficiency and other things like startup speed. We can note the value of 1140 rpm for a two-bladed Wind Turbine, whereas it is 1160 rpm for a three-bladed one.

Also, from the analysis it is found that rotor with less blade number produces higher Torque (Fig.5). Initial value of the torque is 45.5 KN.m towards 43.9 KN.m for three bladed WT.

The value of Power Generated is the same for any blade numbers.

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V. CONCLUSION

In this work, we have provided that number of bladed in an HAWT influences well the aerodynamic behavior of the Turbine.

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