Modeling And Simulation Of The Vertical Axis Wind Turbine By Qblade Software

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ABSTRACT (12 PT)

Wind energy is clean energy. This one is a viable alternative to the problems raised by nuclear waste management and greenhouse gas emissions. Vertical axis wind turbines present a lot of advantages for domestic applications, where wind flow conditions are intermittent, omnidirectional, unsteady and turbulent. In this work, we discuss VAWT type wind turbines. More specifically, we present the geometry and aerodynamic characteristics of the blade profiles. The acting forces and DMS multiple flow tube models are also studied. This work gives Qblade software as a simulation method to optimize the behaviour of the blades from the selected NACA profiles. The analysis first goes through the design of the blades then it calculates the forces on the blade and coefficients of lift, drag and fineness. At the end of this article we have the DMS simulation of the VAWT turbines, by determining the power coefficient and the power collected by the turbine to select the wind turbine adapted to a well characterized site.

NOMENCLATURE

α	Attack angle	NACA	National Advisory Committee for Aeronautics
Cd	Drag coeficient	Re	Reynolds number
Cl	Lift coefficient	TSR	Tip Speed Ratio
Cp	Power corfficient	V	Upwind induced velocity V
DMS	Double Multiple Stream Tube	VAWT	Vertical Axis Wind Turbine
F	Aerodynamic force	$V\infty$	Inflow velocity
F_d	Drag force	Ve	Equilibrium velocity
Fl	Lift force	V’	Downwind induced velocity V’
HAWT	Horizontal Axis Wind Turbines	V’’	Wake velocity V’’
i	Incidence angle		

I. Introduction

The depletion of fossil energy resources coupled to global warming trends led to the need development of a low carbon based economy as an international strategy for sustainable development. Among several green and renewable energy sources, wind energy has seen a rapid growth worldwide and will play an increasingly important role in the future economy [1]. Wind turbines are typical devices that convert the kinetic energy of wind into electricity [1-2].

To develop this energy optimally, it is necessary to develop techniques for the construction of aero-engines, and specifically for the design of wind turbine blades.
Vertical axis wind turbines (VAWTs) are more efficient than the horizontal axis wind turbines (HAWTs) for low wind speed applications. Their ability to capture wind flowing from any direction is an important advantage. The VAWT rotor blade design was presented to overcome the limitations.
During this last decade, many methods were developed to improve the performance (efficiency), based on the optimization of the design characteristics of wind turbine blades [3].
It is important to understand deeply the behaviour of turbine blades. QBlade software was used to simulate the wind turbine blade during the working conditions because of its several advantages.
In this paper the analysis and optimization of the behaviour and performance of the blade of the Vertical Axis Wind Turbine (VAWT) blades of the Darrieus rotor are presented. Numerical simulation encompasses the concept of Double-multiple streamtube model (DMS (Double Multiple Stream Tube)), which can calculate rotor performance with realistic accuracy has been demonstrated.

II. Types of HAWT and VAWT wind turbines

At present, there are two categories of modern wind turbines, namely horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs), which are used mainly for electricity generation and pumping water. The main advantage of VAWT is its single moving part (the rotor) where no yaw mechanisms are required, thus simplifying the design configurations significantly. Blades of straight-bladed VAWT may be of uniform section and untwisted, making them relatively easy to fabricate or extrude, unlike the blades of HAWT, which should be twisted and tapered for optimum performance. Furthermore, almost all of the components of VAWT requiring maintenance are located at the ground level, facilitating the maintenance work appreciably. In general, VAWT can sensibly be used in any area with sufficient wind, either as a stand-alone system to supply individual households with electricity and heat, or for the operation of freestanding technical installations [4]. We can separate VAWT's into two key types; the Darrieus rotor and Savonius rotor.
The Savonius-type VAWT, as shown in Fig. 1, It is basically a drag force driven wind turbine with two cups or half drums fixed to a central shaft in opposing directions. Though typical values of maximum power coefficient for other types of wind turbines vary between 30% and 45%, those for the Savonius turbines are typically not more than 25% according to recent studies. This type of turbine is suitable for low-power applications and they are commonly used for wind speed instruments [2].

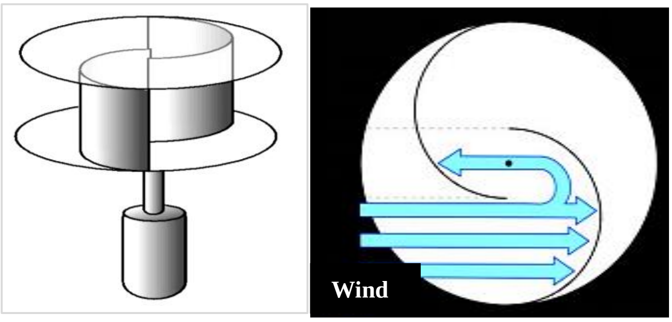


Fig.1. Savonius wind turbine

The Darrieus rotor rotates around a median axis due to the lift created by the rotating wings. It can be subdivided into three categories: Darrieus rotor (Troposkian), H rotor, helical rotor which are shown in Fig.2.

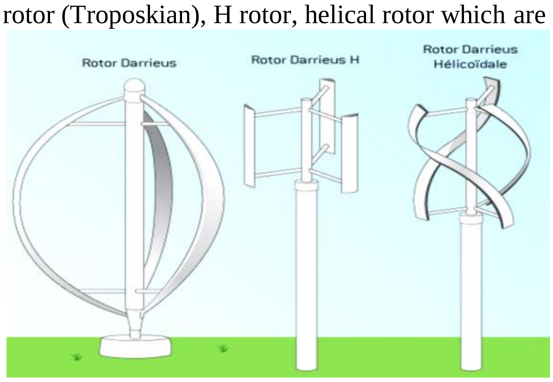


Fig.2. Darrieus-type wind turbine.

III. VAWT Blade Aerodynamics

The shape of a vertical section of a blade called profile, determines its aerodynamic qualities. The profile has a rounded part at the front ealled the leading edge, and a tip at the rear the trailing edge. The profiles are distributed along the blade of the wind turbine, the extrados (the top of the blade) and the intrados (the underside) have a convex shape, which is more acute on the extrados than the intrados sides (Fig.3). The air flow is faster on the upper surface than on the lower surface [3].

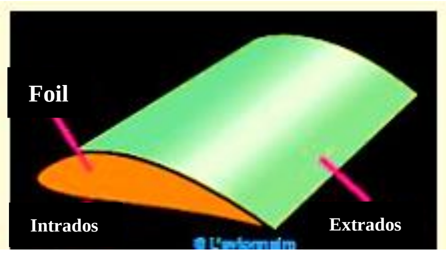
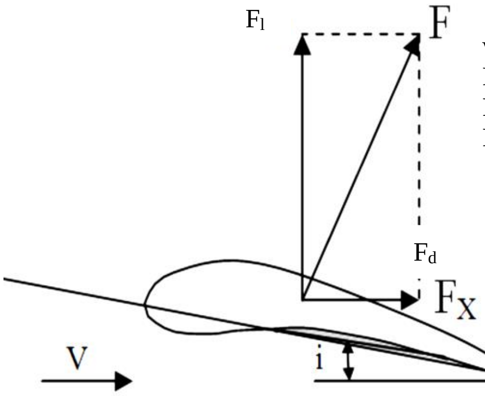


Fig.3. wind turbine blade [14]

The aerodynamic parameters of the profiles depend on the geometrical characteristics presented in (Fig.4).



with :
F: Aerodynamic force [N]
F_d : Drag force [N]
Fl : Lift force [N]

Fig.4. Geometrical characteristics of a profile (4).

The majority of VAWTs utilize NACA (National Advisory Committee for Aeronautics) airfoil sections because they are easy to manufacture and their characteristics are widely available (Fig. 5).

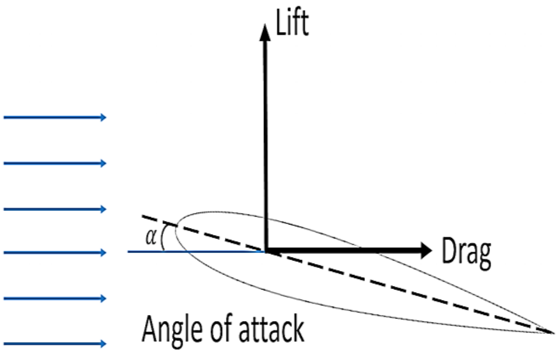


Fig.5. Lift and drag forces.

Where in Fig 5, α is the angle of attack and represents the angle between the apparent wind direction and the blade (middle line).Two forces are applied to the blade:

- Drag force (Fd), in the same direction as the vector the resulting blade movement is opposed to the movement of the blade.
- Lift force (Fl), orthogonal to the resulting vector pushing the blade.

The direction of these two forces depends on the angle of attack, and the angle of orientation. These two vectors form the aerodynamic force applied to the blade: Fig (6).

3.1 DMS (Double Multiple Stream Tube) model theory

Double Multiple Stream Tube Model was developed by Ion Paraschivoiu for the performance analysis of Darrieus type rotors [7].

The streamtube flowing through the VAWT rotor is splitted up into a set of smaller streamtubes. The blades of the rotor pass through each of these streamtubes on their 360 degree path and extract energy from the fluid by reducing its velocity. Thus, the standard actuator disk theory can be applied for every streamtube. Due to the circular path of a VAWT blade, it passes each streamtube twice. These two steps of energy extraction are taken into consideration in the DMS model by dividing the rotor into an upstream and downstream half (see fig.6). Each one is represented by a separate rotor disk. This double disk acts like two single actuator disks in tandem. The subsequent iteration algorithm is hence executed twice for every streamtube. Additionally, the DMS algorithm is executed for each height position where the fluid flows through the respective blade section [8].

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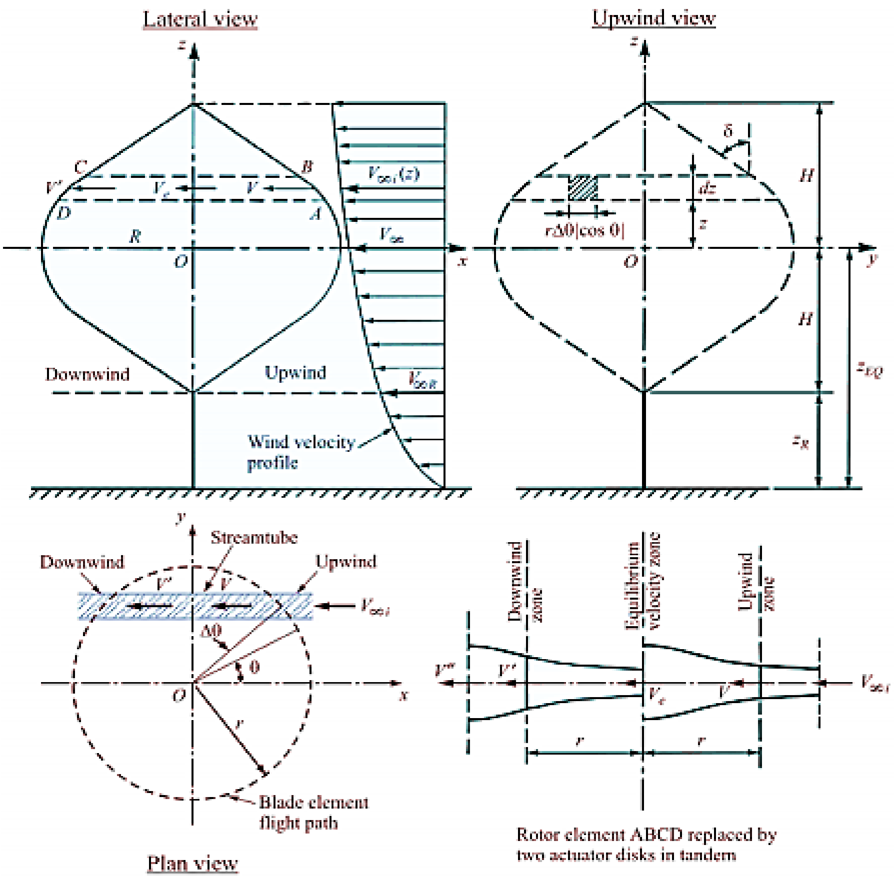


Fig.6.VAWT rotor geometry definition and two actuator disks in tandem [13]

As already described, a rotor blade is composed of several blade sections. According to the selected number of elements, the intermediate blade sections are interpolated from the given geometry. All sections can be treated as independent 2D foils producing lift and drag as a function of their local angle of attack α. The resultant total force on a blade can be found by integrating over the whole length of the blade [8]

There are five important velocities in a DMS calculation (see Fig.6) : **inflow velocity** $V\infty$ (of the undisturbed free stream flow), **upwind induced velocity** V (due to the energy extraction of the blade in the upstream rotor half), **equilibrium velocity** Ve (in the plane between up- and downstream rotor half (represents wake velocity of upstream rotor disk and inflow velocity of downstream rotor disk), **downwind induced velocity** V' (due to the energy extraction of the blade in the downstream rotor half), and **wake velocity** V'' (of the whole double disk). According to these velocity determinations, one can define the interference factors for the energy extraction in the up- and downstream rotor half [9]:

$u = \frac{V}{V\infty}, \qquad u' = \frac{V'}{Ve}$

IV. Simulation and interpretation

To perform an aerodynamic study and a numerical analysis of the performance of a vertical axis wind turbine, the Qblade software is used for the simulation of profiles and the numerical realization of the blade elements. In our case we have chosen the following profiles: NACA 0016, NACA 2412 and NACA 23015 (see Fig.7).

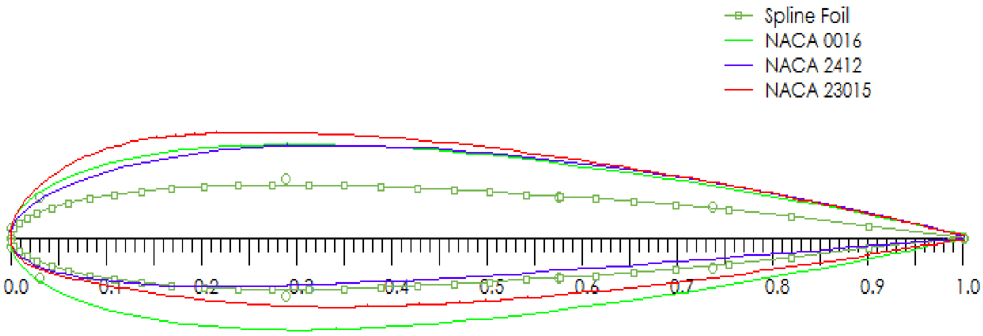


Fig.7. Shape of the three NACA blade profiles.

We are interested in the numerical evaluation of aerodynamic performance in the study of the influence of these profiles on the aerodynamic parameters (Cl, Cd, thikness...). In Fig.8 and 9, we show the simulation results of the selected profiles.
The ratio between lift and drag gives the thinness of the profile. It characterizes the "performance" of the profile (9).

Fig.8 shows that the lift coefficient (Cl) increases progressively for the three types of profiles for an optimal angle of attack (α). This coefficient drops sharply for each type of profile. This shows that the lift coefficient depends strongly on the low angle of attack, the laminair air flow along the blade and is faster on the extrados than on the intrados. The resulting vacuum on the upper surface creates lift. It is this force that "sucks" the blade forward. If α increases, the lift increases to a certain point and then the flow becomes turbulent. The lift resulting from the vacuum on the upper surface disappears. This phenomenon is called aerodynamic stall (10). When the coefficient of lift is high, the thinness is more important in fig.9, we show the evolution of the thinness (Cl/Cd) as a function of the angle of attack (α) for the three profiles. The thinness of the NACA2412 profile is the best for α=5˚ and for α=10˚ the thinness of the NACA23015 profile is the most important.

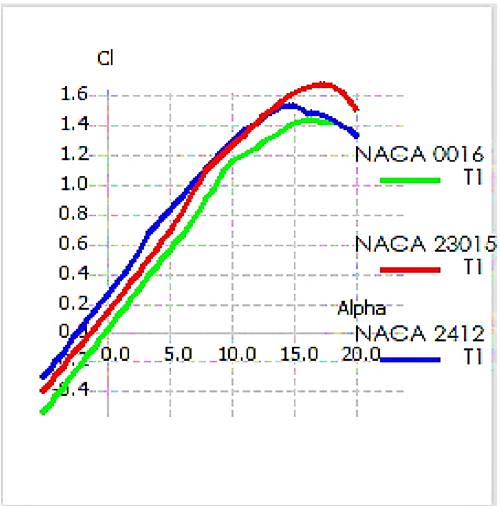


Fig.8. Lift Coefficient (Cl) vs angle of attack (α)

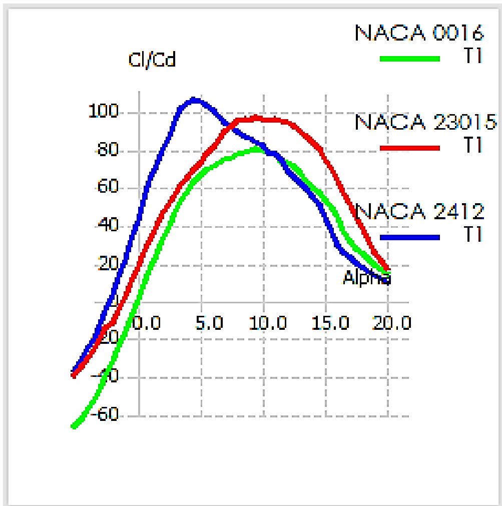
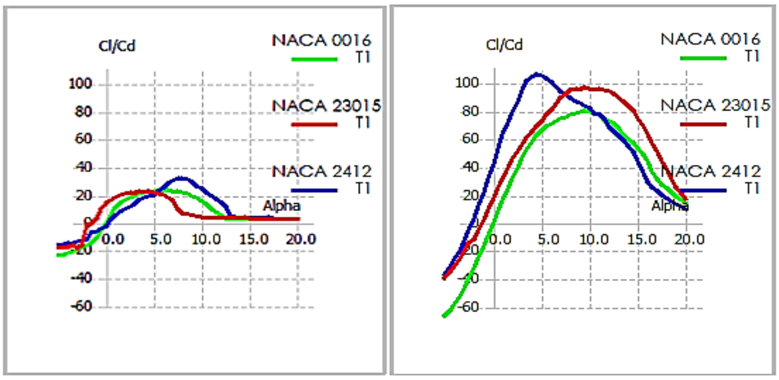


Fig.9.Thikness (Cl/Cd) vs angle of attack (α)

The influence of physical parameters on the performance of a vertical axis wind turbine is also studied. First, we discuss the influence of the Reynolds number of the three profiles, and as shown in fig.10 we see that the ratio (Cl/Cd) increases with the the Reynolds number (Re), this increase delays the onset of the stall and makes it possible to obtain a higher effort.



(a). Re=50000 (b). Re=1000000

Fig.10. Influence of the Reynolds number.

We can also study the influence of the relative thickness of the profile on the coefficient of lift and drag. In fig (11 and 12) we show the variation of these coefficients as a function of the angle of attack for different relative thicknesses.

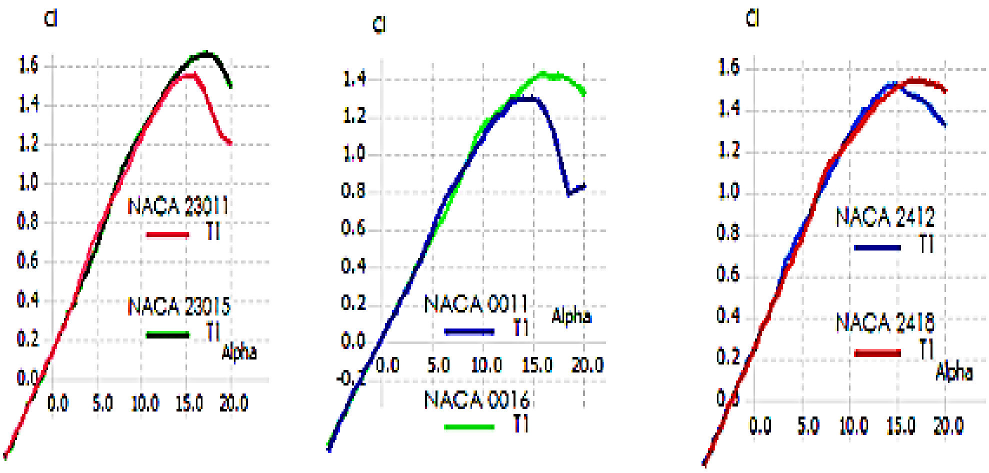


Fig.11. Influence of the relative thickness (e) on the lift coefficient (Cl).

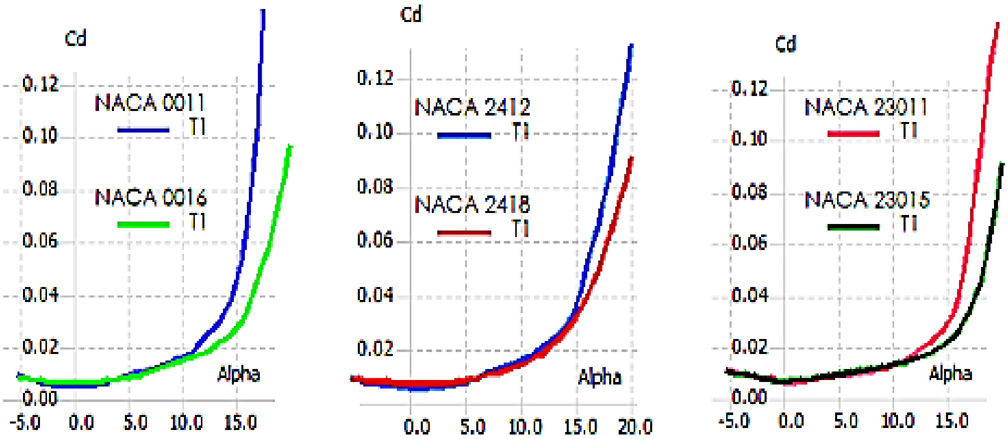


Fig.12. Influence of the relative thickness (e) on the drag coefficient (Cd).

This study shows that the relative thickness affects the coefficient of lift and drag. The maximum lift is more important when the thickness is greater, but the coefficient of drag decreases, as the upper surface flap position approaches the trailing edge and the steering angle is greater. The presence of the flap causes a sudden drop in pressure on the upper surface of the profile, which leads to an improvement in aerodynamic forces in the right direction and an increase in glide, i.e. an increase in lift.

IV.1. DMS (Double Multiple Streamtube) Simulation of the rotor

Numerical simulation tool Q Blade includes a module for the simulation of wind turbines which allows for the proficient and innate design of rotors and blade shapes. The implemented algorithm is applicable for the performance analysis of lift based Darrieus rotor blades (7). In this simulation, we present the result of a comparative study between two types of rotor blades (see Fig.13): H-type and Troposkein blades.

(a) H-type design model (b) Troposkein shape

Fig.13. Different blade shapes for VAWT [7, 14]

Fig.14, shows the variation of the power coefficient (Cp) as a function of the normalized speed (TSR) of the two types of form H and troposkein. For optimum efficiency, the troposkein type power coefficient (Cp) is important for low normalised speeds but for higher speeds the H-type power coefficient (Cp) is more important, therefore the power recovered by the wind turbine is important because it is proportional to the power coefficient (Cp).

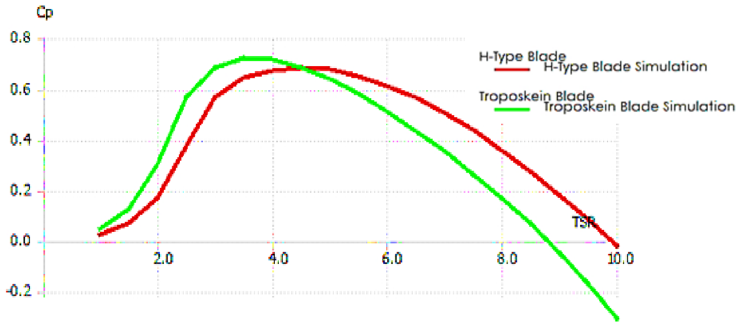


Fig.14. Coefficient of power (Cp) vs normalized speed (TSR).

Fig.15 shows the results of the DMS (Double Multiple Streamtube) simulation of optimized turbines derived from Qblade software.

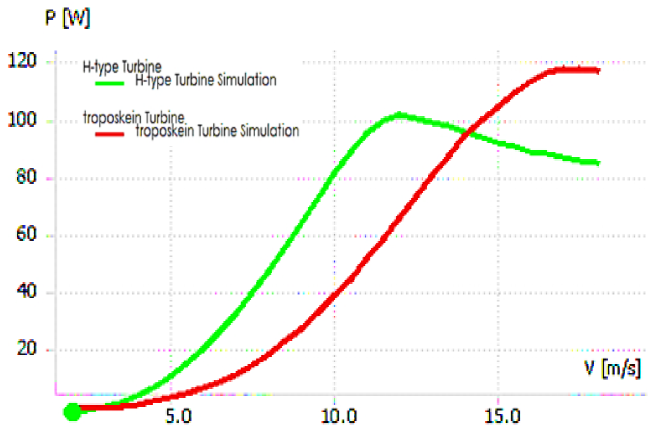


Fig.15. Power curve vs wind speed

The power curves for the two different types of VAWT have been shown graphically. The troposkein type shows best results; around 120W for high wind speeds around 18m/s, followed by H type: its power is equal to 100W and its wind speed is around 12m/s.

V. Conclusion

This work focused on the aerodynamic loads effect on the wind blades. Vertical axis wind turbine was considered. Qblade software was used as simulation method. This tool permits to predict the VAWT performance and to develop aerodynamic profiles. Three NACA profiles (NACA0016, NACA2412 and NACA23015) were studied. Numerical evaluation of aerodynamic performance (coefficient of lift Cl, coefficient of drag Cd and the thinness) were presented. The influence of the physical parameters (Reynolds number and relative thickness) on the aerodynamic performance of the blade was subsequently studied. It was found that the thikness' ratio of (Cl/Cd) increases with Reynolds number. Moreover the increase of relative profile thickness yields to optimal profile efficiency. Finally, DMS simulation of H and Troposkian types wind turbines was analysed. This study allows to designing the rotors and blade shapes by determining the power coefficient and the mechanical power harnessed by the wind turbine. In order to select the right wind turbine for a well-defined site.

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