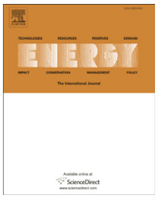
Energy xxx (2014) 1–10

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy



Proposal for an innovative chord distribution in the Troposkien vertical axis wind turbine concept

Gabriele Bedon, Marco Raciti Castelli, Ernesto Benini*

Department of Industrial Engineering of the University of Padua, Via Venezia 1, 35131 Padua, Italy

ARTICLE INFO

Article history:
Received 25 June 2013
Received in revised form
24 December 2013
Accepted 2 January 2014
Available online xxx

Keywords:
Darrieus VAWT (vertical axis wind turbine)
WOMBAT (Weatherly Optimization Method for Blades of Air Turbines) algorithm
Variable chord distribution
Aerodynamic optimization

ABSTRACT

An innovative design for the Troposkien concept is introduced by means of an advanced chord distribution, computed using the WOMBAT (Weatherly Optimization Method for Blades of Air Turbines) algorithm for the performance optimization of vertical axis wind turbines. Five rotor blade architectures, characterized by a constant value of the thickness-to-chord ratio and a varying chord length along the blade span, are evaluated. The optimization process is conducted with respect to the power coefficient for a target wind speed of 9 m/s, obtaining a consistent improvement of rotor performance with respect to the baseline blade configuration.

1. Introduction

In the near future, VAWTs (vertical axis wind turbines) are going to play an important role in the energy production planning. In fact, their typical characteristics of small size and lightweight allow their installation also in the urban context, on the building roofs and yards. In this scenario, the Darrieus VAWT represents one the most promising architecture [1], thanks to its high aerodynamic performance.

The traditional design of the Darrieus rotor involves a constant distribution of thickness and chord along the whole blade span. In the present analysis, the optimal chord distribution along the blade length is searched for increasing rotor aerodynamic performance.

The Troposkien design procedure usually involves two steps:

- the first step is conducted by considering a BE-M (Blade Element-Momentum) or Vortex based algorithm, thanks to their rapidity to provide a reliable estimation of the rotor performance for a given parameter set;
- the second step involves the turbine simulation by means of CFD (Computational Fluid Dynamics) codes, which provide a very deep knowledge of the rotor aerodynamics, allowing a more advanced power characterization.

Simulation tools based on the BE-M Theory are widely adopted and have been proposed and improved by many authors [2–6]. The main issue regarding these algorithms is their necessity to use airfoil aerodynamic coefficients for angles of attack over 360° [7–9] and low airfoil Reynolds numbers, consistently smaller than those generally considered for aeronautical use [10].

Some aerodynamic databases for a limited number of profiles are available in literature: NACA 0012, SG6043, SD7062 and DU06-W-200 polars, characterized by an angle of attack ranging up to 360° and a Reynolds number ranging from 65,000 to 150,000, were provided by Worasinchai et al. [11]. Sheldahl and Klimas [12] tested NACA 0009, NACA 0012 and NACA 0015 profiles, considering angles of attacks ranging from 0° to 180° and a limited range of Reynolds numbers (from 350,000 to 700,000), successively extending the results to a wider range of Reynolds numbers and also to different airfoil geometries by means of numerical methods.

In the present work, the WOMBAT (Weatherly Optimization Method for Blades of Air Turbines) design algorithm developed by Bedon et al. [13] is adopted. This algorithm includes a rotor aerodynamic performance prediction tool based on the BE-M code developed by Raciti Castelli et al. [14]. The simulation is based on the aerodynamic databases provided by Sheldahl and Klimas [12] and allows also the estimation of the aerodynamic coefficients of

---

* Corresponding author.
E-mail addresses: gabriele.bedon@dii.unipd.it (G. Bedon), marco.raciticastelli@unipd.it (M. Raciti Castelli), ernesto.benini@unipd.it (E. Benini).

0360-5442/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2014.01.004

Please cite this article in press as: Bedon G, et al., Proposal for an innovative chord distribution in the Troposkien vertical axis wind turbine concept, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.01.004

different NACA airfoils by means of the interpolation of such polars. Nevertheless, for the present calculations, since the profile thickness/chord ratio is maintained constant, this functionality is not exploited.

The design procedure is conducted optimizing a given baseline geometry. Nowadays a great number of optimization software based on genetic algorithms is available on commercial platforms, allowing the solution of different problems: applications such as fluid dynamics, structural and modal analyses, as well as financial evaluations represent some examples. The best aerodynamic configuration for the rotor blade can therefore be found using a proper evolutive algorithm, by previously setting the chosen objective functions. An optimum aerodynamic design model for a wind turbine blade was presented by Bourguet et al. [15], who adopted a multi-criteria optimization algorithm coupled to a CFD simulation code, in order to gain an increase of the nominal power production and the reduction of the blade weight, suggesting the adoption of the NACA 0025 profile as the best option. Carrigan et al. [16] considered a baseline rotor architecture based on a NACA 0015 airfoil and increased the turbine efficiency by 6% by means of a differential evolutionary algorithm based on a CFD simulation code. The WOMBAT algorithm adopts the multi-objective genetic algorithm based on work of Deb [17] and implemented in the commercial software Matlab [18]. The reliability of such algorithm was proven by Bedon et al. [19] by optimizing the 2-m Sandia turbine tested by Sheldahl [20], imposing a constant evolution of both chord and a thickness along the rotor blade span [13], achieving an increase in performance up to 6%.

2. The case study

The blades of a Darrieus VAWT are traditionally manufactured extruding a single profile over the whole blade length, eventually bent to form a SCS (straight-circular-straight) shape, a practical approximation for the Troposkien architecture [21].

The 2-m Sandia turbine tested by Sheldahl [20] is here considered as a case study. The rotor is 2 m high, the nominal radius is 0.98 m and the blade shape is SCS. The main geometrical specifications of the turbine are reported in Table 1. A picture of the wind turbine installation in the Sandia site test is reported in Fig. 1.

This type of turbine is widely analyzed in literature, both from the numerical and from the experimental point of view. The WOMBAT algorithm has been preliminary tested using such a rotor architecture [19]: the validation process showed a quite high sensitivity of the numerical results to the selected dynamic stall model, especially for lower wind speeds. As a result, the use of the Gormont–Strickland model [22] determined a better prediction with respect to the experimental data from Sheldahl [20], as can be seen in Fig. 2. For further information about the WOMBAT optimization algorithm and the validation of its performance prediction code, see Refs. [13,19].

Due to the inherent characteristics of the BEM approach (bidimensional simulation and streamtube independency), the prediction reliability is assumed not to be sensibly compromised by a chord variation along the blade span. In order to confirm the consistency of this assumption, an additional validation is shown in Fig. 3, where WOMBAT predictions are compared to experimental data from the Sandia 34-m wind turbine [23], characterized by a variable chord. The aerodynamic coefficients for the SAND 0018/50 profile are retrieved from Ref. [24].

Table 1
Main geometrical features of the Troposkien rotor tested by Sheldahl [20], here assumed as baseline configuration for the optimization process.

H	2 m
R	0.98 m
N	3
Blade profile	NACA 0012
Blade shape	Straight-circular-straight (SCS)
c	58.77 mm

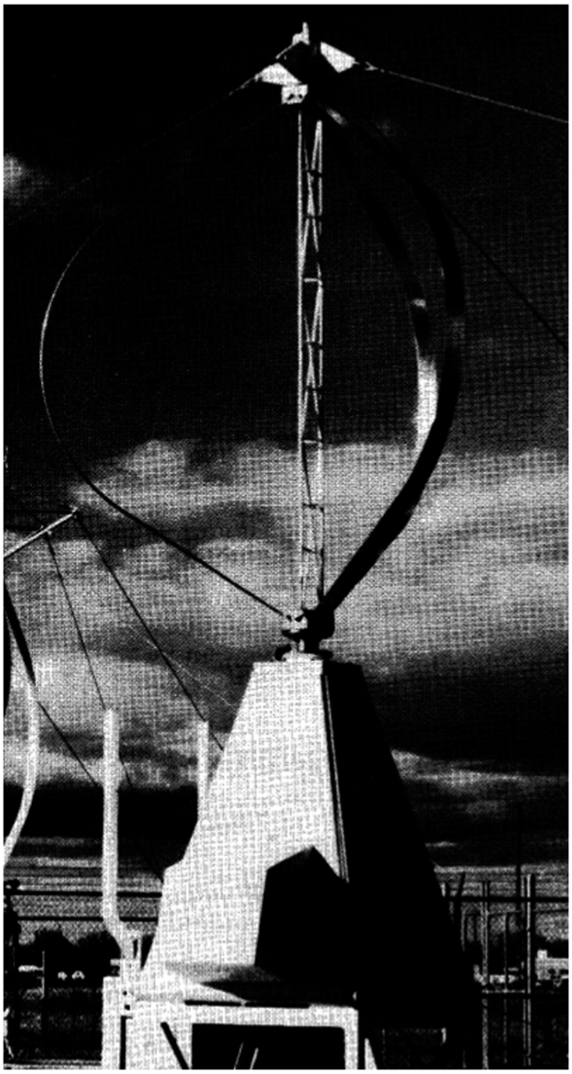


Fig. 1. Sandia 2 m Darrieus wind turbine installation (from [20]).

3. Optimization methodology

In the first optimization campaign, the thickness/chord ratio, which defines the shape of the profile, is considered uniform and equal to the value of the Sandia turbine (0.12), considered as a baseline configuration. In order to have a fair comparison, the same air density (1 kg/m^3 [25]) registered at the Sandia test site is here considered.

Due to its numerical nature, the algorithm can be adapted to accept a non uniform chord distribution. Anyway, experimental data for small turbines with variable chord are not available in literature: the presented numerical results should therefore be confirmed by further experimental activity.

As described in Ref. [13], the WOMBAT algorithm is structured as a loop which involves a genetic algorithm, a BE-M simulation code

Please cite this article in press as: Bedon G, et al., Proposal for an innovative chord distribution in the Troposkien vertical axis wind turbine concept, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.01.004