Energy Conversion and Management 127 (2016) 461–476

Contents lists available at ScienceDirect

Energy Conversion and Management

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

A novel heuristic method for optimization of straight blade vertical axis wind turbine

Mojtaba Tahani, Narek Babayan *, Seyedmajid Mehrnia, Mehran Shadmehri

Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran

ARTICLE INFO

Article history:
Received 10 June 2016
Received in revised form 29 August 2016
Accepted 30 August 2016

Keywords:
VAWT
Heuristic optimization
Continuous/discrete problem
DMST
CFD

ABSTRACT

In this research study it is aimed to propose a novel heuristic method for optimizing the VAWT design. The method is the combination of continuous/discrete optimization algorithms with double multiple stream tube (DMST) theory. For this purpose a DMST code has been developed and is validated using available experimental data in literature. A novel continuous optimization algorithm is proposed which can be considered as the combination of three heuristic optimization algorithms namely elephant herding optimization, flower pollination algorithm and grey wolf optimizer. The continuous algorithm is combined with popular discrete ant colony optimization algorithm (ACO). The proposed method can be utilized for several engineering problems which are dealing with continuous and discrete variables. In this research study, chord and diameter of the turbine are selected as continuous decision variables and airfoil types and number of blades are selected as discrete decision variables. The average power coefficient between tip speed rations from 1.5 to 9.5 is considered as the objective function. The optimization results indicated that the optimized geometry can produce a maximum power coefficient, 44% higher than the maximum power coefficient of the original turbine. Also a CFD simulation of the optimized geometry is carried out. The CFD results indicated that the average vorticity magnitude around the optimized blade is larger than the original blade and this results greater momentum and power coefficient.

1. Introduction

Nowadays, harnessing energy from renewable energy sources is in priority for all countries of the world because of the energy and air pollution crisis. Wind energy is a growing market in the energy sector and because of its many advantages, researchers and also investors are being motivate to spend their time and money on different wind energy convertors, in order to increase the amount of extracted energy from wind flow. Wind turbines are being classified into two main configurations according to their rotational axis: vertical and horizontal axis wind turbines. A comparison between these two types of turbines indicates that both turbines have their own advantages and also disadvantages. For example having higher power coefficient and also higher efficiency are the advantages of horizontal axis turbines and independence from wind direction and also capability of harnessing gusty wind are the positive points of vertical axis wind turbines.

Because of numerous research studies in the field of horizontal and vertical axis wind turbines, several review papers have been published by various researchers. For example Islam et al. [1] introduced the several aerodynamic models which are being used for performance prediction of straight-bladed Darrieus-type turbines. Different design techniques and various configurations of vertical axis wind turbines are introduced by Bhutta et al. [2]. In the review study carried out by Bavanish and Thyagarajan [3] different blade designs of horizontal axis wind turbines are reviewed and the optimization procedure with Blade Element Momentum (BEM) theory is introduced. Bedon et al. [4] evaluated the different aerodynamic databases which are being utilized in simulation of vertical axis wind turbines. Several review and original studies can be mentioned in this field, therefore only some examples of recently published papers are introduced here. In the research study carried out by Sedaghat and Mirhosseini [5] a 300 kW horizontal axis wind turbine has been designed for province of Semnan using Blade Element Momentum (BEM) theory. RISO-A1-18 airfoils were used for this purpose and the design was carried out for maximum power coefficient equal to 0.51 at tip speed ratio equal to 10. The feasibility of utilization of three models of small wind turbines for Kerman, Iran is evaluated by Mostafaeipour [6]. The results indicated that all three turbines can be considered for different applications. A design guideline has been presented by Bianchini

* Corresponding author.
E-mail address: n.babayan@ut.ac.ir (N. Babayan).

http://dx.doi.org/10.1016/j.enconman.2016.08.094
0196-8904/

Nomenclature

C_D	drag coefficient
C_L	lift coefficient
C_N	normal coefficient
C_P	power coefficient
C_T	tangential coefficient
C_n	coefficient of the optimization algorithm
D_n	coefficient of the optimization algorithm
F_{up}	the resultant force on upwind section (N)
N	number of blades
Nbest	number of best solutions
R	radius (m)
TSR	tip speed ratio
V	local upstream velocity (m/s)
V_e	equilibrium velocity (m/s)
V_∞	free stream velocity(m/s)
V'	local downstream velocity (m/s)
a	upstream axial induction factor
a'	downstream axial induction factor
best	best Solution
c	chord (m)
d	diameter (m)
g	global best solution
p	probability
w	local relative velocity (m/s)
worst	worst solution
x	a specific solution
α	angle of attack
γ	a random number
σ	solidity
θ	azimuth angle
ξ	degree of importance of Pheromone
τ	pheromone intensity
ω	rotational speed (rad/s)

Subscripts

dw	downwind
i	the number of solution
k	the number of best solution
sol	solution
up	upwind

et al. [7] for the purpose of optimizing the annual energy of H-Darrieus wind turbines. BEM theory was utilized for analyzing 21,600 test cases in order to find the best configuration which ensures the largest annual energy yield. For the purpose of making wind technology a more competitive player in the energy market Butbul et al. [8] applied morphing blade concept for vertical axis wind turbines. The results indicated, that morphing blade has better performance at low RPMs in comparison to rigid blade. A novel Darrieus vertical axis wind turbine with automatically deformable blades was proposed by Wang et al. [9]. In mentioned research study numerical simulations were carried out using the United Computational Fluid Dynamics code. The results indicated that the maximum power coefficient of the novel turbine with low solidity will increase about 14.56% in comparison to conventional turbine with the same solidity. Three-dimensional numerical simulation of vertical axis wind turbine with different Omni-direction-guide-vane is carried out by Shaizare et al. [10]. The purpose of mentioned study was investigating the effect of these guide vanes on the output power of urban vertical axis wind turbine. The results indicated that by using guide vanes the output power can be improved 40.9% for tip speed ratio equal to 0.745. The numerical wake study of H-type vertical axis wind turbines has been carried out by Zuo et al. [11]. The purpose of this study was investigating the influence of two vertical axis turbines on each other. The results indicated that the needed velocity recovery distance is usually larger than 15D. In the research study carried out by Scappatici et al. [12], the optimization of the design of horizontal axis small turbines is investigated. In mentioned research study a finite element method is utilized for numerical simulation of stress distributions along the blade. The employed method is validated using experimental data and the optimization results indicated that according to the curves presented the optimized turbine can be utilized in turbulent environments.

The focus of this research study is on vertical axis wind turbines and its main goals can be classified into three groups which are developing a double multiple stream tube theory code, obtaining the optimum design of a vertical axis wind turbine by combining heuristic hybrid algorithm and double multiple stream tube theory and finally investigating the flow characteristics of the optimum turbine design using computational fluid dynamics (CFD).

Double multiple stream tube (DMST) theory which is utilized in this study is one of the most popular methods which is classified as one of the blade element momentum theory (BEM) approaches. According to the recently published paper by Batista et al. [13], BEM models can be classified into three categories namely, single streamtube model, multiple stream tube model and DMST. The advantages and also disadvantages of these three methods are presented in [13]. According to the fast prediction and also good performance of DMST in predicting the performance of the turbine, in several studies this theory has been used as design tool for wind turbine [14,15].

Recently heuristic optimization algorithms are being widely utilized in the field of renewable energies. The reason of the popularity of these algorithms can be summarized in their simplicity and also robustness in finding the global optimum solution. For example Tahani et al. [16] optimized the design of a horizontal axis tidal turbine using four different algorithms. The results indicated that the flower pollination algorithm can obtain the optimum design. According to the great performance of flower pollination algorithm (FPA), Tahani et al. [17] proposed a novel hybrid algorithm by combining FPA and simulated annealing (SA) algorithms logics. In this hybrid algorithm the selection of the best solutions is being carried out by SA. This algorithm was utilized for optimization of a PV/Wind/Battery system. These algorithms are also being widely used in the field of wind engineering specially in wind turbine farms for obtaining the best positioning of turbines and also for optimal wind turbine selection [18,19]. But on the other hand there are few studies carried out using heuristics algorithm in the field of aerodynamic design of vertical axis wind turbines. For example, one of the studies which is carried out by Bedon et al. [15] is about optimization of VAWT using BEM theory and evolutionary algorithm. In this research study the pure performance and the annual energy production of the turbine are considered as the objective functions. Because of the stochastic behavior of wind energy, optimization of the wind turbine design is necessary. In this research study for the purpose of aerodynamic optimization of wind turbine four decision variables are considered as design parameters, which are chord and diameter of the turbine and also the airfoil type and number of blades. The first two variables are continues and the last two ones are discrete. Therefore