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Rotor Blade Performance Analysis with Blade Element Momentum Theory

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Abstract

In order to optimally explore and utilize wind energy, an optimal design of wind turbine propeller blades needs to be obtained. Therefore, a computational method to analyze and optimize the performance of the blades needs to be developed. For that purpose, a computational method based on the Blade Element Momentum (BEM) theory is developed in the present study. In this method, the propeller blade is divided into several elements and it is assumed that there is no aerodynamic interaction amongst the elements. Furthermore, the equations from momentum and blade element theories are combined to obtain equations which are useful in blades design process. In the analysis, tip and root losses proposed by Prandtl are also implemented. The computation results are validated using Qblade software. A good agreement can be found from comparison of the results computed from the developed BEM and QBlade.

Keywords: Blade element momentum; momentum theory; NACA2415 airfoil; QBlade; rotor design; wind turbine.

Nomenclature

a	axial induction factor	P	turbine power
a'	angular induction factor	T	thrust force
C_L	lift coefficient	V	wind speed
C_D	drag coefficients	ω	rotational speed
F	axial force	Ω	angular speed

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1. Introduction

Considering the importance of exploration and exploitation of renewable energy resources including wind energy in recent decade, a wind turbine with optimal blades performance needs to be developed. Therefore, for designing the wind turbine blades with optimal performance, various methods have been established and implemented by researchers and scientists to analyze and optimize the performance of the wind turbine blades. Choosing the appropriate method to be adopted in blades designing process depends on the level of required results accuracy.

In the present study, a computational method based on the Blade Element Momentum (BEM) theory is developed. The BEM method is known to able to provide a closed form solution with relatively simple procedures. The method was originally developed from momentum theory and blade element theory [1]. By combining both methods, useful relations to be used in propeller blades design can be obtained. From this original method, various modifications have been performed and corrections are included by several researchers such as Prandtl tip and root losses [1], 3D correction [2], Reynold number drag correction [3], etc.

When using the BEM method, the propeller blade is divided into several elements. It is assumed that each element is independent and the fluid flow over elements has no interaction. Moreover, the forces and moments are computed in each element so that total forces and moments are obtained by integrating the individual forces and moments on each element.

In order to demonstrate the computation procedures and validate the results of the BEM method developed in the present study, a propeller blade with NACA2415 airfoil shape, is chosen. Only tip and root losses proposed by Prandtl [1] which are implemented in the present study. The computation results from the developed BEM is validated using a software package called QBlade [4]. It is a free software based on GNU license which provides friendly interface for propeller design analysis and optimization processes based on the BEM method. It is found from the study that the results computed from the developed BEM method has a good agreement with the ones from QBlade software.

2. Solution Method

In the present study, the Blade Element Momentum (BEM) theory is adopted as the main computation method. The method is combination of momentum theory and blade element theory. The blade element theory sometimes is also called strip theory.

2.1. Momentum Theory

From momentum theory, when assuming that the blades could produce power without rotation, the axial force (F) can be obtained using the following equation [5]

$$dF = 4a(1-a)\rho_a V^2 \pi r dr \tag{1}$$

Where ρ_a is air density, V the wind velocity far downstream, r the distance of the element from hub and a the axial induction factor which could be written as

$$a = \frac{V - V_T}{V} \tag{2}$$

Where V_T is the wind velocity far upstream. When rotation is introduced in the model, the thrust (T) can be obtained using the following relation [5]