A Three Dimensional Numerical Method to Study Aerodynamic Performance of Horizontal Axis Wind Turbine

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ABSTRACT

It is significant to study the aerodynamic characteristics for operational capability of Horizontal Axis Wind Turbine (HAWT), as HAWT have been widely used in offshore wind energy exploitation in recent years.

A 3-D numerical method was developed for the aerodynamic performance of HAWT, which combined panel method with lift line method. Flow phenomena of different blade angles of attack were researched by different tip-speed ratio parts. A 3-D panel method based on the velocity potential was introduced when tip-speed ratio is high, and blade span flow and blade interaction were all considered. Numerical calculation based on lift line method was established for the case of low tip-speed ration, which pays more attention to aspect ratio and viscosity in the high blade angle of attack.

Numerical results of NREL PHASE VI wind turbine by use of the present method show good agreement with experimental results, especially for the prediction of the maximum output power of wind turbine. The method can be applied to optimize turbine configurations and characterize aerodynamic loads which act on the offshore wind turbine foundation.

KEY WORDS: HAWT; aerodynamic performance; 3-D numerical method; panel method; lift line method

INTRODUCTION

Energy is an essential ingredient of socio-economic development and economic growth. Renewable energy sources like wind energy is indigenous and can help in reducing the dependency on fossil fuels. Demand for energy is being devoted in the world to promote the use of renewable energies. Among them, wind energy has already attained a pre-eminent status, and it makes up for a non-negligible share of the energy output. HAWT was identified as having a key role to play in wind energy. Utilize of HAWT are closely related to the aerodynamic characteristics of blades profile. The accurate calculation of aerodynamic performance of HAWT is necessary. Firstly, the accurate prediction of aerodynamic performance can be used as the basis for blades design. Secondly, the calibration for strength, stiffness and stability of wind turbine blades requires aerodynamic performance as original input parameters.

Blade element method (BEM) is simple but widely used theory for the analysis of wind turbine. The code is compiled by Lissaman (1974) and different corrections are proposed largely. However, many assumptions are adopted by BEM, such as the steady flow and two-dimensional flow assumption, and so on. Therefore, BEM can only give relatively reasonable results for performance of wind turbines. Recently, with the advent of the supercomputer, CFD tools have been employed. Narramore and Wood (1991) used a full Navier-Stokes equation solver with an algebraic turbulence model to calculate the blades flowfields. Madsen contrasted results of CFD and BEM. CFD method has to take a lot of computer memory and time. The quality of mesh and turbulence model for wind turbine is not also deal with accurately. Vortex method is a classical method between BEM and CFD. Free wake model in which local velocity is moved freely is proposed by Crouse and Leishman (1993) for aerodynamic performance of HAWT. Wake is divided into two regions by Rosen in order to calculation is simply. Simoes and Graham (1992) put forward a simply model which is applicable for the both of attached and separate flow. Extend of primary wake were used by Parkinson and Jandali (1970) to account for the blades stall delay effect.

In the present work, tip-speed ratio is divided into two parts for predicting the aerodynamic blade load under steady wind conditions. At high tip-speed ratio, the blade angle of attack is small and wind turbine is under fully attached flow. Consequently, panel method can be established. It without any assumptions for blade shape, take into account the 3-D effects and blade interaction. Blade surface pressure distributions can be accurately calculated. At low tip-speed ratio, namely at high angle of attack, stall is a significant factor and panel method is not available. Lifting Line method and empirical model for stall are all introduced adequately.

ESTABLISHMENT OF THE COORDINATES OF WIND TURBINE

For HAWT, global coordinate system and local coordinate system are defined in figure 1. There is a global coordinate system Oxyz, which is fixed. x axis is along shaft axis, and pointing towards the tower. z axis