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Theoretical and experimental study on the aerodynamic characteristics of a horizontal axis wind turbine

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Abstract

The aerodynamic performance characteristics of a horizontal axis wind turbine (HAWT) were investigated theoretically by an analysis involving a combination of momentum, energy and blade element theory by means of the strip element method, and experimentally by the use of a subscale demonstration model. In this study, two approaches involving combination analysis are made use of, namely, the thrust–torque and the thrust–energy methods. Although both approaches yield identical results, the latter is superior for elucidating the relationship of the kinetic energy of the flows on the blades. Scale experiments are performed with three types of wing aerofoil involving different arrangements with the free stream velocity, $U_\infty = 0.8$–4.5 m/s, and for the open type of wind tunnel with an outlet duct diameter of 0.88 m. The experimental and theoretical characteristics of the HAWT using the different three types of the HAWT blades are discussed by reference to the power, torque and thrust coefficients, C_P, C_T, C_{th}, and the tip speed ratio λ from the point of view of variable pitch control and fixed pitch stall control methods for the output regulation. The aeronautical characteristics predicted by means of the present numerical approaches, for large units involving large power generation at high efficiency, are discussed, and it is clear how to obtain optimized design parameters that play a significant role in the overall performance.

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1. Introduction

The technology developed in the Western World during the Industrial Revolution 200 years ago allowed the great step forward towards a modern industrial society. For example, one can mention transport technology facilitated by heat engine developments and information technology facilitated by electronics innovations, leading to many useful products but also to industrial waste, and so there are both positive and negative aspects to this progress. Unfortunately, damage to energy resources and to world environments now threatens the natural resources on which mankind depends: clear air, clean water, a stable climate, and richness of resources and diversity of ecology. In particular, international consensus is directed toward lowering the increasing concentration of CO_2 in the atmosphere to avoid global warming.

A future life style that avoids the wasteful and damaging mass production systems of our modern industrial society should be based on ecological and recycle-oriented and renewable/sustainable energy supply systems.

Natural energy such as solar energy, wind power, biomass and others, involving little environmental pollution should be sustainable in the future, and should play an important role in modern advanced energy supply systems with zero emission. Hence, the construction of new power generation systems with no pollution load and high efficiency is of vital importance.

Wind power is predicted to have the greatest future prospects among the possibilities for renewable/sustainable energy. The leading conversion method for wind energy is the horizontal axis wind turbine (HAWT), which makes use of aerofoil propeller blades, implementing the theory of the airplane. Other several approaches to wind power conversion are also well known. For example, the Savonius rotor [1] making use of the Bernoulli dynamic pressure effect and the cross-flow rotor [2] making use of the momentum exchange effect.

The propeller type of HAWT presented here is expected to have superior characteristics [3–6] in comparison with the other types mentioned above, particularly with regard to operation with a high-efficiency conversion performance at high blade rotation rates owing to the wing aerofoil.

In this study [5], aerodynamic performance characteristics of the HAWT were investigated theoretically by combination analysis involving momentum, energy and blade element theory by means of the strip element method, and experimentally by the use of a subscale model. Three types of blades were examined under conditions in which the free stream velocity is varied from 0.8 to 4.5 m/s for the open-type wind tunnel with an outlet duct diameter of 0.88 m. The blades consist of a combination of tapered rectangular NACA44/LS04 aerofoil series blades and two-stage pitch angle tapered blades from the NACA44 series. The aeronautical characteristics of the HAWT employing the three different types of blades are discussed by reference to power and torque coefficients, C_P and C_q, and to the tip speed ratio λ, derived from the experimental and analytical results. The out put regulation by variable pitch control/fixed pitch stall control method is also discussed in this context.

Predicted results for the aeronautical characteristics of the HAWT for large power units are given, and it is shown how the optimization of design parameters plays a significant role.

2. Combination analysis of momentum, energy and blade element theory

The geometry of the stream tube model of the flow through the rotor of a wind turbine with additional consideration of wake flow rotation, expressed as V_T, is shown in Fig. 1 [3,4], in which