Global Science Research Journals

Global Journal of Agricultural Research and Reviews

Extended Abstract Open Access

Aerodynamic Optimization of Wind Turbine Blades and Wind Energy

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Abstract

Wind has been used as a source of power by human society centuries before the dawn of commercial revolution. Since the start of the economic age, the fossil fuels have dominated as a source of energy. Only in last couple of decade or so, because of concerns about global warming, there has been increased emphasis on using wind as a source of clean, renewable and sustainable energy source. This talk will describe the potential of wind as a crucial source of energy since it's available round the globe at sufficient velocities to get significant amount of power. It is well established that the facility generated by a Horizontal-Axis turbine (HAWT) may be a function of the amount of blades B, the tip speed ratio λ (blade tip speed/ wind free stream velocity) and therefore the lift to tug ratio (CL/CD) of the airfoil sections of the blade. The airfoil sections utilized in HAWT are generally thick airfoils like the S, DU, FX, Flat-back and NACA 6-series of airfoils. These airfoils vary in (CL / CD) for a given B and λ, and thus the facility generated by HAWT for various blade airfoil sections will vary. This lecture will show the effect of different airfoil sections on HAWT performance using the Blade Element Momentum (BEM) theory. The relatively thick airfoils DU 91-W2-250, FX 66-S196-V1, NACA 64421, and Flat-back series of airfoils (FB-3500-0050, FB3500-0875, and FB-3500-1750), both original and optimized, are considered and their performance is compared with S809 airfoil used in NREL Phase II and III wind turbines; the lift and drag coefficient data for these airfoils sections are available. The output power of the turbine is calculated using these airfoil section blades for a given B and λ and is compared with the first NREL phase II clinical trial and Phase III turbines using S809 air foil section. It is shown that by an appropriate choice of air foil section of HAWT blade, the facility generated by the turbine are often significantly increased. Calculations are presented both for uniform wind velocity and variable wind velocity by including the dynamic inflow. We also consider the wind farm layout optimization problem using a genetic algorithm. Both the Horizontal–Axis Wind Turbines (HAWT) and Vertical-Axis Wind Turbines (VAWT) of various sizes in diameter and height are considered. The goal of the optimization problem is to optimally position the turbines within the wind park such the wake effects are minimized, and therefore the power production is maximized. The reasonably accurate modelling of the turbine wake is critical in determination of the optimal layout of the turbines and therefore the power generated. For HAWT, two wake models are considered; both are found to offer similar answers. For VAWT, a really simple wake model is used. In addition, the technologies associated with windmill control are going to be briefly discussed. The issue of intermittency of wind generated power and its integration into the grid will be discussed. The environmental concerns and cost-effectiveness issues will also be addressed.

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Optimization studies are performed for the maximization of power production at a selected wind speed, rotor speed and rotor diameter. The potential flow solver with a physical phenomenon model, XFOIL, provides sectional aerodynamic loads. The sectional chord length, the sectional twist and therefore the blade profiles at root, mid and tip regions of the blade are taken as design variables. The blade sections may be defined by the NACA four digit airfoil series or by arbitrary airfoil profiles defined by a Bezier curve. The sectional flow computations required by Genetic algorithm, which is inherently parallel, are performed during a parallel computing environment with 512 cores. Message Passage Interface (openMPI), is employed in parallel computations. Validation studies are first performed.

Optimize the distribution of chord and twist angle of small turbine blade so as to maximise its Annual Energy Production (AEP). A horizontal-axis turbine (HAWT) blade is optimized employing a calculation code supported the Blade Element Momentum (BEM) theory. A difficult tasks within the implementation of the BEM theory is that the correct representation of the lift and drag coefficients at post-stall regime. In this research, the tactic supported the Viterna equations were used for extrapolating airfoil data into the post-stall regime and therefore the results were compared with various mathematical models. Results showed the high capability of this method to predict the performance of wind turbines. Evaluation of the efficiency of turbine blade designed with the proposed model shows that the optimum design parameters gave rise to a rise of 8.51% within the AEP rate as compared with the corresponding manufactured operating parameters The design model is based on an aerodynamic/aero-elastic code that includes the structural dynamics of the blades and the Blade Element Momentum (BEM) theory. To model the main aero-elastic behaviour of a real wind turbine, the code employs 11 basic degrees of freedom corresponding to 11 elastic structural equations. In the BEM theory, a refined tip loss correction model is used. The objective of the optimization model is to minimize the cost of energy which is calculated from the annual energy production and the cost of the rotor. The design variables used in the current study are the blade shape parameters, including chord, twist and relative thickness. To validate the implementation of the aerodynamic/aero-elastic model, the computed aerodynamic results are compared to experimental data for the experimental rotor used in the European Commision-sponsored project Model Experiments in Controlled Conditions, (MEXICO) and the computed aero-elastic results are examined against the FLEX code for flow past the Tjæreborg 2 MW rotor. To illustrate the optimization technique, three wind turbine rotors of different sizes (the MEXICO 25 kW experimental rotor, the Tjæreborg 2 MW rotor and the NREL 5 MW virtual rotor) are applied. The results show that the optimization model can reduce the cost of energy of the original rotors, especially for the investigated 2 MW and 5 MW rotors.

Biography

Ramesh Agawam has received his PhD from Stanford University in 1975 and Post-doctoral training at NASA Ames Research Centre in 1976. From 1976 to 1994, he was the Program Director and McDonnell Douglas Fellow at McDonnell Douglas Research Laboratories in St. Louis. From 1994 to 2001, he was the Sam Bloomfield Distinguished Professor and Executive Director of National Institute for Aviation Research at Wichita State University in Wichita, KS. He is currently the William Palm Professor of Engineering at Washington University in St. Louis. He is the author/co-author of nearly 250 archival papers and over 500 conference papers. He is on the editorial board of 20+ journals. He is a Fellow of 18 societies including AIAA, ASME, ASEE, SAE, IEEE, APS, and AAAS among others. He is the recipient of many honours and awards.

Keywords

Wind turbine blade, BEM theory, Annual Energy