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Investigation on the impact of design wind speed and control strategy on the performance of fixed-pitch variable-speed wind turbines

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Abstract. Wind turbine blade design optimization remains one of the fundamental research areas for modern wind turbine technology. The general design process for fixed-pitch variable-speed wind turbine blades assumes the rated wind speed as the design wind speed. However, for a fixed-pitch wind turbine with fixed rotor diameter and rated power at rated speed, we do not know the optimum design wind speed, which should be used for the calculation of the wind turbine blade parameters based on a particular aerofoil for a specific site with low annual mean wind speed.

This paper investigates the impact of design wind speed and control strategy on the performance of fixed-pitch wind turbines through a set of design case studies. The design wind speeds are considered at the more prevalent wind speeds than the rated wind speed. Three different control strategies are addressed, i.e. maximum power point tracking, mixture of variable-speed and fixed-speed, and over-speeding. Annual energy production, blade manufacturing cost, aerodynamic load performance and cost of energy are analyzed and compared using the design case studies. The results reveal a clear picture in determining the optimum design wind speed and control strategy for both maximizing annual energy production and minimizing cost of energy.

Key words

Design wind speed, blade design optimization, fixed-pitch, variable speed, wind turbine control.

1. Introduction

Wind energy is one of the most popular sources of renewable energy in today's society and is under rapid development. However, from every point of view, wind energy is not a mature industry sector, such as the automotive and aerospace industries. The most important aspects people care about are the wind turbine performance and the associated cost of energy (CoE).

Wind power is proportional to the cube of the wind speed that comes through the wind turbine rotor - higher wind speed means more power. For a fixed-pitch wind turbine, the power performance is determined dominantly by the wind turbine blade design, as expensive blade pitch control is omitted. In other words, the wind power conversion efficiency depends greatly on the blade geometry and parameters. Generally, the calculation of a fixed-pitch variable-speed wind turbine blade parameters is based on the rated wind speed at which the power output of the wind turbine generator reaches its rated power or nominated power output[1,2].

To maximize energy capture of fixed-pitch wind turbines, variable-speed operation is a good choice. Variable speed control generates 20 to 30% more energy than constant speed control. It also minimizes power oscillation and improves reactive power injection[3].

For a specifically rated power wind turbine, higher rated wind speed means smaller rotor diameter. However, for a fixed-pitch wind turbine with fixed rotor diameter and rated power, we basically do not know, what is the optimum design wind speed, which should be used for the calculation of the wind turbine blade parameters. And more, if a lower design wind speed is selected, what control strategy should be used to improve the turbine's performance. This paper will address these issues.

As a rule, rated wind speed is generally higher than the prevailing wind speed. With different optimum design methodologies available in the research domain, the authors argued that a lower design wind speed could perhaps generate more power for a fixed-pitch wind turbine with fixed rotor diameter and rated power, due to better power performance at prevailing wind speed.

Design wind speed based on a more prevalent wind speed than rated wind speed could make it possible for the wind turbine to operate at constant speed (rated speed) between design wind speed and the rated wind speed.

Alternatively, if the generator could accommodate over-speeding, say 10% above its rated speed, the wind turbine could even operate over-speeding with maximum power point tracking above design wind speed until the generator power