Maximizing wind-generated power using pitching angles and wind speed

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ABSTRACT

In 2021, the electric power generated from wind turbines is estimated to have increased to 380 billion kWh, which is about 9.2% of the total U.S. utility-scale electricity generation. It is currently the largest installed renewable energy technology, and about 17% of the planned utility-scale generating capacity additions for 2022 are wind-based. The primary reason for this growth is the need to utilize free energy resources that are also environmentally clean. Wind-generated power, however, is uncertain and varies from time to time and season to season. Dealing with such uncertainty requires the wind-based electrical generating system to adapt to changes in wind speed and direction, and to adjust its pitching angle in such a way that maximizes output power and efficiency. This study explores and experiments with the relationship between wind speed, pitching angle, and generated electrical power. The data collected during experimentation is used to train and evaluate supervised machine learning (ML) models to capture and approximate those relationships. The study utilizes a WINDLAB™ electrical generation system, a self-contained wind tunnel with various wind profiles. Many experiments using different pitching angles were carried out with the hope of training a predictive model that, given a wind speed, outputs a pitching angle that maximizes system efficiency and generated output power.

KEY WORDS: Wind-generated power, pitching angle, predictive models

INTRODUCTION

Wind energy has become one of the fastest growing sources of energy in the world. In 2021, wind power grew by 1.8% compared to the previous year, adding 93.6 GW to the global cumulative wind power capacity (Frangoul, 2022). The current wind power capacity (both onshore and offshore) is at 837 GW (Frangoul, 2022). Concerns regarding climate change have fueled great interest in the renewable energy sector. Countries are currently implementing initiatives to fight climate change and lessen its impacts by installing renewable energy facilities.

In 2021, the wind turbine market was valued at US $70.54 billions and is expected to grow to US $94.26 billion by 2026 (Global Wind Turbine Market Report, 2022). Such growth has led to more research interest in areas related to wind power prediction. For instance, blade and air flow molding have been used for power generation prediction. Many wind turbine blade settings and aerodynamic variables are useful tools to predict turbine performance (Miller et al, 2013). The Blade Element Momentum (BEM) theory has been used to study the performance of a HAWT (Horizontal Axis Wind Turbine) continuously operating at its maximum power coefficient and has shown that there is an optimum rotational velocity of the turbine rotor at a given wind speed (Lanzafame, 2010).

Numerical simulations and experiments were conducted on HAWT wind turbines with untwisted blades to assess the optimal attacking angle by varying the pitching angles and wind speeds. The generated power reached its optimal at 4.12°, 5.28°, 6.66° and 8.76° for the wind speeds of 7.2, 8.0, 9.0 and 10.5 m/s, respectively (Chalothorn, 2009). Computational fluid dynamics (CFD) has been used to study the aerodynamic characteristics of small-sized wind turbines with regulated wind speed between 7 and 25 m/s with only fixed 5-degree increments of pitch angle (Jang-Oh, 2012).

A study carried out by Sudhamshu et al (2016) using CFD fluid simulation investigated the effect of pitching angle on the HAWT turbine performance and found a correlation between the pitch angle and power generated. They found that there was a maximum power generated at an optimal pitch angle for a given wind speed. This work demonstrated that the wind turbine experienced structural fatigue when generating power at high speeds. To address this problem, a convex optimization was used to find the optimal turbine pitching angle (Biegel, 2011). Another study compared the forces produced by wind speeds to rotate the turbine blades at different pitching angles so as to find the ideal angle (Langlang, 2020).

The difficulty of interaction between the variables that govern the wind turbine operation such as pitching angle, attaching angle, rotor speed, and rated power has led to the exploration of the usefulness of neural networks and other machine learning models to address wind turbines control problems (Sierra-García, 2020). More studies have addressed the impact of pitching angle and wind speed on the performance of the wind turbine. Pitch angles change the blades of a wind turbine to harvest a proper fraction of the available wind and obtain optimal power