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COMPUTATIONAL PHYSICS

AI CONTROLLED WIND TURBINE

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INTRODUCTION

Domain overview

Wind energy is a cornerstone of modern renewable energy solutions, offering a sustainable alternative to fossil fuels. Wind turbines harness the kinetic energy of the wind and convert it into electrical energy, contributing significantly to reducing carbon emissions. However, the efficiency of wind turbines depends on various factors, including wind speed, direction, and the alignment of turbine components such as blade angles and yaw. Efficient operation is crucial for maximizing power output and ensuring the longevity of the mechanical systems involved.

This project aims to address the challenge of optimizing wind turbine performance using artificial intelligence (AI). By analyzing historical data on wind speed and direction from 2018, the project will develop a predictive AI model capable of determining the optimal blade angles required to maximize power generation for the next year. Unlike traditional methods that focus solely on maximizing energy output, this project introduces an innovative approach by incorporating considerations for wear and tear. Frequent mechanical adjustments can lead to significant maintenance costs and reduced turbine lifespan. The proposed model seeks to strike a balance between energy efficiency and mechanical durability, addressing a critical research gap in the field of wind energy optimization.

LITERATURE REVIEW

S.NO	YEAR	TITLE	AUTHOR	KEY CONTRIBUTIONS
1.	2015	Advanced pitch angle control based on fuzzy logic for variable-speed wind turbine systems	T. L. Van, T. H. Nguyen, and D.-C. Lee	Demonstrated fuzzy logic-based pitch angle control for variable-speed turbines; we adopted this approach for dynamic blade angle optimization.
2.	2020	Change in wind turbine performance is predicted based on wear and tear of blades	S. Mandel	Highlighted the impact of blade wear on performance; we integrated wear metrics into our model for durability-focused adjustments
3.	2021	Deep learning and fuzzy logic to implement a hybrid wind turbine pitch control	J. E. Sierra-Garcia and M. Santos	Developed a hybrid deep learning and fuzzy logic system for pitch control; we applied fuzzy logic for multiparameter blade control.
4.	2010	Vertical axis wind turbine with continuous blade angle adjustment	S. B. Weiss	Proposed continuous blade angle adjustments for adaptability; we used this principle for dynamic angle adjustments with servo motors.

RESEARCH GAPS

- [1] Limited Real-Time Adaptive Mechanisms
  Existing wind turbine systems often employ static or semi-adaptive algorithms for blade angle adjustment, which may not effectively respond to real-time fluctuations in wind conditions. The study "Advanced Pitch Angle Control Based on Fuzzy Logic for Variable Speed Wind Turbine Systems" discusses the application of fuzzy logic to enhance adaptive control mechanisms in wind turbines

- [2] Integration of Wear and Tear Metrics
  While predictive maintenance models are prevalent, integrating wear-and-tear indices into real-time blade angle control remains underexplored. The article "Change in Wind Turbine Performance is Predicted Based on Wear and Tear" examines the impact of blade damage on turbine productivity, highlighting the need for real-time integration of wear metrics.

- [3] Fuzzy Logic Systems for Multi-Parameter Control
  Many studies focus on single-parameter optimization. However, fuzzy logic offers a unique approach to handling multiple parameters. The paper "Deep Learning and Fuzzy Logic to Implement a Hybrid Wind Turbine Pitch Control" explores the integration of fuzzy logic with other control strategies to manage various operational parameters.

- [4] Practical Implementation on Embedded Systems
  Implementing fuzzy logic on resource-constrained embedded systems like Arduino is not well-documented. The study "Vertical Axis Wind Turbine with Continuous Blade Angle Adjustment" provides insights into the challenges and considerations of implementing blade angle adjustments on embedded platforms.

PROBLEM STATEMENT

The efficiency and longevity of Wind turbines has been a concern for a long period of time, leading to huge operational cost and Manual labor. There is a need for a smart, prediction model system that optimizes turbine blade angles to balance power generation, reduce wear and tear and improve the overall durability of wind turbines under varying wind conditions.

OBJECTIVES

1. Data Collection and Preprocessing
2. Develop Predictive AI Model
3. Optimize Power Generation
4. Incorporate Wear and Tear Considerations
5. Simulation and Testing
6. Model Evaluation and Optimization

METHODOLOGY

Hardware

- Wind Turbine prototype
- Servo motors
- Microcontroller

Data Collection

The project uses a historical dataset containing wind turbine performance metrics, including:

- Wind Speed
- Blade Angle
- Power Output (PPP)
- Operational Stress

Feature Engineering

- Blade Angle Change Rate (**Δθ**)
- Wind Speed Fluctuations (**Δ*Vw***)
- Operational Stress

AI Model Development

A regression model is chosen
Algorithms Used:
Random Forest, Gradient Boosting, and Support Vector Regression (SVR)

Training the Model

The historical dataset of 2018 available in the is split into the training or testing sets.
Model evaluation -
K- fold Cross-Validation
Metrics - MAE, MSE

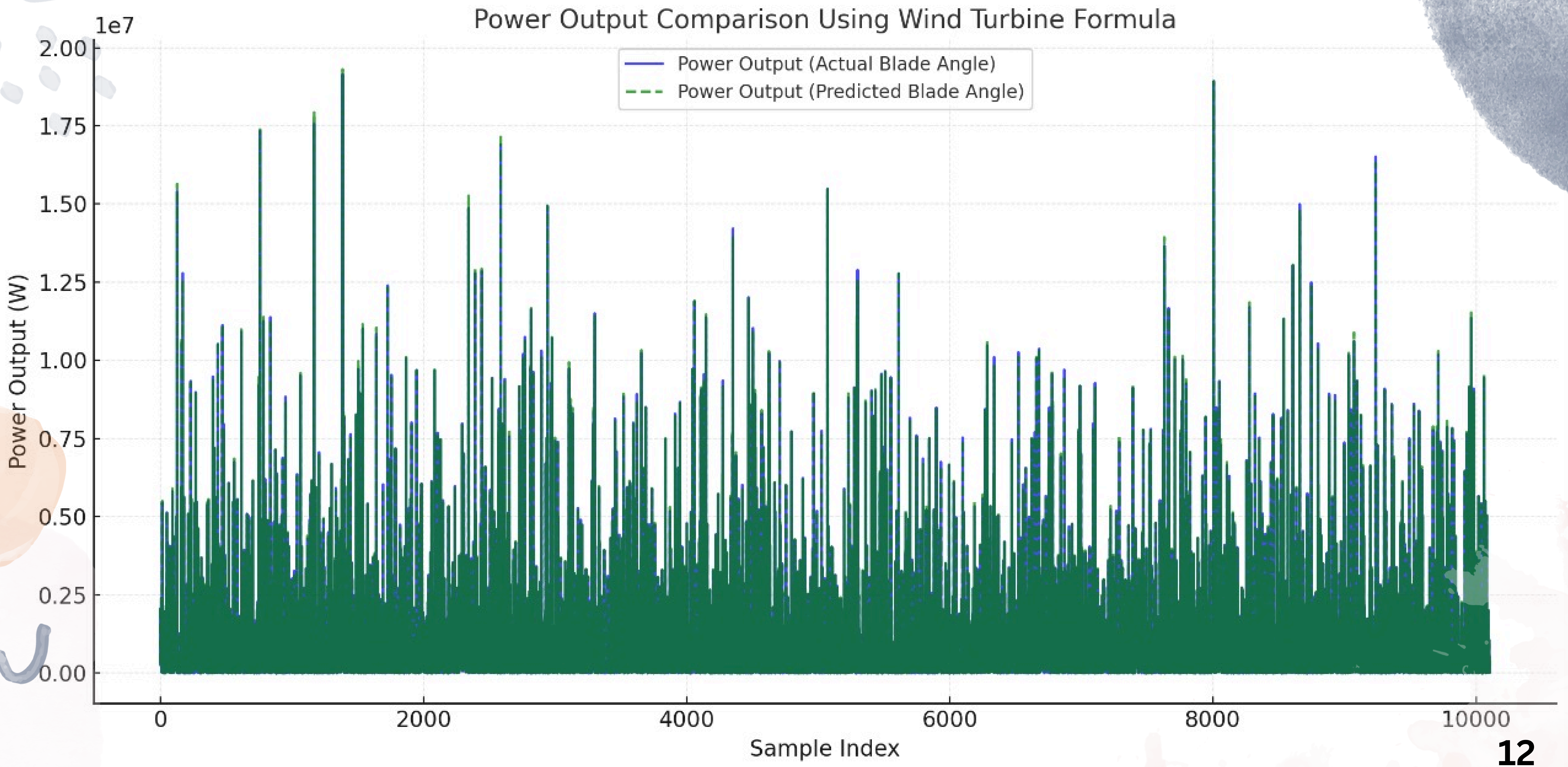
Blade Angle Prediction

- Feature Inputs
- AI Output
- Wear and Tear Prediction

Methodology for Optimization

Predicting Blade Angle Adjustments

Power Output Maximization


Power Output Comparison Using Wind Turbine Formula
1e7
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Power Output (Actual Blade Angle)
Power Output (Predicted Blade Angle)
Power Output (W)
0
2000
4000
6000
8000
10000
Sample Index


PRINGLES
ORIGINAL


PRINGLES
ORIGINAL

RESULTS

01

MAE (Mean Absolute Error)

This value tells you how far, on average, your predicted blade angles were from the true values A lower MAE would indicate that the model's predictions are generally closer to the true values, which means the model is doing well in estimating the optimal blade angle.

02

MSE (Mean Squared Error):

This metric indicates how much squared error your predictions have.

A lower MSE means fewer large errors, but MSE is sensitive to large deviations, so even a single large error can increase the MSE significantly.

03

Numerical Results

The Random Forest prediction model that we have used give the following report:

- Mean Absolute Error (MAE): 0.4145
- Mean Squared Error (MSE): 0.2694
- R2Score: 0.9575

CONCLUSION

1. Dataset and Variables Used: You used a dataset containing several key variables like wind speed, blade angles, wind direction, and theoretical power curve. The primary goal was to predict the optimal blade angle to maximize power output and reduce wear and tear. Wind Speed (m/s), Proxy Blade Angle, and Operational Stress (represented by LV Active Power (kW)) were the key features used to make predictions.

2. Model Development: We chose fuzzy logic algorithm for the following aspects:

- Wind speed fluctuation
- Blade Angle Change Rate
- Operational Stress

Based on these inputs, we derived a Wear and Tear Index (WTI), which is used to adjust the blade angle to either increase or decrease the blade angle depending on the wear.
The fuzzy logic system generated rules such as: If wind speed fluctuation and blade angle change rate are high, then the wear and tear index is also high, indicating the need for a lower blade angle. If both parameters are low, the wear and tear index is low, suggesting an optimal or higher blade angle.

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THANK YOU