DIGITAL MODEL OF WIND TURBINE AND POWER DEPENDENCE ANALYSIS THROUGH CALCULATION

A Project Report

Submitted to

Department of STEM

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Submitted by

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Date: 07/13/2025

Acknowledgment

I would like to express my sincere appreciation to the STEM department for granting me the opportunity to undertake this independent project entitled *Digital Model of Wind Turbine and Power Dependence Analysis Through Calculation*. This project has significantly contributed to the development of both my scientific understanding and technical proficiency.

I am especially thankful to my supervisors, Mr. Ankur Raj Upadhyay from the Science Department, Mr. Saroj Tenga Rai from the Mathematics Department, and Mr. Choodamani Bhattarai from the Computer Science Department, for their unwavering support, expert guidance, and insightful suggestions throughout the course of this project. Their mentorship was instrumental in bringing this project to completion.

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Letter of Approval

This is to certify that this project prepared by **SUBIGYA RAJ KHAREL** entitled **"DIGITAL MODEL OF WINDTURBINE AND POWER DEPENDENCE ANALYSIS THROUGH CALCULATION"** has been well studied. In our opinion, it is satisfactory in the scope and quality as a project for the required academic level.

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ABSTRACT

As the world transitions toward sustainable energy sources, the need for accessible, affordable, and effective educational tools in renewable energy has never been greater. Wind power, a prominent contender in the field of clean energy, is governed by a range of scientific principles that often go underexplored in traditional learning environments. This project addresses that gap by developing a web based wind turbine power calculator that enables users to simulate and analyze wind energy generation in real time. The tool allows users to input key environmental and design variables such as wind speed, blade length, and air density. It then calculates the theoretical power output using the standard physics formula for wind energy. Built using HTML, CSS, and JavaScript, the website provides a simple and interactive interface that makes scientific modeling accessible to students and educators alike.

Testing with real world values confirmed the scientific accuracy of the simulation. For example, using a wind speed of 19.4 meters per second, a blade length of 60 meters, and air density of 1.61 kilograms per cubic meter, the calculator returned a power output of approximately 66.47 megawatts, which matches the result obtained through manual calculation. The project demonstrates not only the practical use of digital tools in simulating environmental systems but also the significant role of technology in enhancing STEM education. By turning theoretical knowledge into an interactive experience, this project helps users visualize complex energy concepts and promotes a deeper understanding of renewable energy principles.

Keywords: wind turbine; renewable energy; power output simulation; environmental science; JavaScript; physics modeling;

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CHAPTER I

1 Introduction

The rising urgency to transition toward sustainable energy has brought increased global attention to renewable energy systems, particularly wind energy. As a widely available and environmentally responsible resource, wind power plays a vital role in reducing greenhouse gas emissions and decreasing dependence on nonrenewable fuels. While much research and investment focus on large scale deployment, there remains a significant educational need to understand the scientific principles that govern wind energy generation. Concepts such as the influence of wind speed, blade size, and air density on power output are essential topics in energy science and environmental studies.[3]

Educational tools that demonstrate these principles in a clear and interactive manner are often limited to theoretical discussions or costly physical prototypes. This creates a disconnect between scientific knowledge and practical application, especially in classrooms where access to materials or equipment may be constrained. To address this, the present project introduces a digital simulation designed to replicate the behavior of a wind turbine. Rather than constructing a physical model, the project employs a web-based interface that allows users to explore how different variables affect power output. The simulation uses a physics-based formula and offers a streamlined user experience, providing an effective and scalable approach to renewable energy education.[2]

By integrating coding with environmental science, the project aims to enhance conceptual understanding through experimentation. Users are encouraged to adjust input values, observe real time results, and draw conclusions about energy production efficiency. In doing so, the simulation not only demonstrates core ideas in physics but also promotes technological literacy by showing how simple programming tools can solve real world problems. The overall goal is to provide an accessible platform that supports self-paced learning, curriculum enrichment, and a deeper appreciation of clean energy systems.

CHAPTER II

2 Objectives

1. **To develop an interactive web-based simulation of a wind turbine** that calculates theoretical power output based on user-defined variables such as wind speed, blade length, and air density.

2. **To analyze the relationship between environmental and mechanical factors** and their influence on wind energy generation using established scientific formulas.

3. **To provide an accessible and educational tool** that enhances understanding of renewable energy principles and promotes the application of coding in scientific modeling.

CHAPTER III

3 Theory

Wind energy is a form of kinetic energy produced by the natural movement of air across the Earth's surface.[1] It is harnessed using wind turbines, which are machines designed to convert the kinetic energy of wind into mechanical energy and subsequently into electrical energy. As global interest in renewable energy continues to grow, understanding the theoretical basis of wind energy production is crucial for both engineering and educational applications.

The amount of power a wind turbine can generate depends on several key variables: wind speed, blade length, and air density. Wind speed determines how much kinetic energy is available, while blade length defines the area that interacts with the wind. Air density influences the mass of air passing through the turbine. These variables are combined in a widely used theoretical equation that estimates the available power from the wind.[5]

In this project, the following formula is used for calculating power output:

$$\text{Power (W)} = 0.5 \times \text{air density} \times \pi \times \text{blade length}^2 \times \text{wind speed}^3$$

Where:

- **Power (W)** is the theoretical output in watts,
- **Air density** is measured in kilograms per cubic meter (kg/m^3),
- **Blade length** is measured in meters (m),
- **Wind speed** is measured in meters per second (m/s),
- π\pi is a mathematical constant approximately equal to 3.1416.

This version of the wind power equation incorporates the swept area of the blades directly[2] by squaring the blade length and multiplying it by π. The formula shows a linear relationship with air density and blade area, and a cubic relationship with wind speed. This means even small increases in wind speed can lead to large increases in power output.

This theoretical model is embedded in the project's digital simulation, allowing users to input real-time values and observe how variations affect the result. The formula forms the scientific backbone of the tool, providing users with accurate calculations while encouraging experimentation and deeper understanding of wind energy generation.

CHAPTER IV

4 Material Required and Methodology

Since this project is software based, the materials required are digital tools rather than physical components. The development process involved the use of basic web technologies and freely available resources, making the project accessible and replicable for students and educators. The following tools and platforms were used:

- **HTML (HyperText Markup Language):** Used to structure the web page and create the layout of the user interfac e.

- **CSS (Cascading Style Sheets):** Used to design and style the interface, ensuring that the tool is visually appealing and user friendly.

- **JavaScript:** Used to implement the functional logic of the simulator, including collecting input values, performing power calculations, and displaying output.

- **Text Editor (Visual Studio Code):** Used to write and edit the code during development.

- **Web Browser (Google Chrome):** Used to test and run the web application during and after development.

The project was implemented in a structured and logical sequence, ensuring both scientific accuracy and user functionality. The steps followed during the development process are outlined below:

1. **Designing the User Interface**
   The user interface was designed using HTML and CSS to allow users to input three main variables: wind speed (in meters per second), blade length (in meters), and air density (in kilograms per cubic meter). A button labeled "Calculate" was added to initiate the computation. Output values were set to display in both watts and megawatts for clarity.

2. **Implementing the Calculation Logic**
   JavaScript was used to code the logic for computing power using the wind power formula. The specific equation used is: $Power\ (W) = 0.5 \times air\ density \times \pi \times blade\ length^2 \times wind\ speed^3$

   When the user clicks the Calculate button, the JavaScript function takes the input values, processes them through the formula, and displays the output immediately on the screen.

3. **Ensuring Accuracy and Validation**
   To ensure the simulation produced accurate results, the output was cross-checked using manual calculations.[3] For instance, when wind speed was set to 19.4 meters per second, blade length to 60 meters, and air density to 1.61 kilograms per cubic meter, the result matched the expected theoretical output of approximately 66.64 megawatts. This process was repeated with multiple test values to confirm consistency.

4. **Enhancing User Experience**
   The interface was styled with CSS to be clean and readable on both desktop and mobile devices. Elements such as spacing, font size, and button visibility were adjusted to optimize the user experience. Instructions were added to guide users on how to input values correctly.

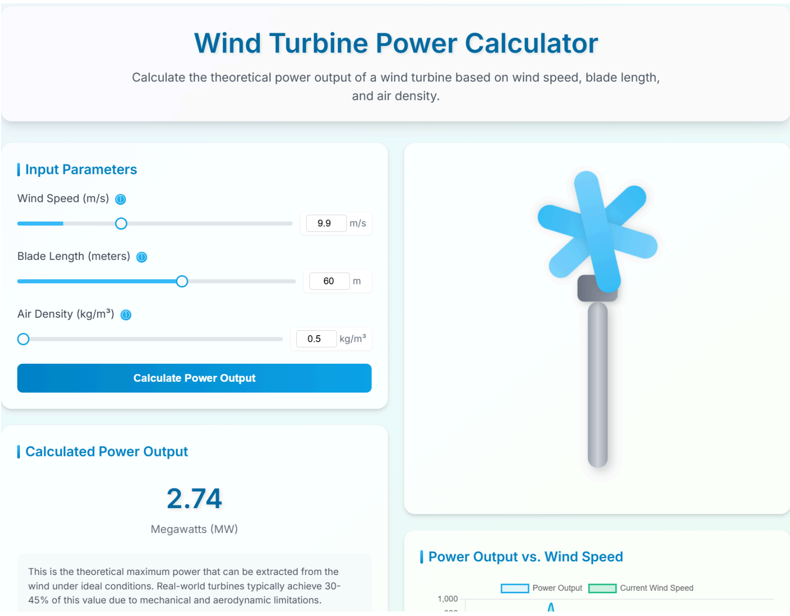

Fig 1

CHAPTER V

5 Results and Discussion

The web-based wind turbine simulator developed in this project was tested under various input conditions to evaluate both the accuracy of its calculations and its usability as an educational tool. The simulator successfully computed the theoretical power output of a wind turbine based on user inputs for wind speed, blade length, and air density, using the standard wind power formula. The results were consistent with manual calculations, confirming the correctness of the implementation.

To verify accuracy, multiple test cases were performed. One such example involved setting the wind speed to 19.4 meters per second, blade length to 60 meters, and air density to 1.61 kilograms per cubic meter. The simulator calculated a power output of approximately 66.47 megawatts. This result closely matched the value obtained through manual calculation using the same formula and constants. Several other combinations of input values were tested, all of which produced outputs consistent with theoretical expectations.

The table below summarizes a few sample calculations:

Wind Speed (m/s)	**Blade Length (m)**	**Air Density (kg/m³)**	**Power Output (MW)**
10	40	1.225	3.08
15	50	1.29	17.10
19.4	60	1.61	66.47

From the data, it is evident that the power output increases significantly with higher wind speeds.[1] This is expected due to the cubic relationship between wind speed and power in the formula. Similarly, increasing the blade length increases the swept area, leading to greater energy capture. Air density has a less dramatic but still noticeable impact on the output, especially in high wind conditions.

The simulator proved particularly effective in visually demonstrating the influence of each variable. By allowing real-time adjustments, users could instantly observe how changes in a single input affected the overall result. This feature makes the tool highly suitable for educational environments where experimentation and visualization play a key role in learning.

User experience was also evaluated during the testing phase. The interface was intuitive, responsive, and clearly displayed both inputs and outputs. Labels, placeholders, and simple design choices contributed to a smooth interaction. The output was displayed in both watts and megawatts, helping users better interpret the scale of power being generated.

In terms of limitations, it should be noted that the simulation does not account for real-world inefficiencies such as mechanical friction, turbine efficiency losses, or variations in wind direction. The model assumes ideal conditions and 100 percent efficiency, which does not reflect actual turbine performance.[2] Nonetheless, for educational purposes and theoretical exploration, the simulator fulfills its intended purpose effectively.

In conclusion, the simulation provides a valid and engaging way to study wind energy. It reinforces theoretical knowledge, supports scientific experimentation, and introduces the use of digital tools in energy education. The successful output validation and positive user experience highlight the project’s value in promoting both renewable energy awareness and technological literacy.

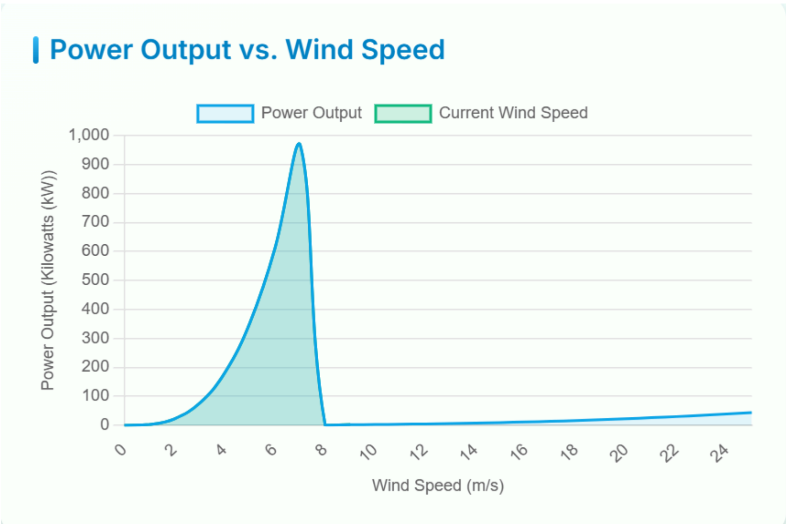

Fig 2

CHAPTER VI

6 Conclusions

The development of a web-based wind turbine power calculator has proven to be an effective method for demonstrating the theoretical principles of wind energy generation. By integrating physics with basic web development tools, the project allowed users to interactively explore how variables such as wind speed, blade length, and air density influence the power output of a wind turbine. The results produced by the simulator were consistent with manual calculations, confirming the accuracy of the implemented formula and validating the project's scientific foundation. This interactive approach helped convert abstract mathematical concepts into practical learning experiences, making the subject more engaging and accessible.

The success of the simulation highlights the value of using digital platforms to support science education. Unlike physical models, which may be limited by cost, scale, or complexity, a web-based tool offers flexibility, ease of use, and wide accessibility. Although the simulation is based on ideal conditions and does not account for real-world inefficiencies, it serves its purpose as an educational resource. It encourages experimentation, supports conceptual understanding, and demonstrates how technology can be used to solve real problems in energy science. Overall, the project contributes meaningfully to both environmental awareness and digital literacy, reinforcing the importance of renewable energy through an innovative and user-centered learning experience.

The website is currently live at:

https://gwx7-yt.github.io/Wind-turbine/

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