Design and Optimization of a Hybrid Vertical Axis Wind Turbine with Solar Panel System

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Abstract — Our nation's growing energy demands lead to frequent power outages in rural areas. This is due to both high-power consumption by factories and the limited availability of non-renewable energy sources. Adopting a hybrid renewable energy system for electricity generation is a well-known, quick, reliable, and cost-effective solution for rural households. A solar-wind energy combination can significantly reduce electricity dependency in remote areas. However, wind speed fluctuates between day and night, impacting the horizontal axis wind turbine's output. To address this, a vertical axis wind turbine with a C-type blade has been introduced to generate power at low wind speeds. By integrating the C-type blade wind turbine with solar photovoltaic, a hybrid system has been developed.

Keywords: Design, Fabrication, Solar Wind Turbine, Hybrid Renewable Energy

I. INTRODUCTION

Developing an aero leaf wind turbine utilizing Vertical Axis Wind Turbines (VAWT) to convert wind into usable electricity. According to Arab News, Saudi Arabia's energy demand is significantly higher than the global average, with Saudis consuming three times more electricity per person than the global norm. This high demand highlights the need to explore alternative energy sources. Renewable energy, such as solar, wind, and hydropower, aligns with the principles of sustainability. Unlike solar energy, which is limited to daylight hours, wind turbines can generate power continuously throughout the year. Efficient and eco-friendly utilization of this renewable resource supports sustainability, reducing environmental threats and enhancing the health and lifestyle of Saudi Arabian communities. Major energy consumers such as streets, parks, schools, and public buildings frequently experience wind exposure. This project aims to harness this wind using Vertical Axis Wind Turbines (VAWT) to generate useful electricity, serving these essential consumers.

A. Wind Turbine

A fixed-ratio gearbox connects the wind turbines rotor to the generator shaft, requiring the turbine to operate at a constant speed. While variable generator rotor resistance can be utilized, modern high-power wind turbines in the 2–10 MW range predominantly use variable-speed operation with blade pitch angle adjustment, managed through power electronic equipment. These wind turbines are primarily designed using either a doubly-fed induction generator (DFIG) system, which includes a DFIG with a partial-scale power converter linked to the rotor windings, or a direct-in-line system, which employs a direct-driven (gearbox-free) PMSG connected to the grid via a full-scale power converter.

The most commonly used wind turbine designs fall into four categories based on these concepts, as discussed below. The topology illustrated in Fig. 1.1 represents a wind turbine with constant or fixed-speed control using an asynchronous squirrel cage induction generator (SCIG) directly connected to the electrical grid through a step-up power transformer.

This setup requires a reactive power compensator, such as a capacitor bank, as the squirrel cage induction generator continuously draws reactive power from the AC network. By utilizing capacitor banks (typically in 5–25 steps) to match the active power output, the reactive power demand on the grid can be significantly reduced or even eliminated. Additionally, a soft starter ensures a smooth grid connection.

In fixed-speed machines, wind fluctuations lead to mechanical variations, which in turn result in electrical power fluctuations, regardless of the power control strategy. In weak networks, these fluctuations can cause voltage instability at the wind turbine's point of common coupling (PCC) with the grid. Without a capacitor bank, these voltage fluctuations force the fixed-speed wind turbine to draw varying reactive power from the utility grid, increasing both voltage instability and line losses.

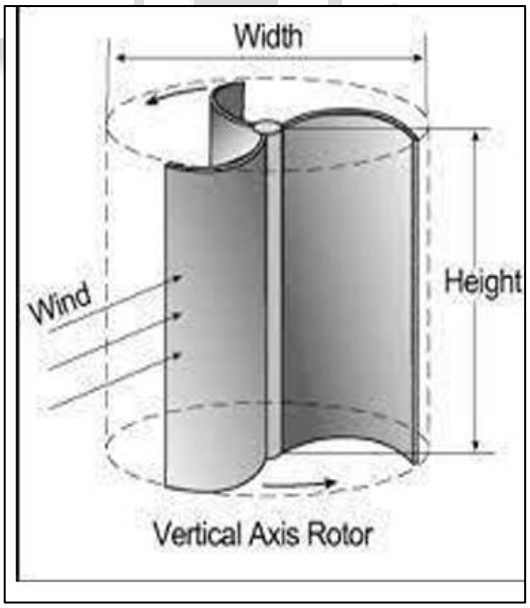

Fig. 1: Wind Turbine

B. Solar Panel

A solar panel consists of electrically connected solar photovoltaic modules mounted on a base. A photovoltaic module is a bundled assembly of solar cells designed to generate electricity. Solar panels supply power for residential and commercial applications as part of a larger photovoltaic system. The power output of each module, typically ranging

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from 100 to 320 watts, is determined under standard test conditions (STC) based on its DC output. The physical size of a module with the same rated output varies depending on efficiency; for instance, a 16% efficient 230-watt module occupies half the area of an 8% efficient 230-watt module.

Since a single solar module has a limited power output, most installations utilize multiple modules. A complete photovoltaic system includes a panel or array of solar modules, an inverter, and, in some cases, a battery, a solar tracker, and connector cables.

Fig. 2: Solar Panel

II. Literature Review

A. Experimental Design and Fabrication of Portable Hybrid Wind and Solar Energy System

A 5 KW freestanding hybrid wind and solar power system was designed, manufactured, and ground-tested in this study. This portable unit measures 8 feet, 5 inches in width, 8 feet, 4 inches in depth, and 38 feet in height. It consists of four 120-watt solar panels, a 1.5 KW wind turbine, a solar charge controller, remote power storage, a battery, and battery control. The hybrid system operates independently without requiring a grid connection. The study presents the system's description, characterization, and photovoltaic data collected in April (Mangalore). This hybrid device enhances solar panel efficiency while maintaining a simple construction approach. The hybrid energy tower integrates solar panels and vertical wind turbines, capturing energy from both sources. Positioned on roadways between barriers and vehicles, the system benefits from airflow generated by moving cars. The solar panel directs this airflow toward the turbine, while gear systems and generators convert the energy into electricity, offering a portable solution to energy challenges [1].

B. Design and Fabrication of Wind and Solar Hybrid Power Plant

Wind turbines operate at a maximum theoretical efficiency of 59% (Ref: Betz's Law). Due to the need for large turbine separations caused by rotor wake formations, conventional wind power generation requires reevaluation. One innovative approach is the VAWT with a vortex turbine, which enhances turbine performance by introducing a secondary vortex using vortex generators. This study involves designing a vortex chamber using Unigraphics, developing a scaled functional model with three-dimensional modeling to demonstrate energy generation, and testing the impact of wind speed on turbine speed, voltage, current, and power output [2].

C. Design and Fabrication of Transportable Hybrid Solar and Wind Energy System

A 7 KW freestanding solar and wind hybrid system has been designed, built, and field-tested. This transportable system, when folded, measures 7 feet, 3 inches by 7 feet, 3 inches by 34 feet. Its components include sixteen 280-watt solar panels, a 2.4 KW wind turbine, a charge controller, an inverter, remote power management, control, and monitoring capabilities, along with a 72 kWh battery storage system. This hybrid setup functions without a grid and is applicable in remote areas, including space applications. The study provides a system description, technical details, and photovoltaic data collected on February 7, 2015. The implementation of this technique contributes to improving solar panel efficiency [3].

D. Design and Fabrication of a Hybrid Solar & Micro Wind Power Generator

This study focuses on constructing a micro hybrid system that concurrently utilizes solar and wind energy. Electricity is a fundamental necessity, yet the availability of conventional energy sources is declining. A transition to renewable energy is crucial. This research combines solar and wind energy in a hybrid system, detailing its design and fabrication. Both micro wind turbines and solar PV cells offer great potential. The hybrid system, designed without a gearbox, generates electricity efficiently, is easy to install, and requires minimal maintenance. It is capable of producing up to 40 W of power. The system includes ten 3.2 W solar PV cells and 24 horizontal-axis wind turbines arranged in a vertical plane for maximum power generation. The study evaluates various design parameters and discusses factors affecting the efficiency of solar PV cells and micro wind turbines.

E. Design and Fabrication of Maglev Wind Turbine

Maglev wind turbines present an alternative to conventional wind turbines by eliminating the need for tall towers and large blades. Estimates suggest that renewable energy sources could account for 20% to 50% of total energy consumption in the late 21st century. Maglev wind turbines offer several advantages over traditional models. They can operate at wind speeds as low as 1.5 m/s and withstand gusts exceeding 40 m/s. The largest existing conventional wind turbines produce only 5 MW, whereas a large maglev wind turbine has the potential to generate 1 GW, sufficient to power 750,000 homes. This study systematically examines the design and fabrication processes of Vertical Axis Maglev Wind Turbines

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while incorporating solar panels to harness solar energy efficiently.

III. Problem Identification

The main drawback of wind turbines with horizontal plates is their lower energy efficiency due to moderate rotational speed. To capture more wind energy, the horizontal plate must keep rotating.

- When used independently, solar energy has a low power output.
- The energy generated by renewable sources is often not compatible with most devices.
- Many devices consume more energy than what wind and solar power can generate.

IV. Objectives

- Efficient power generation even in low-wind conditions, ensuring emergency off-grid power for communities.
- Helps homeowners save money while providing a reliable energy source.
- Simple installation and wiring process.
- Versatile tower top interface suitable for various tower types.

V. Proposed Model

A digital mockup (DMU) is designed based on available components and standard dimensions in the market. This allows for optimal packaging assessment using DMU technology. Our expertise in production-ready development ensures precise component positioning, including geometric adaptation and accurate placement. This guarantees a seamless transition to production. Utilizing 3D software in design provides an efficient industry approach for machine development.

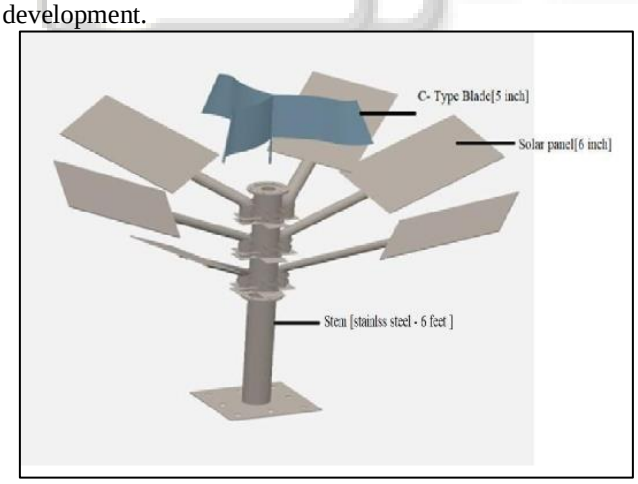

Fig. 3: Design of a Solar Wind Turbine

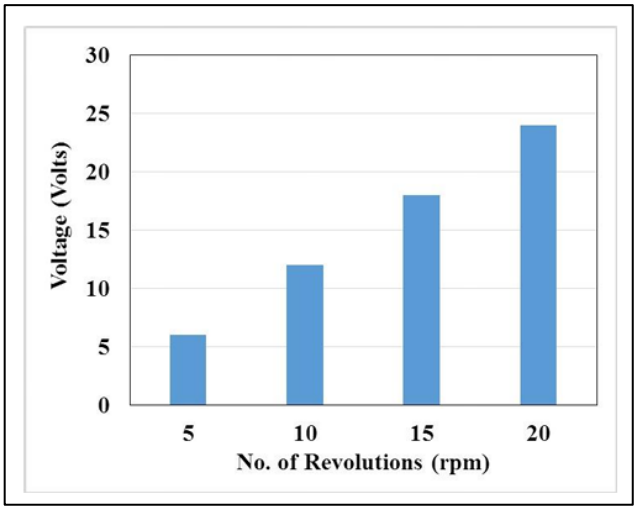

Fig. 4: Turbine Revolution Graph

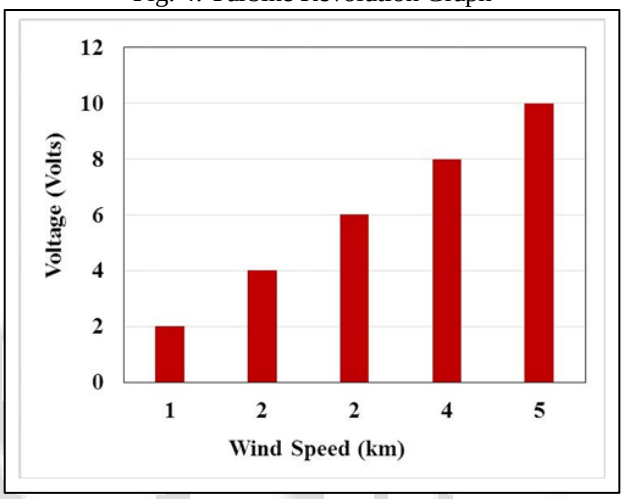

Fig. 5: Wind Speed Graph

VI. Conclusion

Through this study, we reached key conclusions and recommendations that will contribute to the advancement of standalone vertical axis wind turbines. Compared to previous designs, we successfully developed a Vertical Axis Wind Turbine framework that enhances power output. Our collected data allowed us to introduce new design elements aimed at improving efficiency. A minimum wind speed of 12 m/s is required to achieve a satisfactory power output, considering a 31–35% efficiency gap between theoretical and experimental results. Insufficient wind speed greatly affected power generation.

Although we successfully designed a vertical axis wind turbine integrated with a solar panel, there is always potential for further improvements. By shifting away from polluting energy sources, society can mitigate environmental damage through the installation of wind turbines. This project aims to support further research and experimentation on Vertical Axis Wind Turbines (VAWT) with solar panels, providing valuable insights for future studies to enhance their efficiency and overall performance.

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