Exploring the Vertical Axis Wind Turbines Generation in Puerto Rico for Emergency Use

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***Abstract*—The Caribbean region is frequently affected by severe storms and hurricanes, which expose the vulnerability of the electrical power systems across several countries. Puerto Rico has experienced recurring power outages, particularly since the landfall of Hurricane Maria in 2017, underscoring the critical importance of developing a resilient and decentralized energy infrastructure. This paper explores the integration of vertical axis wind turbines within a hybrid portable power station to provide reliable electricity during emergencies. The results demonstrate that both 4-blade Savonius and Darrieus rotors can generate usable power under moderate wind speeds, reaching up to 38W under test conditions. These findings confirm that low-cost hybrid systems combining solar and wind energy can enhance energy resilience and support critical loads during power outages in hurricane-prone regions.**

***Index Terms*—Extreme Events, Power Generation, Power Outages, Renewable Energy, Vertical Axis Wind turbine.**

I. Introduction

The Caribbean region is frequently impacted by storms, affecting more than 40 million people every year, making it one of the most disaster-prone regions in the world [1], [2]. In Puerto Rico, in addition to the economic losses, these natural events caused deaths because the lack of electricity prevented the operation of medical equipment, water pumps, and communication systems, as a result of severe damage to the electrical grid [3], [4].

Different studies are focused in the extreme weather effects on power systems for disaster preparedness in hurricane-prone areas [5]–[7]. Also, there has been a significant trend toward adopting solar systems to improve the resilience and reliability of electricity in homes [8]–[10], but these systems are expensive [11], making them inaccessible to most of the population. Some large-scale solar projects, such as the Oriana Facility, are focused on producing energy for cities and rural areas to support the current power grid ($>$ 45 MW), but its capacity is limited to specific regions [12].

Hybrid portable power stations, which integrate multiple renewable energy sources with energy storage, have emerged as a promising solution for post-disaster recovery and remote applications [13], [14]. In [15], authors designed and built a low cost hybrid power station that can provide a reliable power supply during and after such events. The proposed prototype produced good results in terms of power generation and charging time, reaching an average of 100% State of Charge in 8 hours of solar radiations at 5.4 hours average peak irradiance per day. Then, the prototype was equipped with a IoT monitoring circuit based in Blynk platform to measure in real time the voltage, current and the power generation of each source [16].

This paper explores the potential of vertical axis wind turbines (VAWT) as part of a hybrid portable power system designed to enhance Puerto Rico's energy resilience. The find-

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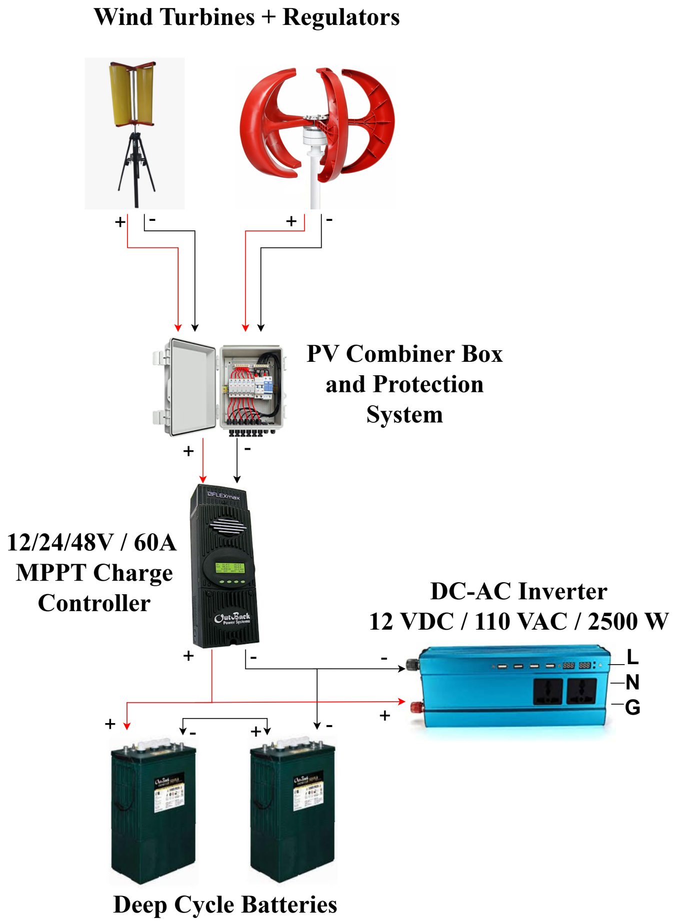

Figure 1: Power Station Circuit Diagram

ings aim to inform the development of robust, scalable systems that can provide reliable off-grid power during emergencies and support the island's long-term transition toward sustainable energy independence. The organization of this paper is as follows: Section II describe the electrical circuit and the turbine design details for the proposed system. Section III outlines the experimental setup and testing conditions. Section IV discusses the turbine's performance and the experimental test results. Finally, Section V provides a summary of findings and the main conclusions.

II. Proposed Hybrid Power System Details

A. Circuit Description

Fig. 1 shows the circuit diagram of the proposed hybrid power station. The system consist of two 370AH batteries, a combiner box, and a 12/24V/48V 60A charge controller with a 2.5kW peak inverter. The charge controller is a MPPT Outback FLEXmax 60 with a maximum input voltage of 150V and a maximun input current of 60A (at temperatures as high as 104°F). The system is powered by two VAWTs: one conventional 4 blades Savonius designed and built by authors (see Fig. 2-A) and one commercial Darrieus with 4 semicircular blades (see Fig. 2-B). The proposed hybrid portable power station is presented in Fig. 2-C.

Figure 2: Final Proposed Prototype Components

B. Conventional Savonius Wind Turbine Design and Construction Details

1) Wind Power: The theoretical power available in the wind that flow through a given area is expressed as:

$$P_{\text{wind}} = \frac{1}{2}\rho V^3 A \tag{1}$$

- P_{wind} = Power available in the wind (W).
- ρ = Air density $(\mathrm{kg/m^3})$. For this design: $\rho = 0.892\,\mathrm{kg/m^3}$.
- V = Wind speed $(\mathrm{m/s})$.
- A = Swept area of the rotor blades $(\mathrm{m^2})$.

2) Savonius Rotor Operating Parameters: For a Savonius rotor, a typical power coefficient is considered as:

$$C_p = 0.12 \tag{2}$$

The rotor's swept area is limited to:

$$A \leq 1\,\mathrm{m}^2 \tag{3}$$

The Tip Speed Ratio (TSR) is defined as:

$$\lambda = \frac{\omega R}{V} = 0.9 \tag{4}$$

- λ = Tip Speed Ratio (ratio between the tangential speed at the blade tip and the wind speed).
- ω = Angular velocity of the rotor $(\mathrm{rad/s})$.
- R = Rotor radius (m).
- V = Incident wind speed $(\mathrm{m/s})$.

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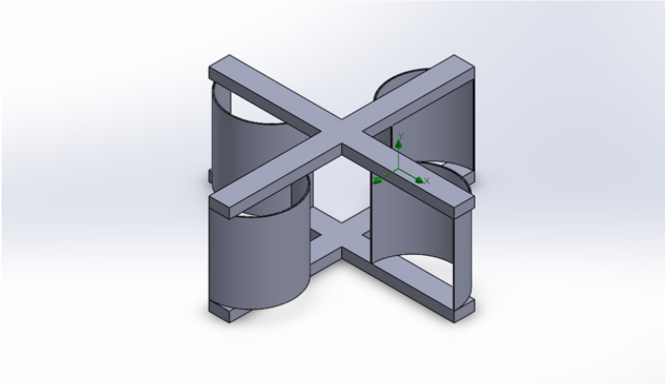

Figure 3: Solid Works Prototype

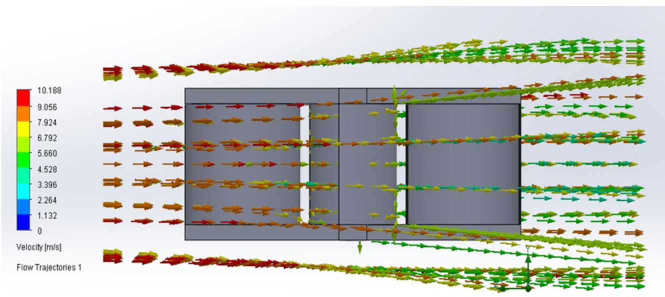

Figure 4: Solidworks Prototype Simulation

3) Power Generated by the Turbine: The actual power extracted by a wind turbine is calculated as:

$$P_{\text{turbine}} = C_p \cdot \frac{1}{2}\rho V^3 A \tag{5}$$

- P_{turbine} = Useful power generated by the turbine (W).
- C_p = Power coefficient (dimensionless), typically between 0.1 and 0.5.

Considering that the turbine area is $0.42\mathrm{m}^2$ and its efficiency is 0.12, the calculated power produced by the turbine is 52W at 14 m/s. The geometry was implemented in SolidWorks (see Fig. 3) to perform Aerodynamic simulations and evaluate the feasibility of the design (see Fig. 4).

The selected permanent magnet generator produces 300W at 300 rpm (model SkyMax Energy Legacy PMG). The turbine supports were made from 1 inch square steel tubing. 1/20 inch iron sheets were used for the turbine blades, and the mechanical couplings and balancing were done in a machine shop.

III. Description of the Experiments

A. Wind Speed Data Acquisition

The wind speed measurements were performed using a Sainlogic WS0310 Weather Station (see Fig. 2-D) installed one meter from the road shoulder and at a height of one meter (optimal height [17]). The current and voltage measurement was adquired using the IoT circuit described in [16].

Figure 5: The Wind Turbines Installed at Punta Santiago

B. Laboratory Test

The experimental tests were conducted in the university campus laboratory under controlled conditions. To simulate the required airflow, two industrial blowers were used, each capable of producing a steady wind flow of up to 14m/s. This value was verified using the Sainlogic Weather Station and a digital anemometer. The results show that the maximum power generation at the wind speed of 14m/s was 50W and 45W for the four-blade Savonius and Darrieus, respectively.

C. Field test

For test purpose, various locations across Puerto Rico were strategically selected to represent a range of geographical conditions:

- ***Humacao, Punta Santiago***: This coastal location is equipped with horizontal-axis wind turbine farms, making suitability in assessing VAWT performance within an existing renewable energy environment. This area also experiences frequent natural disasters, offering a valuable context for evaluating system resilience and operational reliability under extreme conditions. Figure 5 shows the installation of the turbines on the shore of the coast.
- ***San Lorenzo***: The urban area of San Lorenzo, along road 203, was selected due the high speed vehicular traffic that produce wind gusts of up to 6m/s. The figure 6 presents the turbines installed on the side of the road.

IV. Results and Analysis

A. Performance and Generation at Punta Santiago

The maximum voltage for the Savonius 4 Blade was 19.5V at 11.5m/s as shown in Fig. 7. The current and power are shown in Fig. 8 and Fig. 9, respectively. The Savonius 4 blade wind turbine performed better than the Darrieus producing a maximum power of 39W and 28W at 11.5m/s.

B. Performance and Generation at San Lorenzo Road

The results of voltage, current, and power generation are shown in Fig. 10, Fig. 11, and Fig. 12, respectively. The highest maximum power measured was 28.1W for the Savonius wind turbine. Furthermore, at wind speeds below 3m/s, the

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Figure 6: The Wind Turbines Installed at San Lorenzo Road

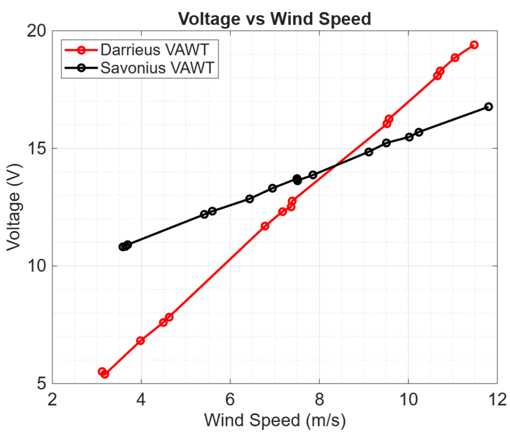

Figure 7: Punta Santiago Voltage Results

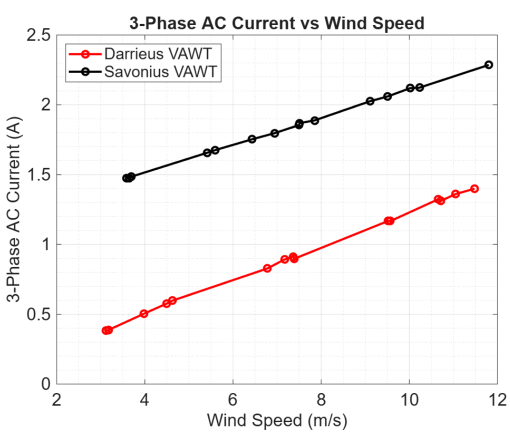

Figure 8: Punta Santiago Current Results

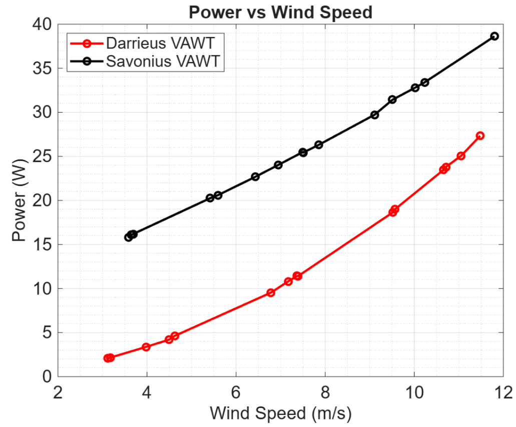

Figure 9: Punta Santiago Power Results

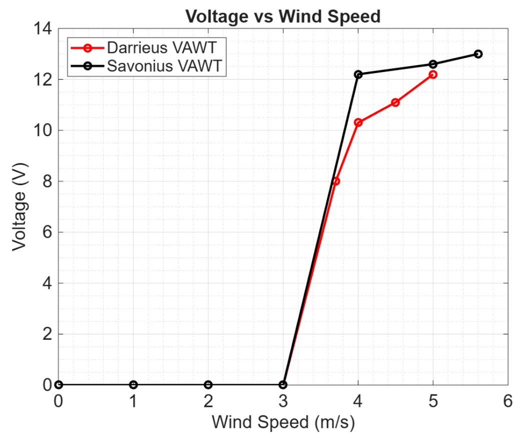

Figure 10: San Lorenzo Voltage Test

turbine generated negligible voltage, current, and power due to insufficient aerodynamic force to overcome the rotor's inertia. However, once wind speeds exceeded 3.5m/s, the turbine output increased significantly. Also, the voltage curve stabilized around 12V–13V beyond 4m/s, while the current reached a maximum of nearly 2.2A under similar conditions. This behavior indicates that the turbine operates most efficiently in the mid-to-high wind speed range observed at the test site.

The Darrieus turbine results indicate that no power was generated at wind speeds below 3m/s. However, once the wind speed exceeded 3m/s, the turbine demonstrated a significant increase in performance, delivering approximately 1A and 12W at 5m/s.

V. Conclusions

This work presented the design, simulation, and testing of a hybrid portable power station incorporating a vertical axis wind turbine to improve Puerto Rico's energy resilience during emergencies. Results demonstrate that both the Savonius and Darrieus turbines are capable of producing useful electrical power under varying wind conditions, with a peak power outputs of approximately 39W and 27W in field tests, respectively. In addition, the Darrieus design demonstrated smoother

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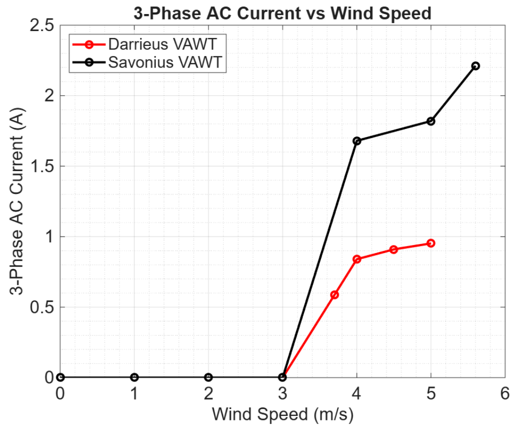

Figure 11: San Lorenzo Current Test

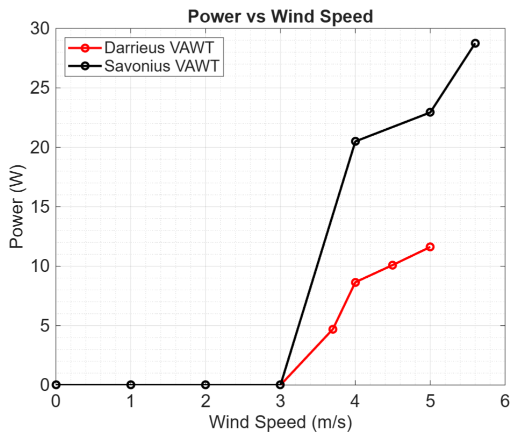

Figure 12: San Lorenzo Power Test

performance across a range of wind speeds, while the Savonius turbine delivered higher output in moderate wind conditions.

The field tests conducted in coastal, urban, and mountainous regions provided valuable insight into the real-world performance of these systems. Although the generated power is relatively modest, the hybrid station proves capable of supporting small critical loads such as LED traffic lights, medical devices, fans, and communication equipment. Compared with large-scale microgrids or residential PV systems, this approach offers a low-cost and rapidly deployable alternative for disaster preparedness. Also, this study confirms that small-scale hybrid systems are a viable pathway to strengthen the resilience of Puerto Rico's power infrastructure in hurricane-prone contexts.

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