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ASSESSMENT OF THE POTENTIALS OF VERTICAL AXIS WIND TURBINE (VAWT) IN NORTH-EASTERN NIGERIA: A CASE STUDY OF THE DEPARTMENT OF MECHANICAL ENGINEERING, FEDERAL POLYTECHNIC, DAMATURU

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ABSTRACT
Nigeria faces a persistent energy deficit characterized by an unstable national grid capacity and heavy reliance on fossil fuels. While Horizontal Axis Wind Turbines (HAWTs) dominate commercial wind power globally, their large-scale deployment faces significant constraints, including high capital expenditure for land acquisition, transmission infrastructure, complex directional yaw mechanisms, and ecological threats to local bird populations. Furthermore, HAWTs perform poorly in turbulent, low-altitude urban wind regimes typical of North-Eastern Nigeria. Vertical Axis Wind Turbines (VAWTs) offer a viable technological alternative because they are omnidirectional—capturing wind from any direction without requiring a yaw system—and possess a lower center of gravity, making them well-suited for localized and institutional off-grid applications. However, the localized technical and economic feasibility of fabricating small-scale VAWTs using regional materials remains largely underexplored in Damaturu. This work seeks to design, fabricate, and performance-evaluate a prototype Vertical Axis Wind Turbine within the Department of Mechanical Engineering Technology at The Federal Polytechnic, Damaturu. The outcome will provide empirical wind data, validate local fabrication methodologies, and establish a framework for decentralized renewable energy integration in North-Eastern Nigeria.

Keywords: Vertical Axis Wind Turbine (VAWT), Renewable Energy Integration, North-Eastern Nigeria (Damaturu, Yobe State), Savonius and Darrieus Configurations, Local Fabrication and Prototype and Decentralized Off-Grid Power Systems.

INTRODUCTION
Background of the Study
Access to reliable and sustainable electricity remains a major bottleneck to socioeconomic development in Nigeria. According to recent demographic and infrastructural assessments, national electricity generation frequently fluctuates below 4,000 MW against an estimated demand of over 25,000 MW (Adejumobi et al., 2013). This acute shortfall leaves a substantial percentage of the population—particularly in rural and semi-urban northern communities—without reliable access to electricity. The resultant reliance on petroleum and diesel generators contributes significantly to environmental pollution, noise, and high operational costs for households, small businesses, and academic institutions (Agba, 2011). North-Eastern Nigeria, specifically Yobe State (Damaturu Metropolis), experiences distinct climatic conditions characterized by open terrain and favorable seasonal wind regimes that present viable prospects for small-to-medium wind energy conversion systems. Wind energy conversion historically evolved from simple mechanical windmills used for water pumping and grain grinding into modern wind-electric generators. Harnessing this resource via appropriate technology like VAWTs can power decentralized applications such as campus laboratory instrumentation, water pumping, and low-voltage institutional lighting.

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Statement of the Problem

Traditional Horizontal Axis Wind Turbines (HAWTs) require consistent, high-velocity laminar winds and complex mechanical alignment systems (yaw drives) to operate efficiently. In institutional and urban or semi-urban settings like Damaturu, wind flow is frequently turbulent and multidirectional due to structural obstructions and terrain features, rendering HAWTs less effective. Additionally, imported commercial wind turbines involve prohibitive procurement, shipping, and maintenance costs. There is a critical need to investigate, design, and locally fabricate a cost-effective Vertical Axis Wind Turbine (VAWT) utilizing readily available engineering materials. This approach builds local technical capacity, reduces capital flight, and provides an empirical baseline for evaluating wind energy potentials in North-Eastern Nigeria.

Aim and Objectives

The aim of this project is to design, fabricate, and evaluate the performance of a prototype Vertical Axis Wind Turbine (VAWT) at the Federal Polytechnic, Damaturu, to assess its viability for regional clean energy generation.

The specific objectives are to:

1. Design and fabricate a prototype Vertical Axis Wind Turbine utilizing local engineering workshops and readily available materials.
2. Collect and analyze meteorological wind speed and direction data for the Damaturu environment using anemometry and statistical distributions (Weibull/Rayleigh models).
3. Evaluate the electrical power output, efficiency, and mechanical stability of the fabricated VAWT under real-world operating conditions.
4. Quantify the potential benefits of the system in reducing institutional carbon emissions and dependency on fossil-fueled generators.

Scope and Limitations

Scope: The research covers the engineering design calculations, material selection, mechanical workshop fabrication, electrical integration (alternator, inverter, and battery storage), and wind data monitoring centered within the Department of Mechanical Engineering Technology, Federal Polytechnic, Damaturu.

* Limitations: The physical fabrication is scaled to a prototype model constrained by institutional workshop funding, local material availability, and localized microclimatic wind data collection over a designated monitoring window.

LITERATURE REVIEW

Historical Evolution of Wind Energy Systems

Wind energy utilization dates back millennia, from early sail-driven boats along the Nile River (5,000 BC) to Persian vertical-axis windmills for grinding grain and pumping water (U.S. Energy Information Administration). European refinement led to Dutch wind pumps, which subsequently influenced modern wind-electric turbine developments in the 19th and 20th centuries. The global oil crises of the 1970s renewed interest in renewable energy alternatives, steering modern research toward efficiency optimization, aerodynamic blade profiles, and localized generation systems.

Previous Studies on Wind Energy Potential in Nigeria

Wind energy mapping across Nigeria reveals significant regional variations. Adaramola et al. (2011) analyzed long-term wind data across North-Central stations, applying levelized cost methodologies to demonstrate economic feasibility under varying operational parameters. Similarly, Olayinka et al. (2011) evaluated wind power potentials in Jos using long-term meteorological records, establishing

capacity factors for standardized wind conversion systems. While macro-level studies confirm favorable wind regimes in northern Nigeria, localized micro-scale studies—especially concerning VAWT adaptability in states like Yobe—remain scarce, justifying this localized institutional study.

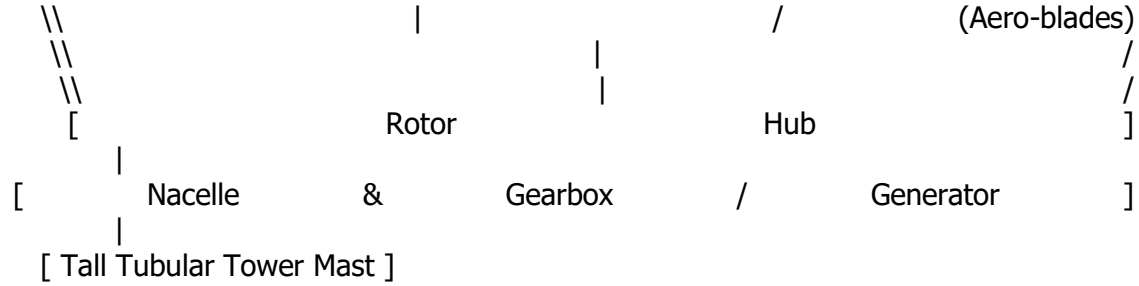
Classification and Configurations of Wind Turbines

Wind turbines are fundamentally classified based on the orientation of their rotational axis relative to the wind stream:

1. **Horizontal-Axis Wind Turbines (HAWT):** The rotational axis lies parallel to the wind stream. They feature high conversion efficiency in steady laminar winds but require complex yaw mechanisms to track shifting wind directions.

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Plate 1. Horizontal-Axis Wind Turbine (HAWT)



2. Vertical-Axis Wind Turbines (VAWT): The main rotor shaft stands perpendicular to the wind stream, allowing omnidirectional wind capture without a yaw drive.

Plate 2. Darrieus Vertical-Axis Wind Turbine (Lift-Driven)

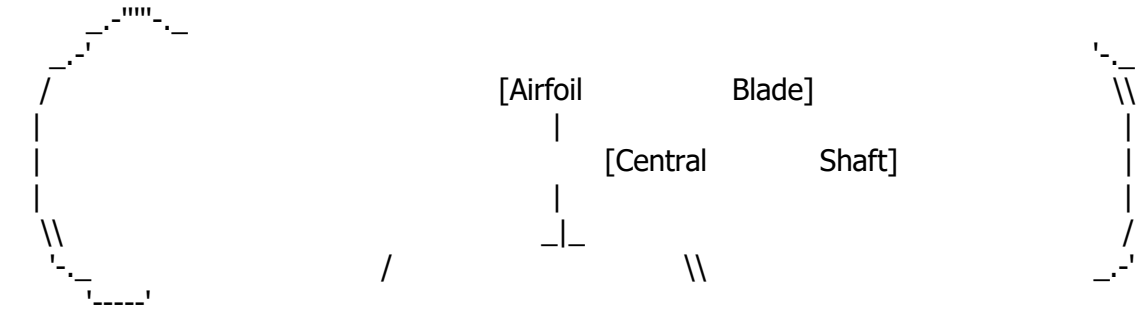
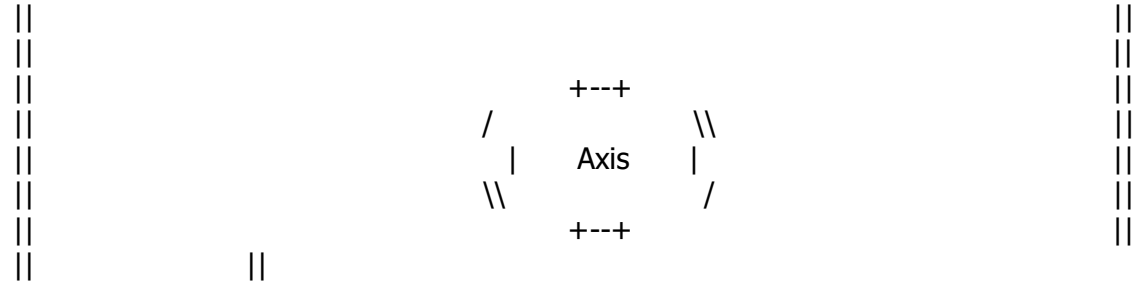


Plate 3. Straight-Blade Vertical Wind Mill (Savonius / Hybrid)



MATERIALS AND METHODOLOGY

Research Methodology

The project adopts an engineering design and experimental research methodology consisting of:

* Information Gathering: Review of existing wind turbine designs, meteorological parameters, and material specifications.
* Concept & Detailed Design: Mathematical modeling of blade surface areas, torque calculations, gear ratios, and structural load distribution.
* Fabrication & Assembly: Machining, welding, turning, and structural integration executed within the Federal Polytechnic Damaturu Mechanical Engineering Workshop.
* Testing & Data Analysis: Deployment of anemometers and electrical measuring instruments to evaluate power generation performance against statistical wind models.

Major Components and Technical Specifications

The fabricated VAWT assembly incorporates the following major components:

* Turbine Blades: Fabricated using durable 6-inch PVC pipes (1m length).

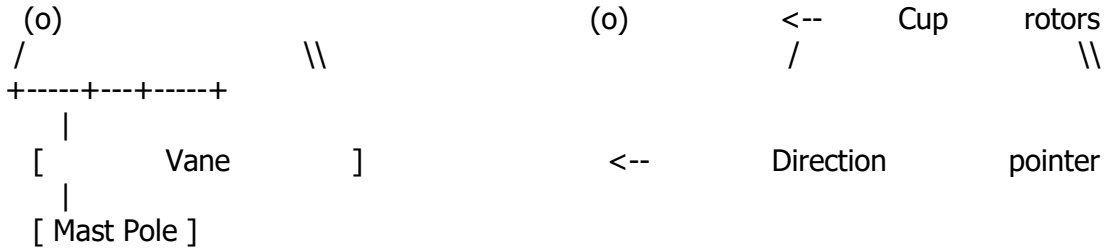
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* Structural Tower/Column: Galvanized steel pipe (3m height, 2-inch diameter).
* Base Support: Reinforced concrete base (1m x 1m).
* Drive Mechanism: Planetary gear set (300mm diameter) coupled to a rotary arm (500mm radius).
* Electrical Subsystem: 2.5 kW Alternator, 3.5 kVA Inverter, 200Ah Storage Batteries, Ammeter, and Galvanometer.

Workshop Machining Operations:
* Turning, facing, drilling, and welding operations performed on structural frames, brackets, and shaft couplings.

Method of Data Collection
Wind velocity data is captured continuously as random variables using digital logging anemometers mounted on meteorological testing masts to generate monthly wind roses and velocity frequency profiles.

Instruments for Data Collection
An anemometer is used to measure instantaneous and average wind speeds across the site.
Plate 4. Cup-and-Vane Wind Anemometer



ENGINEERING DESIGN CALCULATIONS
4.1 Available Wind Power Calculation
The available power in wind is calculated using:
$P_{wind} = \frac{1}{2}\rho A V^3$
Where:
ρ = 1.168 kg/m³ (assumed air density at Damaturu ambient conditions)
$A = H \times D$ = 1.0 m × 1.0 m = 1.0 m²
V = 5.5 m/s (assumed mean wind speed)
Therefore:
$P_{wind} = \frac{1}{2} \times 1.168 \times 1.0 \times (5.5)^3$ = **97.16 W**

Rotor Torque Calculation (T)
Torque is estimated using:
$T = P_{wind} / \omega$
Assuming a tip-speed ratio λ = 1.5:
$\omega = (2 \times 1.5 \times 5.5) / 1.0$ = **16.5 rad/s**
T = 97.16 / 16.5 = **5.89 N·m**
Note: This is an idealized estimate based on available wind power, not measured turbine output. Actual shaft torque depends on rotor performance and conversion losses.

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Structural Column Buckling Analysis (Euler's Critical Load)
Given:
Moment of inertia (I) for the assumed 2-inch steel pipe: 1.98×10^{-7} m⁴
Modulus of elasticity (E): 2.1×10^{11} N/m²
Effective length (Le): 6.0 m
Euler's critical load:
$Pcr = \pi^2 EI / Le^2$
$Pcr = [\pi^2 \times (2.1 \times 10^{11}) \times (1.98 \times 10^{-7})] / (6.0)^2$ = **approximately 11,385 N**
The effective length, end conditions, pipe wall thickness, actual section properties, and design loads must be verified before relying on this result for structural safety.

BUDGET ESTIMATION
Table 1. Equipment and Material Costs

S/N	Equipment / Item	Quantity	Rate (₦)	Total (₦)
1	Galvanized Steel Pipe (2")	36 pcs	9,800	352,800
2	PVC Pipes (6")	36 pcs	9,000	324,000
3	Alternator (2.5 kW)	1 unit	126,000	126,000
4	Ammeter	1 unit	14,400	14,400
5	Inverter (3.5 kVA)	1 unit	504,000	504,000
6	Deep Cycle Battery (200 Ah)	5 units	190,000	950,000
7	Flat Bar	27 lengths	2,000	54,000
8	Metal Sheet (5 mm)	7 pcs	18,000	129,600
9	Copper Cable Wire	100 m	50,000	100,000
10	Anemometer	1 unit	46,900	46,900
11	Galvanometer	1 unit	11,000	11,000
12	Cable Clips	12 pcs	280	3,360
13	Planetary Gear Sets	2 sets	30,000	60,000
14	Bearings	15 pcs	400	6,000
15	Cement	8 bags	5,000	40,000
16	Sand	1 truck	60,000	60,000
17	Gravel	1 pickup load	80,000	80,000
18	Bolts and Nuts	20 sets	300	6,000
19	Steel Rods	10 lengths	4,750	47,500
20	Neodymium Magnets	30 pcs	300	9,000
	Subtotal (Materials and Equipment)			**₦2,922,660.00**

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Table 2. Consumables and Workshop Operations

S/N	Item Description	Quantity	Rate (₦)	Total (₦)
1	Drill Bit Set	1 set	15,000	15,000
2	Grinding Discs	5 pcs	1,200	6,000
3	Cutting Discs	5 pcs	1,200	6,000
4	Diesel (generator fuel for welding/tools)	40 litres	850	34,000
5	Engine/Machine Oil	30 litres	1,500	45,000
6	Welding Electrodes (assorted)	5 packs	7,000	35,000
7	Hacksaw Blades	1 set	6,700	6,700
8	Spraying Gun and Brush Set	1 set	6,000	12,000
9	Body Filler (putty)	4 litres	3,500	14,000
10	PVC Adhesive	5 litres	3,000	15,000
11	Storage/Mixing Containers	5 pcs	3,500	17,500
12	Safety PPE (wears and boots)	2 sets	15,000	30,000
13	Hand Trowel	1 unit	1,000	1,000
14	Plumb Bob (4 m)	1 unit	3,000	3,000
15	Shovels	2 units	4,500	9,000
16	Hand Files (assorted)	3 pcs	2,500	7,500
	Subtotal (Consumables)			**₦256,700.00**

Table 3. Logistics, Testing, and Documentation Costs

S/N	Item Description	Quantity / Scope	Rate (₦)	Total (₦)
1	Field Site Survey and Wind Data Collection Logistics	3 trips / field visits	45,000	135,000
2	Material Transport and Workshop Haulage	Lump sum (delivery of pipes and cement)	85,000	85,000
3	Electrical and Load Testing Instrumentation Calibration	Testing phase	75,000	75,000

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4	Technical Drafting, Blueprinting and CAD Modeling	1 complete package	60,000	60,000
5	Report Typing, Binding and Colour Documentation	5 bound copies	15,000	75,000
6	Conference / Committee Presentation and Defense Logistics	Incidentals	70,000	70,000
	Subtotal (Logistics, Testing and Documentation)			**₦500,000.00**

Summary Budget Breakdown

Budget Head	**Amount**
Materials and Equipment Subtotal	₦2,922,660.00
Consumables Subtotal	₦256,700.00
Logistics, Testing and Documentation Subtotal	₦500,000.00
GRAND TOTAL	**₦3,680,160.00**

Grand Total in Words: Three Million, Six Hundred and Eighty Thousand, One Hundred and Sixty Naira Only.

CONCLUSION

The successful design, fabrication, and testing of this Vertical Axis Wind Turbine prototype will demonstrate a localized engineering solution to the persistent energy deficits experienced in North-Eastern Nigeria. Supported by robust mathematical modeling, clear structural layouts, and fully itemized budgeting, this project establishes a scalable framework for sustainable clean energy generation within the Federal Polytechnic, Damaturu, and the broader regional community.

RECOMMENDATIONS

1. Conduct a year-round wind velocity and direction mapping across open sections of the Federal Polytechnic Damaturu campus to account for seasonal variations (Harmattan vs rainy seasons).
2. Use the empirical anemometer data to fine-tune the statistical Weibull distribution models, ensuring the turbines cut-in and rated wind speeds match local micro-meteorological realities.
3. Ensure proper anti-corrosion coating (primer and weather- resistant enamel paint) on the 3-meter galvanized steel column and metal joints to withstand Damaturu's high ambient temperatures and dust conditions.
4. Implement a hybrid charging backup so that the system can seamlessly integrate with the institutional grid or auxiliary solar setups when wind speeds drop.
5. Use this fabrication as a practical training platform for Mechanical Engineering students, providing hands-on experience in machining, welding, electrical wiring, and performance evaluation.

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