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Design and Development of A Mini Vertical Axis Wind Turbine (Vawt) for Battery Charging Applications Using A 12v Lithium-Ion Battery

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ABSTRACT
Renewable energy sources, particularly wind energy, have gathered significant attention as sustainable alternatives to traditional fossil fuels. This paper presents the design and development of a Mini Vertical Axis Wind Turbine (VAWT) tailored specifically for battery charging applications. The project aims to address the growing demand for clean energy solutions while targeting the need for portable, efficient, and environmentally friendly power sources. One of the major issues in this fast-moving world is to meet the demand of energy in the most economical and environment friendly way. This research work on designing of a Vertical-axis wind turbine that gives a solution which is comparatively a cheap alternative of renewable energy. The Windmill rotates with sufficient wind, causing it to generate electricity owing to magnetic coupling between the rotating and stationary coil. The work demonstrates a vertical rotating prototype of windmill. The wind turbine can charge up to 12V battery. Advantage of this design is that it works without any consumption of fossil fuel and works efficiently in appropriate weather conditions without being closely monitored and the battery charges automatically without any harmful emissions or drawbacks. The work presented in this paper is an example of how natural resources like the wind energy can be used efficiently to produce electricity.

Keywords: Battery Charging; Renewable Energy; Wind Turbine; 12V lithium -ion Battery; Sufficient Wind

INTRODUCTION

With the global emphasis on transitioning towards sustainable energy sources, renewable energy technologies have gained prominence as viable alternatives to conventional fossil fuels. In Zambia, a country endowed with abundant wind resources, harnessing wind energy presents a promising avenue for addressing energy access challenges and mitigating environmental impacts. This introduction outlines the rationale and context for the design and development of a Mini Vertical Axis Wind Turbine (VAWT) tailored specifically for battery charging applications in Zambia (African Development Bank Group, 2020; International Renewable Energy Agency [IRENA], 2021)

According to African Development Bank (AFDB) and the International Renewable Energy Agency (IRENA) initiatives that support private investment and clean energy availability in rural regions, such as the REFiT Policy, Scaling Solar program, Rural Electrification Master Plan, and National Energy Policy, have strengthened Zambia's renewable energy sector. The project aims to provide a reliable, cost-effective, and environmentally friendly alternative to conventional energy sources for off-grid communities. The mini VAWT is designed to be compact, efficient, and easy to install, making it suitable for residential and small-scale commercial applications. This study involves the comprehensive design process, including aerodynamics, mechanical components, electrical systems, and control mechanisms, to ensure optimal performance under varying wind conditions.

A key aspect of the project is the selection of materials and components that are readily available and affordable in the Zambian context. The turbine blades, made from durable and lightweight materials, are designed to maximize energy capture from low to moderate wind speeds prevalent in the region. The mechanical structure is engineered for stability and longevity, with considerations for ease of maintenance and repair. The electrical system is integrated with a 12V lithium-ion battery, chosen for its high energy density, long cycle life, and low self- discharge rate. The battery management system (BMS) is tailored to optimize charging efficiency and ensure safe operation. The turbine's generator and power electronics are configured to deliver a consistent and regulated output to the battery, even under fluctuating wind conditions. The project also considers the socio-economic impact of deploying mini VAWTs in rural Zambia (AFDB, 2020; IRENA, 2021). By providing a reliable source of electricity, these turbines can enhance the quality of life, support economic activities, and promote sustainable development. The primary objective of this paper is to create a practical and scalable wind energy solution that can be deployed in rural Zambian communities to enhance energy access and support local development. The mini VAWT is designed to be compact, affordable, and easy to install and maintain, ensuring that it can be adopted widely without requiring significant technical expertise or financial investment.

The project encompasses several key components:

Aerodynamic Design: The aerodynamic performance of the turbine blades is critical to maximizing energy capture. The blade design process involves extensive CFD simulations to optimize the shape, angle, and material of the blades, ensuring they perform well under the wind conditions prevalent in Zambia. The goal is to achieve high efficiency at low to moderate wind speeds, which are typical in many rural areas.

1. **Mechanical Structure:** The structural design of the turbine must balance durability, weight, and ease of assembly. The turbine's support structure is engineered to withstand the stresses and strains of continuous operation while being lightweight enough to facilitate transportation and installation. The use of locally available materials and manufacturing techniques is prioritized to reduce costs and promote sustainability.
2. **Electrical System:** The integration of a 12V lithium-ion battery requires a carefully designed electrical system to manage power generation, storage, and distribution. The generator and associated power electronics are selected and configured to provide a stable output suitable for battery charging. The battery management system (BMS) plays a crucial role in protecting the battery from overcharging, deep discharge, and other potential issues, ensuring long-term reliability and safety.
3. **Control Mechanisms:** Effective control mechanisms are essential for optimizing the turbine's performance and protecting it under adverse conditions. These mechanisms include systems for adjusting blade pitch, controlling rotational speed, and shutting down the turbine during high winds or maintenance periods. The control system also interfaces with the BMS to manage the charging process dynamically.

4. **Prototyping and Testing:** The design process is iterative, involving the development of multiple prototypes to test and refine the turbine's performance. Prototypes are evaluated through a combination of laboratory tests and field trials to gather data on their efficiency, durability, and operational characteristics. Feedback from these tests informs further design improvements and helps ensure the final product meets the desired specifications.

The main advantage considering the renewable energy source as a main stream source for energy generation is that they are clean, non-polluting to the environment and its abundance. Although wind has been harnessed for centuries, it has only emerged as a major part of our energy solution quite recently. Before the 21st century, wind was primarily used to pump water from wells and to grind grain, but over the last twenty years the cost of wind energy has dropped by more than 80 percent, turning it into the most affordable form of clean energy. Recent advances have allowed for sophisticated wind technologies, which previously sat in the mind of thoughtful engineers and inventers, to be developed into cost-effective, reliable solutions. For a small wind turbine to be effective, it must produce energy across a wide range of wind speeds. It must be able to generate energy from winds that are switching directions and gusting. It must also be very quiet, so that it will not disturb people living nearby, and it certainly helps if it is pleasing to the eye as well. Wind power harnesses the power of the wind to propel the blades of wind turbines. These turbines cause the rotation of magnets, which creates electricity. Wind towers are usually built together on wind farms.

Motivation and Significance of Study

This research aims to address energy access inequalities in Zambia by developing a portable, scalable, and environmentally friendly power source for off-grid needs. The vertical axis wind turbine , powered by wind energy, can improve the power of essential electronic equipment, lighting, communication, and small appliances, promoting livelihoods, productivity, and sustainability. The project aligns with global efforts to mitigate climate change and transition to low-carbon energy systems, contributing to poverty alleviation, sustainable development, and resilience building initiatives.

Objectives of Study and Research Questions

The general objective of this study is to develop a feasible, efficient, and cost-effective mini vertical axis wind turbine system for battery charging.

Specific Objectives

1. To design a vertical axis wind turbine.
2. To design a charging circuit that will be used to charge a battery.
3. To integrate the vertical axis wind turbine to the charging circuitry.
4. To test the system design

Research Questions

1. How do you design a vertical axis wind turbine?
2. How do you design a charge control circuit for battery charging?
3. How do you integrate the vertical axis wind turbine to the charge control circuit?
4. How do you test that the system design is working?

LITERATURE REVIEW TO THE RESEARCH

This chapter, literature review serves to show projects and ideas of similar systems that have been developed before and also how these systems would help building on their drawbacks. Vertical Axis Wind Turbines (VAWTs) are a crucial class of wind energy conversion systems, offering omnidirectional wind capture from any direction. Unlike Horizontal Axis Wind Turbines (HAWTs), VAWTs eliminate the need for orientation mechanisms, making them ideal for urban environments, complex terrains, and areas with turbulent wind patterns. Vertical axis wind turbines, dating back to the 1920s, have gained renewed interest due to technological advancements and potential advantages over traditional horizontal turbines.

Classified into Savonius and Darrieus turbines, each has unique applications.

The Savonius turbine is a drag-based device that uses wind drag force to rotate. It consists of semi-cylindrical blades arranged in an S-shape, and is known for its simplicity, robustness, and low wind speed capabilities. Despite having low efficiency compared to lift-based turbines like the Darrieus type, it is suitable for small-scale applications like water pumping, ventilation, and battery charging in remote areas. The simple design of the rotor allows for easy fabrication in small workshops, making it more common in developing countries. The addition of endplates can increase efficiency by up to 36%. Highway turbines are considered to be the quite revolutionary turbine for the future. When a vehicle moves on the highway, it compresses the frontal air and pushes it to the sides which generates the vacuum at its rear. Bundle of air moves to fill up the vacuum. This motion of air provides a high potential wind energy which could be utilized by converting it to electricity via using wind turbine. A turbine placed on the center of the road is able capture wind energy from both sides of traffic while roadside turbine can capture the energy from one side of the traffic. Thus, turbine is preferred to be placed on the center of the road.

The Darrieus turbine, invented by George Darrieus in 1926, is a lift-based, vertical axis wind turbine that converts wind kinetic energy into mechanical energy. It comes in various configurations, including eggbeater and H-rotor designs. Although more complex to design and manufacture than Savonius turbines, they are suitable for small-scale and large- scale electricity generation. H-Darrieus turbines are cheaper and easier to build, but can be challenging in turbulent wind conditions due to high bending moment due to centrifugal acceleration. Surface roughness affects turbine performance, with higher Reynolds number predicting machine lifespan.

There are two ways of extracting the energy from the wind depending on the main aerodynamic forces used:

The drag type takes less energy from the wind but has a higher torque and is used for mechanical applications as pumping water. The most representative model of drag-type vertical axis wind turbines is the Savonius.

- The lift type uses an aerodynamic airfoil to create a lift force, they can move quicker than the wind flow. This kind of windmills is used

for the generation of electricity. The most representative model of a lift-type vertical axis wind turbine is the Darrieus turbine; its blades have a troposkien shape which is appropriate for standing high centrifugal forces.

Aerodynamic Design

The aerodynamic design of VAWTs is a critical factor influencing their performance and efficiency. Research has shown that the shape, size, and configuration of the blades significantly impact the turbine's ability to capture wind energy. For instance, studies by Paraschivoiu (2002) and Howell et al. (2010) highlight the importance of optimizing the blade profile and angle of attack and to enhance energy capture, especially in turbulent wind conditions.

Computational fluid dynamics (CFD) simulations have become a standard tool for analyzing and improving the aerodynamic performance of VAWTs. CFD allows researchers to model complex flow patterns around the blades and identify optimal design parameters. For example, the work of Balduzzi S et al.(2012) demonstrated how CFD can be used to optimize blade shapes for low wind speed conditions, which is particularly relevant for rural Zambia.

Material Selection

The choice of materials for the blades and structure of VAWTs is crucial for ensuring durability, efficiency, and cost- effectiveness. Common materials used in VAWT construction include fiberglass, carbon fiber, and aluminum. Research by Eriksson et al. (2008) suggests that composite materials, such as fiberglass reinforced plastic (FRP), offer a good balance of strength, weight, and cost. These materials are resistant to corrosion and fatigue, making them suitable for long-term use in diverse environmental conditions.

Electrical Systems

The integration of efficient electrical systems is essential for converting the mechanical energy captured by the VAWT into usable electrical power. This involves the selection of suitable generators, power electronics, and battery storage systems. Research by Lubitz (2014) emphasizes the importance of matching the generator characteristics with the wind turbine's output to maximize efficiency and reliability.

Lithium-ion batteries have been widely studied for their high energy density, long cycle life, and low self-discharge rate. Studies by Goodenough and Park (2013) and Nykvist and Nilsson (2015) highlight the advantages of lithium-ion batteries over other types of energy storage, such as lead-acid and nickel-metal hydride batteries. The integration of a battery management system (BMS) is critical for ensuring the safe operation of lithium-ion batteries, protecting them from overcharging, deep discharge, and temperature extremes.

Control Mechanisms

Effective control mechanisms are vital for optimizing the performance and longevity of VAWTs. These mechanisms include systems for adjusting blade pitch, controlling rotational speed, and shutting down the turbine during high winds or maintenance periods. Research by Mertens (2006) and Tjiu et al. (2015) explores various control strategies and their impact on turbine performance and safety.

Advanced control systems can significantly enhance the efficiency and reliability of VAWTs. For example, adaptive control algorithms that adjust the turbine's operating parameters in real-time based on wind conditions can improve energy capture and reduce mechanical stress. The work of Wang et al. (2018) demonstrates the potential of such adaptive control systems in small-scale wind turbines.

Environmental Impact

The environmental impact of mini VAWTs is a growing area of interest, particularly in urban settings. Toja-Silva et al. (2013) conducted a comprehensive assessment of the environmental benefits and challenges associated with deploying VAWTs in urban areas. They concluded that mini VAWTs could contribute to reducing greenhouse gas emissions and mitigating urban heat islands, but also highlighted potential issues such as noise and visual impact.

Moreover, research by Meyer and Turner (2015) has explored the potential for integrating VAWTs with green roofs and other urban sustainability initiatives. Their study found that combining VAWTs with green infrastructure can provide synergistic benefits, such as improved air quality and enhanced aesthetic appeal, which can help mitigate some of the perceived drawbacks of urban wind turbine installations.

Smart Grids and Internet of Things (IoT) Integration

The integration of mini VAWTs with smart grids and IoT technology represents an exciting frontier in renewable energy. According to a study by Guerrero et al. (2013), smart grid integration can enable real-time monitoring and control of VAWT systems, optimizing their performance and ensuring reliable energy supply. IoT devices can provide detailed data on wind conditions, turbine performance, and energy storage levels, facilitating predictive maintenance and dynamic energy management.

RELATED WORKS

VERTICAL AXIS WIND TURBINE WITH CHARGING SYSTEM

By

Shobhit Sahu , Shubham Agrawal , Shubham Gupta , Varun Chitale, Dr. Adarsh Sachdeva , Ashish Chaturvedi – 2018

The vertical axis wind turbine (VAWT) is a rapidly growing renewable energy sector in India, crucial for economic growth. The project aims to study the feasibility of installing VAWT systems at roof tops, focusing on efficiency and ground-level potential. The Savonius type model, with DC motor input and electrical output, has low efficiency but offers advantages over Horizontal axis wind turbines (HAWT). VAWTs can work on low heights, making them suitable for individual households. The project addresses the drawbacks of inconsistent power production and low conversion efficiency, finding feasible designs that yield continuous energy at different wind speeds. Further research is needed to improve VAWT designs and test their effectiveness.

DESIGN OF ALTERNATIVE ENERGY SYSTEMS: A SELF-STARTING VERTICAL AXIS WIND TURBINE FOR STAND-ALONE APPLICATIONS (CHARGING BATTERIES)

By

Andrew Tendai Zhuga , Benson Munyaradzi , Clement Shonhiwa - 2006

A general aerodynamic optimization method was used to improve the torque characteristics of a multi-blade vertical axis wind turbine. A decomposition, deformation, and reassembly method was developed to accommodate the variable geometry of the blade during the optimization process. The deformation of the grid was accomplished by a modified version of the Transfinite Interpolation (TFI) method. The method is first applied to a single blade of the turbine and yields a 27% improvement in overall torque. Further analyses were performed on a single blade with a spanwise slot and two-blade configuration with and without the slots and results indicated more than 10% further improvement in the overall torque with the slots in place. Two small-scale multi-bladed (3-blades and 5-blades) prototype turbines were built and tested in the low speed wind speed at stream mean velocity of 2.5 m/sec, which correspond, to Reynolds numbers based on cord length of 1.225 X 10 5 . The experiments were performed in free air stream on raised ground and in a closed room with a 3-speed stand fan. Results show that at the free stream mean velocity of 2.5 ms -1

, the turbines were self-starting and the 5-blade turbine could turn a 6V rated bicycle dynamo generating 4.83V of electricity. At increased wind speeds, the turbines still produced electricity without damage. The power coefficients for the optimized blades extend to a tip speed ratio of 1.6.

DESIGN AND CONSTRUCTION OF A PROTOTYPE VERTICAL AXIS WIND TURBINE (VAWT) FOR BATTERY CHARGING APPLICATION

By

Sunil Thomas , Mohammed Ashar , Riyan Khan , Adhir Baran Chattopadhyay - 2018

One of the major issues in this fast moving world is to meet the demand of energy in the most economical and environment friendly way. This research work on designing of a Vertical- axis wind turbines(VAWT) that gives a solution which is comparatively a cheap alternative of renewable energy. The Windmill rotates with sufficient wind, causing it to generate electricity owing to magnetic coupling between the rotating and stationary coil. The work demonstrates a vertical rotating prototype of windmill. The wind turbine can charge up to 12V battery. Advantage of this design is that it works without any consumption of fossil fuel and works efficiently in appropriate weather conditions without being closely monitored and the battery charges automatically without any harmful emissions or drawbacks. The work presented in this paper is an example of how natural resources like the wind energy can be used efficiently to produce electricity.

DESIGN, MODELING AND ECONOMIC PERFORMANCE OF A VERTICAL AXIS WIND TURBINE

By

R. Shah , Rakesh Kumar , Kaamran Raahemifar , Alan

S. Fung - 2018

Vertical Axis Wind Turbine (VAWT) is relatively simple to implement in urban areas on ground or/and building-roofs, the development of appropriate design of VAWT will open new opportunities for the large-scale acceptance of these machines. The primary objective of this research was to design and modeling of a small-scale VAWT, which can be used to meet the power for low demand applications. Two new shapes of Savonius rotor blades were examined in terms of their rotational performances against the conventional straight and the curved blades. MATLAB simulation was utilized to develop a mathematical model, which comprised of wind power coefficient, tip speed ratio, mechanical and electrical subcomponents. The measured results of developed turbine were used for the validation of the model. The aims were to analyze the turbine blade shapes, develop a mathematical algorithm, and to establish the techno-economic performance of the new curved shape design. It was modeled that the proposed turbine is capable of producing an annual energy output of 7838 kWh and the annual electricity cost/saving in Ontario turned out to be $846.51 (the price of electricity was taken $0.108/kWh).

ASSESSMENT OF WIND ENERGY POTENTIAL IN ZAMBIA

By

Gershom Mwandila , Henry Mulenga , Peg Thole , Eliz abeth Siwawa ⁻ 2024

An assessment of potential for wind energy in Zambia was carried out to help address the shortage of energy due to increasing energy needs arising from energy requirements for newly opened mining industries and unreliable hydropower generation due to climate change. The assessment was carried out by collecting wind speed data of 25 sites owned by Zambia Meteorological Department. The objective of the study was to analyse wind patterns and determine areas in Zambia where production of electricity from wind can be invested. The analysis was based on the use of Weibull shape factor and yielded 3.32 m/s wind speed and 13.2 shape factor from a site with the most suitable wind speeds (Kasama Meteorological Station). A correlation study was carried out using these results and Goldwin 1.5 MW wind turbine of model GW82/1500. The study results showed that 44.46 kW power output could be obtained at 3.83 m/s wind speed by a correlation equation of this turbine power output with wind speeds. A series of similar power output results were obtained for wind speeds recorded in the years from 2013 to 2021 and compared with those obtained in the same period by using model equation due to Al Buhariri, and found that the power outputs compared very closely at low wind speeds ranging 3 to 3.2 m/s but rather widely at higher wind speeds.

This study is significant in that it provides information on decision making and helps determine policy direction for wind utilization in Zambia and it can also help influence investment decision by Zambian mining companies who have financial ability to undertake large scale investments.

METHODOLOGY

The project is experimental based. Here we will have an overview of the components used to achieve the implementation of the project. The success of the project is based on the integration of different hardware components to design a project.

3.1System Design

The figure below shows a system design of a vertical axis wind turbine integrated to a charging.

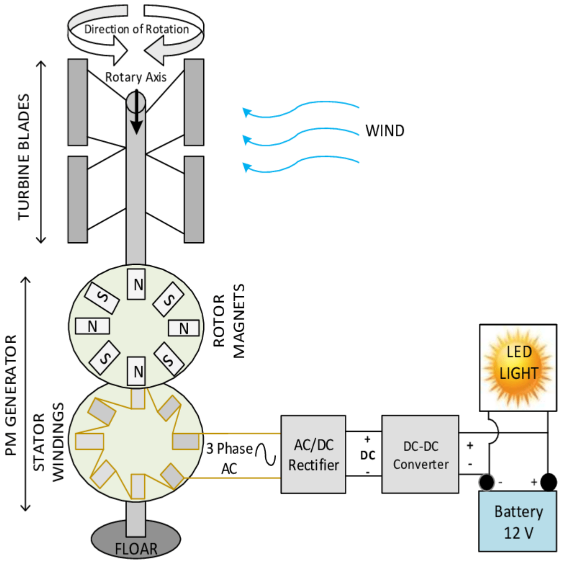

Figure 1 (Turkish journal for electromechanics and energy, Sep 2021)

How each component works

The rotor and blades are crucial in wind turbines, capturing wind energy through rotation. The blades' design and shape determine their effectiveness. The rotor drives the shaft, transferring mechanical energy to the generator. Fewer blades have faster rotation but require higher wind speeds. The rotor's design must align with the turbine's purpose and environmental conditions.

DC motors operate using the Lorentz force and Faraday's law of electromagnetic induction. They are powered by a stator with electromagnetic coils or magnets, and windings on the rotor, which conduct current when DC power is provided. DC motors come in various types, including Brushless DC Motor (BLDC), Shunt DC Motor, Series DC Motor, and Compound DC Motor. Brushless DC motors use controllers for electronic commutation, offering reduced maintenance, increased longevity, and improved efficiency. Shunt DC motors maintain steady speed irrespective of load, while series DC motors have high torque at low speeds but decrease speed as load increases. Compound DC motors combine features of shunt and series motors, making them suitable for various applications. DC motors are ideal for wind turbines, small-scale turbines, and battery charging systems due to their efficiency in converting mechanical energy into electrical energy.

Lithium-ion batteries are ideal for use in wind turbines due to their efficiency and longevity, but they must operate within a specific temperature range of 0°C to 45°C for charging. The battery's capacity must be sufficient to store enough energy for the planned charge, and its size should be based on the expected power of the wind turbine. Lithium-ion batteries are economical and eco-friendly due to their multiple rechargeability, and can tolerate 500-1,500 cycles of charging and discharging.

An inverter converts direct current into alternating current by rapidly reversing the input voltage, generating a sinusoidal AC waveform. It regulates output voltage, ensuring stability in solar and wind energy systems. To create an oscillating waveform, semiconductor devices like transistors or MOSFETs switch the DC input voltage. The pulsating DC is routed through filters or regulated circuits, and transformers step up the voltage to meet output requirements.

A transformer is a voltage control device that transfers electrical energy from one circuit to another using electromagnetic induction. It increases or decreases AC voltage, used for alternating current transmission and distribution, and is commonly used for long-distance electricity transmission and low-voltage devices.

Mathematical formulations

The efficiency of a VAWT is typically expressed as the power coefficient, Cp , which represents the fraction of the wind's

kinetic energy that the turbine can convert into useful electrical power. The power coefficient is a function of the TSR, denoted by λ , which is the ratio of the tangential speed of the rotor blades to the wind speed.

Paraschivoiu (2002) emphasized that optimizing the tip speed ratio is essential for achieving maximum efficiency in vertical axis wind turbnies. The tip speed ratio can be calculated as:

$$\lambda = \frac{W \,.\, R}{V}$$

where:

- W is the angular velocity of the turbine (rad/s),
- R is the radius of the turbine (m),
- V is the wind speed (m/s).

The power coefficient Cp is then derived from the mechanical power output P of the turbine relative to the available wind power.

energy yield, including turbine placement and wind speed variations and turbulence.

$$E = \int_{t1}^{t2} P(t)\, dt$$

Derivation of Wind turbine Power and The Bertz Limit

Utilizing the public framework, wind turbines convert the dynamic vitality of the breeze into rotating motor vitality and then electrical vitality that may be supplied. The kinetic energy of an object E with

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mass m and speed v under continuously increasing speed is equal to the work done W to uproot that object from rest to a separation s under a power r F, i.e.: E=W=Fs

As per Newton's Law, we have: F=ma
Henceforth, E=mas… … (1)

Utilizing the third condition of motion:

$$V^2 = u^2 + 2as$$

where:
- ρ is the air density (kg/m³),
- A is the swept area of the turbine (m²),
- V is the wind speed (m/s).

Making "a" subject of the equation, we get:

$$a = \frac{v^2 - u^2}{2s}$$

Since the underlying speed of the item is zero, for example u = 0, we get:

Since Cp is maximized at an optimal tip speed ratio, the design of the vertical axis wind turbine must ensure that the tip speed ratio is near this optimal value under typical operational wind conditions.

The entire amount of energy generated by the VAWT over a specific time period is referred to as the energy yield. Danao et al. (2013) investigated the effects of environmental variables on

$$a = \frac{v^2}{2s}$$

Substituting it into condition (1) we get:

$$E = \frac{1}{2}mv^2$$

The force P of the breeze is given by the rate of progress of the work, in this way:

$$P = \frac{dE}{dt} = \frac{1}{2}v^2\frac{dm}{dt}$$

We realize that mass stream rate:

$$\frac{dm}{dt} = \rho Av$$

Thus power, P:

$$P = \frac{1}{2}\rho Av^3$$

RESULTS

The layout design of the prototype is displayed in figure 2 which is followed by the principle of operation.

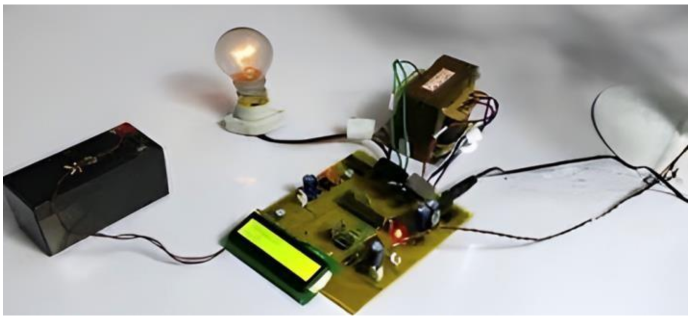

Figure 2 working prototype

Principle of operation

A circuit, in its simplest form, is a loop through which matter, such as electrical charge, flows. In an electronic circuit, this charge is carried by electrons coming from the positive terminal of a voltage source. When the charge passes through the circuit components and returns to the negative terminal, the circuit is considered complete. The components of the circuit affect the flow of charge in different ways. Some components resist or impede the flow, while others store or dissipate charge. In addition, some components require external power, while others generate or regulate power.

In the system described, the power supply begins with a voltage source that must be processed by a rectifier. The rectifier converts alternating current (AC) into direct current (DC), ensuring that the power supplied to the circuit is stable and compatible with the components. The rectified energy is then passed through a voltage regulator, which maintains a stable voltage level to protect sensitive electronic components.When the turbine blades rotate, mechanical energy is converted into electrical energy. This generated energy is then managed by a charge controller. The charge controller ensures that the energy generated is efficiently and safely transferred to a 12V battery. The battery serves as a storage device, holding the generated energy for later use or distribution.

The energy stored in the battery is then transmitted to a DC inverter. The inverter converts the direct current from the battery to alternating current, which is required for many appliances and devices. In addition, a step-up transformer is used in the system to step up the voltage from the primary winding to the secondary winding. This process ensures that the correct voltage levels are available for the required applications. The transformer operates at the rated frequency, handling high voltage and low current conditions in the winding.Finally, a MOSFET transistor acts as a switch in the circuit. The MOSFET regulates the flow of current, controlling the supply of electricity to the load or output. By efficiently switching the flow of electricity, the MOSFET ensures that the circuit operates reliably and with minimal energy loss.

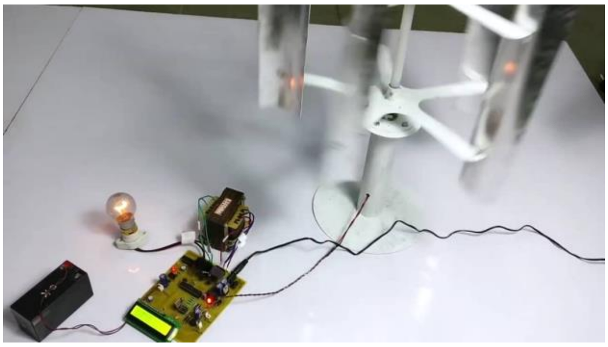

Figure 3 vertical axis wind turbine in motion

Advantages of Vertical Axis Wind Turbines

- Vertical axis wind turbines receive wind from any direction and do not require steering mechanisms to achieve this. This is particularly useful in places where wind is irregular or turbulent.
- They are able to start rotating at lower wind speeds compared to horizontal axis wind turbines. This allows power to be produced even in light winds.
- Have a smaller footprint and can be installed closer to the ground, thus eliminating the requirement for tall towers.
- Lower sound levels, thus rendering these systems more appropriate for urban or suburban applications.
- Reduced environmental impact
- Easier maintenance
- Economical for Small Scale Application
- Scalable

Applications of Vertical Axis Wind Turbines

- In renewable energy education to demonstrate the principles of wind energy conversion and energy storage in schools, colleges and laboratories.
- In off-grid energy for lighting small appliances and low-power devices in remote areas.
- Suitable for home use, to power LED lights, security cameras or IoT devices.
- Can be integrated with solar energy for rural homes, remote monitoring stations and small agricultural equipment such as irrigation pumps.
- Can contribute to community microgrids to reduce dependence on fossil fuels

FUTURE SCOPES

Improving the turbine`s performance across a broader range of wind conditions would increase its reliability and energy output, making it even more valuable for rural electrification. Further research could also explore the use of different materials and manufacturing techniques to enhance the turbine`s durability and reduce costs.

For example, composite materials or advanced manufacturing methods such as 3D printing could be investigated as potential ways to improve the turbine`s performance while keeping costs low.

The integration of the turbine with other renewable energy sources, such as solar panels, could also be explored as a way to create hybrid energy systems that maximize energy availability and reliability.

By combining wind and solar power, it may be possible to ensure a more consistent energy supply, even in areas with variable wind and sunlight conditions.

In conclusion, the design and development of this mini vertical axis wind turbine prototype represent a significant achievement in the field of renewable energy for rural electrification.

CONCLUSIONS

The idea behind this initiative was to use Zambia's plentiful wind energy to create a dependable off-grid power source. The simplicity of the design ensures ease of manufacturing and maintenance, which is crucial for its deployment in rural areas where technical expertise and resources are limited.

The performance testing of the prototype revealed that the turbine is capable of generating sufficient power to charge batteries, even in low-wind conditions typical of many rural areas in Zambia.

The turbine`s ability to start up at low wind speeds and operate efficiently in turbulent wind conditions is particularly noteworthy, as these are critical factors for ensuring reliable energy generation in varying environmental conditions. Despite the project`s successes, several challenges were encountered during the design and development process. While the turbine performed well in moderate wind conditions, its efficiency decreased at very low and very high wind speeds.

This is a common issue with small-scale wind turbines, and it highlights the need for further research and development to improve the turbine`s performance in extreme conditions.

For example, while more advanced materials or design features could potentially improve the turbine`s efficiency, they would also increase the cost, making the turbine less accessible to the communities it is intended to serve.

Batteries can store energy for use during periods of low wind or at night, ensuring a continuous supply of power. The project`s success also demonstrates the potential for local manufacturing and job creation. The recommendations outlined in this chapter provide a roadmap for the continued development and deployment of mini Vertical Axis Wind Turbines in Zambia. By focusing on performance optimization, cost reduction, maintenance, integration with other renewable energy sources, policy engagement, and environmental and social impact assessment, it is possible to enhance the effectiveness and sustainability of this technology. These efforts will contribute to the broader goal of improving energy access and promoting sustainable development in rural communities.

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