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Vertical Axis Wind Turbine with Inverter

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Abstract: Increased demand for renewable energy has led to efficient wind energy conversion systems. This project focuses on the design and implementation of vertical axis wind turbines (VAWTs) with inverters to efficiently produce and use clean energy. In contrast to traditional wind turbines on horizontal axis, VAWTS can grasp the wind from all directions and be ideal for urban and distributed applications. Changes in the current generated often vary in frequency and voltage. This requires the rectifier and inverter systems to be converted to stable, usable alternating current outputs. Inverters play a key role in synchronizing performance with the network or in direct delivery of electrical loads. The combination of VAWT and Inverter technology provides sustainable energy solutions suitable for daily life and small cultural applications.
Keywords: VAWTS, Inverter, HAWTS

I. INTRODUCTION

Rapid fatigue in fossil fuels and the increasing environmental problems associated with traditional energy sources have strengthened the global change towards renewables. Under a variety of sustainable alternatives, wind energy has evolved into one of the most promising solutions, minimizing its abundance, sustainability and environmental impact. Traditional wind turbines (HAWTS) spread on a horizontal axis, but there are certain such limitations. As a result, vertical axis wind turbines (VAWTs) are attentive as a practical alternative, especially for dispersed energy generation in urban and small quantities of applications. In contrast to hawks that need to be consistent with the direction of the wind, VAWTS can capture wind from any direction, making it ideal for environments with unpredictable wind patterns. The compact design allows for installation in urban areas. It can be installed in urban, residential roofs, or in remote areas where space and wind conditions are not suitable for large wind farms.

Furthermore, VAWTS has a lower poisoning footprint and lower wildlife impact compared to traditional wind turbines. The wind energy conversion process involves several stages, from mechanical generation to electrical energy. The power generated is usually in the form of variable frequency switching current (AC) and must be converted to a stable, usable supply. To achieve this, an electrical and electronic system is installed in the system, including a rectifier and an inverter. The rectifier converts unstable alternating current outputs directly to current (DC) and is processed by an inverter to create a stable alternating current output that is compatible with the appliance or grid used. The focus is to optimize performance, improve system efficiency, and ensure seamless integration with electrical loads. By using MPPT techniques (Maximum PowerPoint Tracking), the system can maximize energy extraction due to wind and improve overall performance. Additionally, energy storage solutions such as batteries can be integrated to preserve excess energy to ensure continuous power availability in low wind conditions. Implementing such systems can reduce dependence on fossil fuels, promote energy independence, and support the development of environmentally friendly energy solutions for residential and commercial use.

Two main types of WTs: horizontal axis and vertical axis. Horizontal axis WTs (HAWTs) are widely used in large wind farm applications in remote and offshore areas where the clean and an undisturbed wind is available. Wind patterns in urban areas are more chaotic, less predictable, and full of turbulence, which makes HAWTs relatively ineffective [1], [2], [3], [4]The Vertical Axis Wind Turbines (VAWTs) might be an effective option in all these areas due to their low cut-in wind speed, no yawing requirement, less structural support, and no noise concerns [5]Numerous small-scale wind turbine designs have been suggested, tested and implemented in many urbanized areas where the wind is gustier and inconsistent. The efforts have also been undertaken in several countries on VAWT to make them a viable technology. The research and development activities were focused on the design, modeling, integration, sitting, and environmental aspects [6], [7], [8], [9]Aerodynamic and economic performances of VAWTs have been studied in Iran) [10].

The main difference between VAWT and HAWT is the position of the main shaft. The shaft is perpendicular to the wind direction in VAWT while it is parallel in case of HAWT. The usage of HAWT is very vast in industrial applications. The researcher's lack of interest in VAWT has caused a great gap in its innovation and practical applications. This gap has led to the failure of the VAWT turbine designs in recent years and this has also created hesitation among the researchers. One of the main reasons for these failures is that there are not enough studies conducted on the CFD analysis of these turbines.

To achieve the complete aerodynamical analysis multiple diagnostic approaches are applied including numerical, computational and experimental setups. This helps in authenticating the results and efficiency. With the help of the critical analysis done on these diagnostics, it was established that DMST (Double Multiple Steam-tube Theory) is a very realistic technique that can provide result-oriented analysis. This theory is classified as the most reliable in terms of precision of results.

The rest of the paper is structured as follows. Section 2 provided connected run through literature survey. Section 3 gives the problem defination of the project. Section 4 demonstrates design methodology and ways of this analysis. Section 5 discusses our experimental methodology, and Section 6 presents the analysis of our results and output. Finally, the conclusion of the research is stated in section 7.

II. LITERATURE REVIEW

Vertical Axis Wind Turbines (VAWTs) have gained renewed interest in recent years, particularly for offshore applications and urban environments. VAWTs offer several advantages over Horizontal Axis Wind Turbines (HAWTs), including omnidirectionality, lower noise emissions, and the ability to operate closer to the ground [11]. The development of VAWTs has progressed from small-scale prototypes to large-scale installations, with some projects reaching capacities of 100 kW or more [12].

One interesting aspect of VAWT research is the use of electrical control systems with direct-driven energy converters. At Uppsala University, researchers have developed a concept featuring an H-rotor connected to a direct-driven permanent magnet synchronous generator (PMSG) located at ground level. This approach allows for simplified control through the electrical converter system, reducing investment costs and maintenance needs [13]. While not explicitly mentioned in the provided papers, it can be inferred that inverters play a crucial role in such systems to convert the variable AC output of the generator into grid-compatible AC power.

In conclusion, VAWTs show promise as a complementary technology to HAWTs, especially for offshore deployments and decentralized generation in urban areas. The integration of advanced electrical systems, including inverters, is likely to play a significant role in improving VAWT performance and grid integration. However, challenges remain, such as aerodynamic complexities and structural reliability issues related to dynamic stall [14]. Further research and development in areas such as blade design, materials, and control systems will be essential to fully realize the potential of VAWTs in the renewable energy landscape.

III. PROBLEM DEFINATION

Vertical Axis Wind Turbines (VAWTs) face several challenges in their design and operation, particularly when integrated with inverter systems for power generation. The primary issues include aerodynamic performance, structural stability, and power output optimization.

VAWTs suffer from complex aerodynamics due to their three-dimensional operation, which makes their performance more difficult to simulate and predict compared to conventional Horizontal Axis Wind Turbines (HAWTs) [11]. The circular wakes, strip-like wakes, and shedding vortex structures interact, resulting in unstable performance [15]. Additionally, VAWTs are prone to dynamic stall, which negatively impacts their efficiency and structural integrity [15] [16].

Interestingly, some studies have shown promising results in addressing these issues. For instance, the use of airfoils with trailing edge flaps has demonstrated potential in improving flow fields around the turbine, damping wake separation, and deferring dynamic stall [15]. Similarly, optimizing blade thickness and exploring helical blade designs have shown improvements in aerodynamic performance and noise reduction [16], [17]. In conclusion, the main problem definition for VAWTs with inverters involves optimizing aerodynamic performance, mitigating dynamic stall, improving structural stability, and enhancing power output consistency. Future research should focus on innovative blade designs, active flow control mechanisms, and advanced simulation techniques to address these challenges and improve overall VAWT efficiency when coupled with inverter systems.

IV. DESIGN METHODOLOGY

A. *System Design*

The blades of a windmill rotate around and are linked to a generator which transforms their mechanical motion into electrical energy. This motion is caused from a windy day, where a windmill accompanies a gearbox that turns with shafts towards the wind. The energy created is stored in an inverter, which is powered by the turbine. Once the electricity is generated and is attached to the local grid, it can be used to power devices. The blades in the windmill are designed to effective make the most of wind energy, thus supporting the windmill in both effortless and productive spins. In research analyzer work, it is well known how helpful windmills tend to be during theoretical rotations. When there is inadequate wind, power can be devised from the inverter which could then be supplied to any device, creating limitless sustainable energy.

Recently, the researchers have turned their attention towards VAWT. Even though this turbine is very cost effective and it is easier to manufacture, however, there is a big research gap left by the researchers on VAWT due to their unfettered working on HAWT [13]. Many researchers have provided a lot of new innovative ideas to use the wind energy effectively, but most of them couldn't be implemented. It is the need of time that this industry elaborates and finds the solutions of the fundamental aspects that question the credibility of (Wind energy efficiency evaluation procedure) .
The working efficiency of this mechanical contraption hinges on how well the physical axis of the mill is positioned within the fences because the windmill converts raw wind energy into the significant amount of rotary motion needed by the mill to operate.

B. Block diagram and Circuit Diagram

In this project model have used some known & popular hardware such as Generators, 12v DC Battery, Step-up Transformer, jumper wires, Inverter, switching device and a lamp load. Below fig shows the block diagram in which all the components are connected.

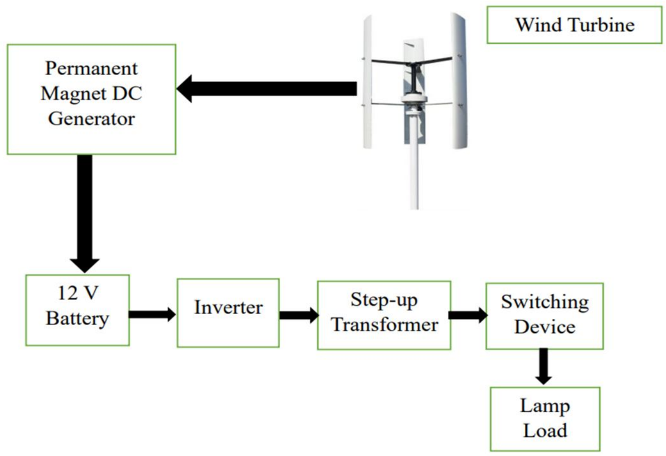


Figure 1: Block diagram of VAWT system

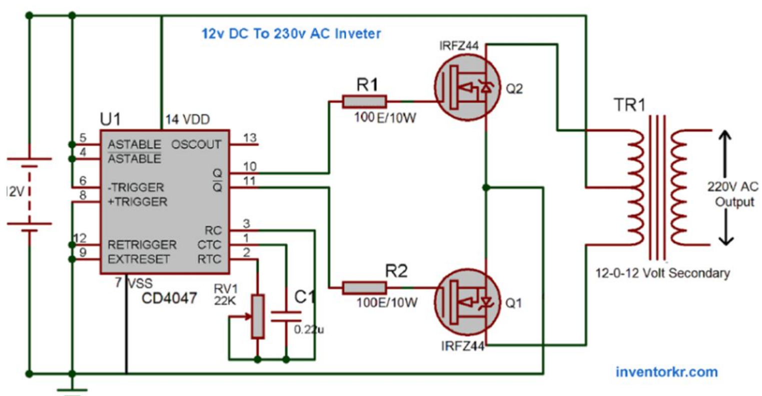


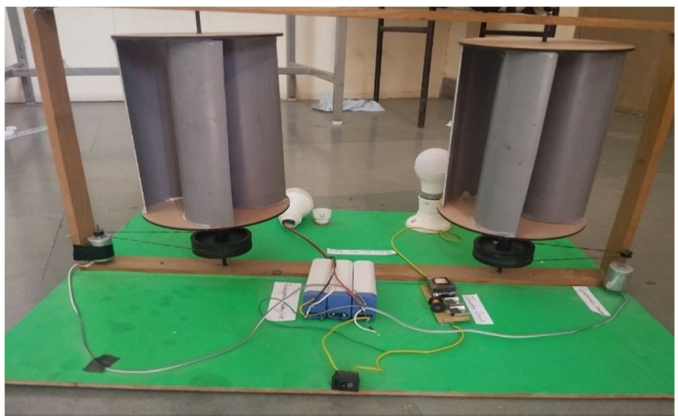
Figure 2: 12V DC to 220V AC Inverter Circuit

Figure 2 shows the circuit diagram of inverter with different components:

- Step-up Transformer: The main winding of the transformer needs to be built for a 12V input, and the secondary winding needs to be built for a 220V output. Based on your needs, pick a transformer with a suitable power rating.
- Four MOSFETs should be used to build an H-bridge in the MOSFET-Based H-Bridge design. By switching the polarity across the transformer, the H-bridge enables the transformation of DC electricity into an AC waveform.
- Add capacitors across the transformer's output terminals as a filter to tame harmonics and smooth the output waveform.
- Protection circuitry: Provide freewheeling routes for the inductive load as well as diodes to safeguard MOSFETs from reverse current.
- Integrate a voltage regulator circuit to preserve a constant output voltage.

V. WORKING METHODOLOGY

In this a permanent magnet generator with a maximum speed of 2400 RPM with output of 12 V DC is used. The generator converts mechanical energy into electrical energy produced by the wind power. As wind strikes on the blades the rotor rotates and simultaneously the generator also rotates. Then the output of generator is given to charge controller A charge controller, charge regulator or battery regulator limits the rate at which electric current is added to or drawn from electric batteries to protect against electrical overload, overcharging, and may protect against overvoltage. This prevents conditions that reduce battery performance or lifespan and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life. The terms "charge controller" or "charge regulator" may refer to either a stand-alone device, or to control circuitry integrated within a battery pack, battery-powered device, or battery charger [18]. With the help of Charge controller battery gets charged. Model consists of a rechargeable battery of 12 V to store the energy passed through the charge controller circuit. An inverter circuit is attached to a battery from which DC voltage is converted in AC voltage and passes to step up transformer which step up output voltage upto 220 V AC by which 40 W / 220 V lamp load glows.



VI. RESULT & OUTPUT

The implementation of the wind turbine vertical axis (VAWT) with the inverter has shown promising results in terms of energy production, efficiency and stability. The system has successfully transformed wind energy into a usable alternate power.

1) Power and efficiency connections
- The VAWT system efficiently captured wind energy and converted it into electricity.
- Using a permanent magnet alternator (PMA), the system generated a variable frequency alternating power, which was then remedied and turned to a stable power of 50 Hz/60 Hz.
- Implementation of Maximum Power Monitoring (MPPT) has improved energy extraction and ensured maximum use of available wind sources.

2) Quality and stability of energy
- The inverter has successfully regulated voltage and frequency, which makes the performance compatible with standard electric appliances and commercial grid.
- The system maintained consistent energy supply, even at fluctuating wind speed, due to efficient energy conditioning and integration of energy storage.

3) Storage and backup of energy
- The integration of the battery storage system has allowed continuous power supply, even during the low wind speed.
- The charging controller efficiently managed to charge and discharge batteries, ensured long battery life and reliable energy availability.

4) Environmental and economic benefits
- The system operated with minimal noise and low maintenance requirements, so it is suitable for urban and residential areas.
- The use of renewable wind energy has reduced fossil fuels relying, leading to environmental benefits such as reduced carbon emissions.
- The system has proved to be cost -effective, with potential return on investment (ROI) based on long -term energy savings.

VII. CONCLUSION

Vertical axis wind turbine has economically feasible energy solution for isolated areas missing from combined grid systems. Design of wind turbine rotor blades plays an important role in performance evaluation and extraction of energy from turbine. Vertical axis wind turbine placed in a location where moderate wind is available and by optimizing blade parameters, design specifications higher power generation can be achieved. For remote areas, the designed vertical axis wind turbine will be serving as good feasible energy generation unit.

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