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Design and Wind Tunnel Testing of Funnel Based Wind Energy Harvesting System

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Abstract

Modern wind energy systems are of giant structures having a turbine generator on the top of tower at a height of 80 metres with control mechanisms like yaw control and pitch control. With this modern wind energy systems, exploitation of wind energy at low wind speeds is not possible, operation and maintenance and yaw control are difficult. In other fact, environmental problems related to disturbance in signals and birds life are considerably high. Considering all the difficulties that are faced with modern wind energy systems, a new approach for extracting wind energy is studied here. In this paper, design and experimental setup of funnel based wind energy harvesting system (FBWEHS) is explained in detail. For studying the feasibility of this new approach, a subsonic wind tunnel testing is carried out. Further smoke test in the wind tunnel is also carried out for visualizing the flow of air into the nested funnel. The results of wind tunnel testing showed the performance of the FBWEHS, in which the velocities at the turbine section is increased by a venturi speed ratio of 1.80 to 3.22 than the inlet velocities at nested funnel. Power availability at the turbine section is also increased with increase in velocity than the power available at the nested funnel. Experimental setup of FBWEHS with a propeller blade of diameter 7cm coupled with a small size generator is used for generating power. Generated power is in the range of 0.0001 W to 9.93 W over a range of wind velocities at funnel inlet as 0.5 m/s to 7.89 m/s. With this, FBWEHS is feasible to generate more power than modern wind turbines under similar conditions of wind turbine swept area and the wind velocities by eliminating the yaw control.

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1. Introduction

Wind energy systems have been harvesting energy from the wind for centuries, from early wind mills used for grinding grains and pumping water to the present day large scale electricity generating wind turbines. Early use of wind energy for sailing ships in the Nile River was dated to 5000 B.C. Recorded history, the pneumatics of Hero of Alexandria by (Marie Boas Hall, 1971) explains the first use of wind energy [1] (Manwell et al., 2009) clearly described the existence of first wind mill from Hero of Alexandria [2]. Wind mills were in the use by Persians between 500 and 900 B.C., [3] later this was spread to surrounding areas in the Middle East and to the European nations. European wind mills made their first recorded appearance with advanced design incorporating top rotor blades and yaw mechanism that is seen in modern wind turbines. Initially in the 18th century, wind mills were meant for mechanical power, later the development of electrical generators in 19th century gave a great approach in using wind for electricity generation. In the 20th century, technological advancement in wind power conversion led to the development of modern wind turbine systems used primarily on large scale for generating electricity [2]. Today's most common design of wind turbine systems is horizontal axis wind turbine (HAWT) having a turbine generator on the top of tower of height 80 m. The present day HAWT was incorporated with highly proven technology, but still there were challenges related to exploiting wind energy at low wind speeds, operation and maintenance, changing of rotor direction as per wind direction, transportation of massive structures and installation at specific site. [4] describes few innovative concepts in wind power generation like diffuser augmented wind turbine (DAWT) to address the above mentioned challenges. The concept of DAWT is accelerating the flow of air inside the duct by inducing the mass flow rate through an intake. This will improve the output power of wind turbine that is placed optimally inside the duct. An experimental study by [5] shows the effect of diffuser length on the performance of bare and nozzle diffuser augmented turbines. However the nozzle diffuser augmentation shows the better response. An integrated ducted wind turbine with solar system was implemented by [6] for reliable power generation in Bangladesh. This system has a conical shaped duct in front of the traditional wind turbines, which allowed to extract the wind energy even at low wind speeds [6]. Even though these ducted turbines performs better than traditional HAWT, but still there are challenges of tower mounting turbine-generator and operation and maintenance. A new concept called INVELOX by Daryoush Allaei et al. [7-9] gave better performance than other traditional wind turbines as well as ducted wind turbines. In fact INVELOX is also another ducted turbine having five different parts: Intake, Pipe carrying and accelerating wind, Boosting wind speed by venturi, Wind energy conversions and Diffuser. This is having few special features: tower elimination, ground level based turbine-generator and elimination of yaw mechanism. This newly emerged INVELOX technology offered a solution to all the challenges in wind energy that we are facing today.

In this paper, the concept of INVELOX and its outer look is taken for implementing an experimental setup for demonstrating the performance based on the resources available in Karunya University. The main objective of this paper is to design a Solid Works 3-D model and to fabricate FBWEHS, to test its feasibility in wind tunnel and a comparison of power availability in wind at turbine section of FBWEHS to the power availability in wind before the wind turbine that is mounted on conventional tower is shown.

2. Design of FBWEHS

FBWEHS has three major parts: Nested funnel, Bent section and Convergent-Divergent duct with a turbine section in the center. Mathematical design of FBWEHS is done using empirical relations involved in convergent and divergent nozzle [10, 11]. Apart from the mathematical design, a 3-D modelling is done using the Solid Works and a prototype is implemented as a hardware model for checking the feasibility of FBWEHS. Each individual parts involved in FBWEHS are designed separately as follows:

2.1. Nested funnel design

Nested funnel structure is used for capturing the wind, because its ability to capture wind from all directions is possibly high. Other important factor is, the funnel design can be enhanced for smooth flow of wind into the duct by designing opening of funnel with best suitable angle. Designing of nested funnel needs a best suitable mathematical

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