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COMPUTATIONAL AND EXPERIMENTAL ANALYSIS OF EFFECT OF DIMPLED ON AERODYNAMIC PERFORMANCE OF SAVONIUS VERTICAL AXIS WIND TURBINE

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Abstract

This study assign with the design and fabrication of Savonious wind turbine with dimples on its blade surface. Savonious vertical axis wind turbine are installed in the regions where the wind speeds are not high enough for installing conventional horizontal axis wind turbines. .The paper introduces a unique concept of testing a Savonius wind turbine with dimple structures on its blades and investigating its effect on the turbine's efficiency. The study also deals with evaluated computational results using ANSYS CFX experimentally by developing a work model in the lab.Research interest for the addition of dimple structures on the blades to increase the lift and reduce the drag for the improvement of power coefficient.

Keywords: Vertical Axis Wind Turbine; Savonius; Dimples; Experimental Testing; power coefficient

1. Introduction

The world is getting hotter over the decades [2], and the emission of greenhouse gases is the major reason behind it. Thermal energy sector contributes significantly to the sources of these emissions [3] and if we want to resolve the problem we must move towards renewable sources of energy. One such renewable energy resource worth being harvested is Wind Energy. Wind energy is one of the cost-effective technologies and is a targeted sector for the electricity production units for the future. The potential of wind is an unevenly distributed commodity in the world. The Northern and Western parts of India experience much higher wind speeds than the south-western part of India [4]. As a consequence, conventional wind turbines cannot be installed everywhere. The relatively unexplored Vertical Axis Wind Turbines could prove to be very useful to bridge the energy crisis in such regions. VAWT (Vertical Axis Wind Turbine) which has two or more blades and the main rotor shaft runs vertically. Ryoichi S. Amano [5] and Ashwani K Gupta [6] have explained in detail about the research carried out on Vertical Axis Wind Turbines in the current century. Types of wind Turbine is as shown in Fig.1 below.

Savonious VAWT has many advantages over other turbines because its construction is simpler and cheaper. It rotates in a fixed direction regardless of the flow of wind direction and has a good starting torque at lower wind speeds. The performance of the Savonius rotor has been studied by many researchers to determine the optimum design parameters of this rotor.

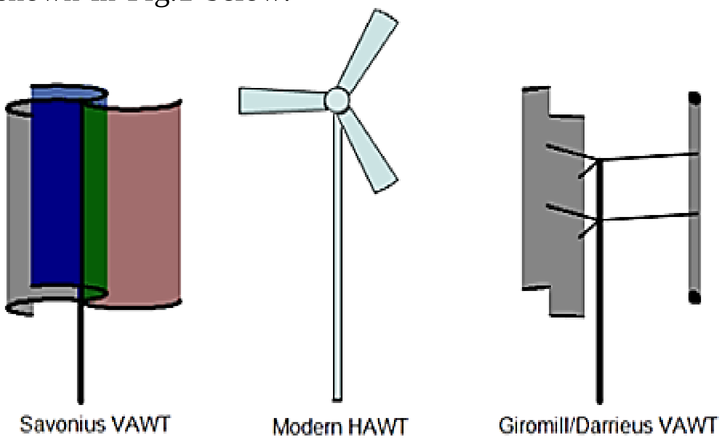


Fig. 1. Types of wind turbines

Research interest on increasing surface modifications to achieve the lift and reduce the drag has attracted greater attention in recent years. There are many techniques such as active and passive. The active techniques involve steady suction or blowing [8-10] and passive involves geometric shaping like formation of external and internal dimples and other structural modifications. External dimples have been considered in numerous research papers [11,12] which also focus on increasing lift and reducing the drag. But in case of internal dimples, formation of inward cavity has been taken into consideration. The dimples are small depressions or indentation on the surface of the turbine blade. The purpose of dimple is to create a rough surface that changes laminar flow to turbulent flow quickly. The turbulence generated helps the flow to remain attached to the surface of the blade and reduces the extent of the separated wake. The wakes reduces the drag and improve the lift in the blade [15].

Chear and Dol (2015) conducted an experiment on circular dimples to achieve lift enhancement and drag reduction. They observed that due to the presence of external dimples over the airfoil surface the drag was reduced up to 1.95% [16].The outward dimple produces lesser drag and inward dimples produces higher drag for the useful range of angle of attack. In this research, attempt has been made to study the performance difference by introducing dimples on the vertical axis wind turbine blade surface. Both computationally using ANSYS CFX and experimentally by developing work model in lab Prior to the work, an model was developed without dimples on the blade surface and performance was measured and same compared with by applying the dimples on the blade surface. The idea of additional lift generation is inspired from golf balls. A golf ball with a dimpled surface can travel longer distance than a smooth surfaced golf ball. The dimples on the golf balls provide extra momentum causing delay in flow separation thus reducing the total drag. Fig. 2 shows the effect of with and without dimples on the golf ball.

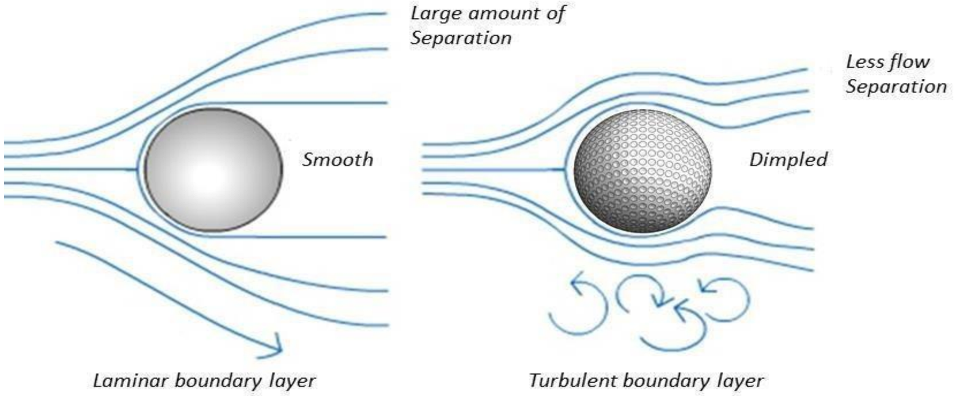


Fig 2. Golf ball with and without dimples

II.Methodology

. *Mathematical calculations*

To calculate the power and efficiency of Savonius VAWTs, one may use the following formula:

The total quantity of attainable wind power, P, equals

P = ρ × A × V32 …. (1)

Where,

ρ = a measure of the weight of the air

A = turbine's sweeping area, and

V = wind velocity.

Cp or the power coefficient, is the relationship between how much energy created by a wind turbine Po and the amount of energy it can harvest Pw from the wind.

Cp = Po Pw (Cp, max = 0.59) (2)

The most effective wind turbine design can only capture around 59% of the notional energy carried by the wind and convert it into useful electricity. Variables such as wind turbine construction quality and atmospheric conditions (such as air thickness and turbulence) all contribute to the Cp value, making each configuration unique. As a result, Cp is often essentially lower than 0.59, and although additional planning systems used in a wind turbine installation may increase overall efficiency, (such as a gearbox, generator, or guiding system) are included, productivity reduces even more. Cp is a representation of the breeze turbine's streamlined output, which accounts for losses due to choppy air and other environmental factors but not mechanical failures. So, using Eq. (2), we can calculate how much power Po the turbine gained by converting the wind into rotational energy (3) [17].

PO = ρ × A × V3CP2 ……………..(3)

Also,

PO = 2πNT60 …………………...(4)

In which,

ρ = Density of air, kg / m^3

T = wind turbine's Nm of torque

N = The rotations per minute of the wind turbine.,

A = area of wind turbines i.e. A = D x H,

V = what is considered to be the top speed, m/s

H = Windmill Height, m

The value of CP varies depending on the operating conditions of the turbine, i.e., at various turbine rotational speeds. That means the Tip Speed Ratio (TSR) λ, defined as, influences CP.

TSR = Tip Speed of the BladeWind Speed

$= V_{tip}V_{air}$ …. (5)

$= (\omega \times R) V$

Where,

$V_{tip} = \pi DN60$ …. (6)

D = Diameter of wind mill, m

B. Tool Used:

Power output is determined using a CFD study, with pressure distribution, velocity profile, and torque calculated using Ansys CFX 19.2 and Ansys Design Modeler, respectively.

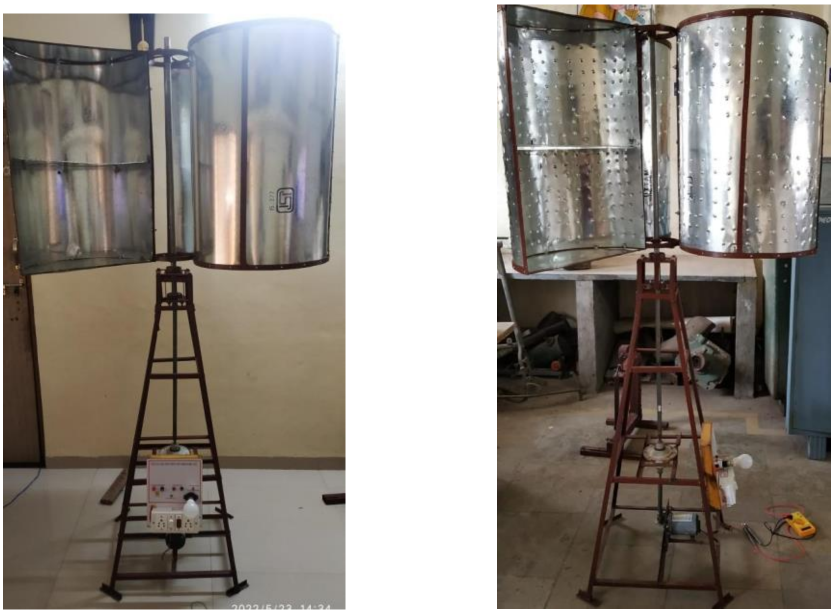
With ANSYS CFX, you can examine liquid stream, heat move, and pressure in perplexing calculations including incompressible and compressible fluids. You can bring in meshes, set materials, boundary conditions, and solution parameters, run computations, examine the outcomes, and generate reports with the help of in-built features.

ANSYS CFX is a multi-purpose Computational Fluid Dynamics (CFD) software package that includes a state-of-the-art solver in addition to robust pretreatment and post-processing tools. The following amenities are included into it:

- A dependable and robust state-of-the-art coupled solver.
- The defining of the issue, its analysis, and the presenting of the findings are all seamlessly combined.
- A configuration procedure that is both straightforward and engaging, with the aid of menus and sophisticated visuals.

III.Experimental Set-up

The experiment takes into account various models of Savonius wind turbine with and without dimple structures. These models were tested in combination by applying the wind pressure with different velocities. The overlap and aspect ratios of the turbine were chosen according to the literature survey [6-8] and the details are mentioned for each case as below: The schematic diagram of the test model shown in Fig. 3 (A) and (B) below.



(A) (B)

Fig.3 : Test Model without dimples (A) with dimples (B)

An anemometer measured the velocity of the wind. The rotation of the rotor was measured by a tachometer. Experiments were conducted for comparison of performance analysis with and without dimple structures The wind speed ranging for all the above mentioned testing was kept from 3.5 m/s to 6 m/s. This speed was taken in accordance with the design parameters. The primary objective of this research was to capture and test the performance of a Savonius turbine for low to high wind speeds which is otherwise not possible through any other wind turbines. Design parameters of the different geometry configurations used in the investigations are described below.

- **Settings for SAWTs (**computational results using ANSYS CFX)
- Mill's Floor Space = 6,667 Sq. Ft.
- The blade diameter of the wind turbine is 2.866 m
- Windmill height is 2.325 meters
- Wind turbine blade width = 0.477 meters
- Assume a molar mass of 28.96 kilogrammes per mole
- The formula for density is:
- Indicative Temperature: 25 degrees Celsius
- For reference, the average wind speed is 5 meters per second.
- 1 atmosphere is equal to 1 bar

(1) Result of a CFD study without dimples and fins

The Savonius wind turbine produces 3.64E4 kW and 115619 N-m of power and torque, respectively.

- **The velocity plot:** Besides aiding in the comprehension of the evolution of flow within the domain, this figure demonstrates that the flows at high speed near the inlet, validating the turbulent flow assumption.

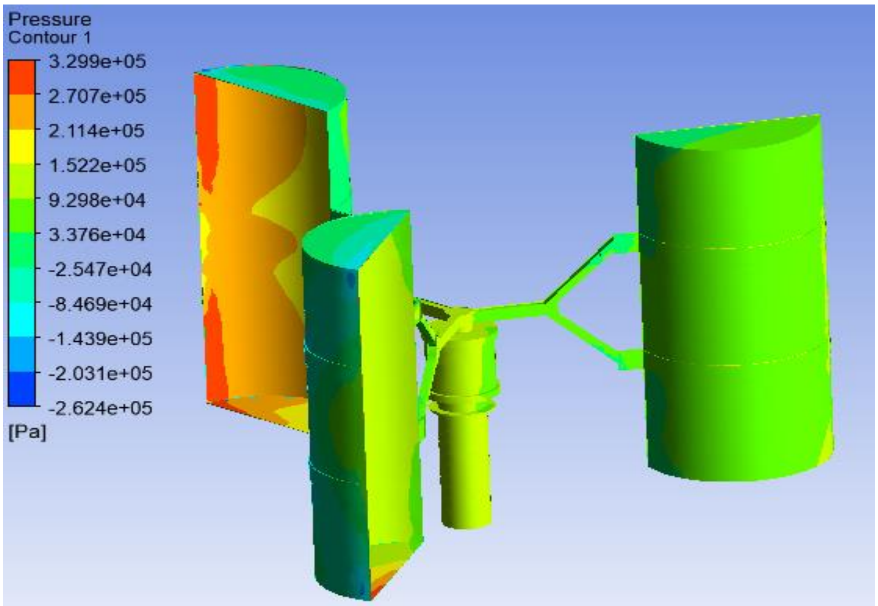


Fig. 4. SAWTs without dimples and fins have a different pressure profile on the blade.

(2) Dimpled and finned CFD findings

The Savonius wind turbine can produce 5.46E4 kilowatts (kW) and 173708 Newton-meters (N-m) of torque.

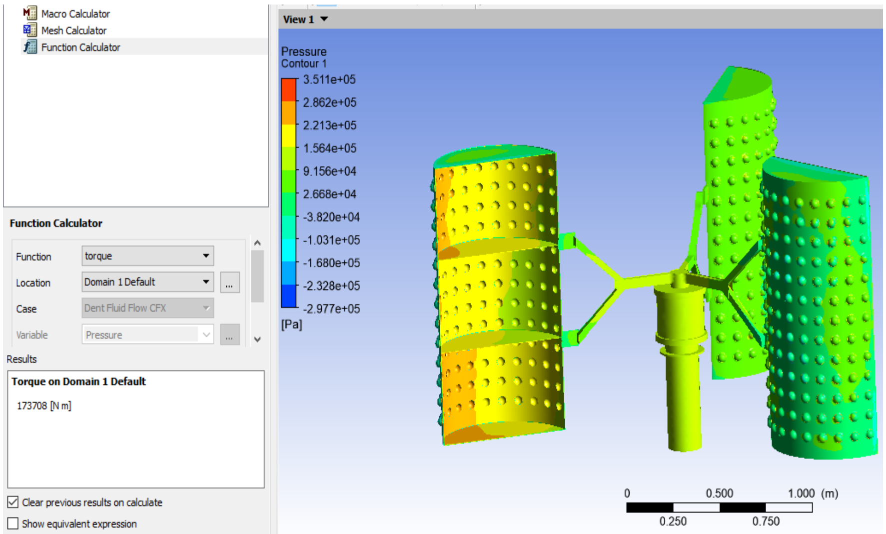


Fig. 5. CFD model with dimples and fins on a Savonius wind turbine.

When comparing dimpled and non-dimpled Savonius VAWTs, the wind turbine with dimples and fins was more efficient and produced more electricity. When compared to a conventional wind turbine, the output of one with dimples and fins is 5.46104 kilowatts (KW). Also, the power coefficient and efficiency is also high with dimples and fins.

A. Settings for SAWTs (Experimental Analysis)

After obtaining above results, experimental performance analysis was done by fabricating model Fig 3.in lab with following parameters and dimples created on them. The literature review on dimples helped finalize the size and the spacing between the dimples.

Following are the Parameters for Vertical Axis Wind turbine Test Model

Vertical axis wind turbine is design to produce 12 W

1. Height of blade (h) = 0.68m
2. Diameter of turbine blades (d) = 0.46m
3. Spacing between blades = 0.16m
4. Total Height of VAWT = 1.9 m
5. Material Of Blade = Galvanized Steel(0.4mm)
6. Gear Ratio=1:16

- Specifications of the dimples are:

1. Dimples Dia=1cm
2. Depth Of Dimples=0.4cm
3. Spacing between Dimples=2cm
4. DC Generator of Capacity 12V

Experiments were performed to compare the performance of the turbines with and without dimples. Voltage measured across the terminal, external resistance attached to the circuit. As the resistance of the DC motor is negligible when the external resistance is attached in series with the motor.

Results And Discussion

Comparison Between performance of vertical axis wind turbine - with and without Dimple Structures.

The following data were recorded during the experiments.

Table 1(A) shows wind speed versus RPM without dimples, and (B) shows wind speed versus RPM with dimples

(A)

Wind speed (m/s)	RPM
2.5	55
3.5	68
4.5	75
5	78
6	84.1

(B)

Wind speed (m/s)	RPM
2.5	67
3.5	73
4.5	84
5	86
6	90

Table 2(A) shows wind speed versus Voltage without dimples, and (B) shows wind speed versus Voltage with dimples.

(A)

Wind speed (m/s)	Voltage (w)
2.5	9.3
3.5	11.9
4.5	13.7
5	14.1
6	15

(B)

Wind speed (m/s)	Voltage (w)
2.5	11.2
3.5	13.1
4.5	16.2
5	16.9
6	18.1

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The following graph shows the relations obtained using the turbine with different configurations between various parameters for dimple and without dimple.

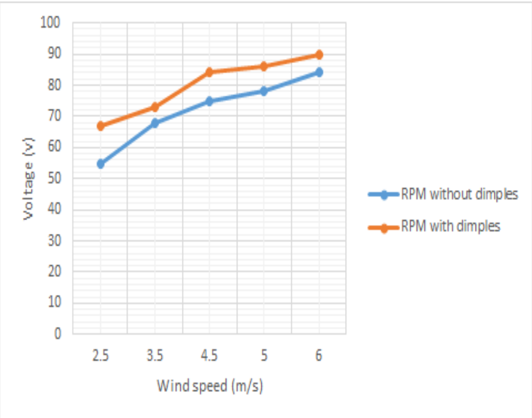

Fig.6. Variation in Voltage with wind speed with and without Dimples

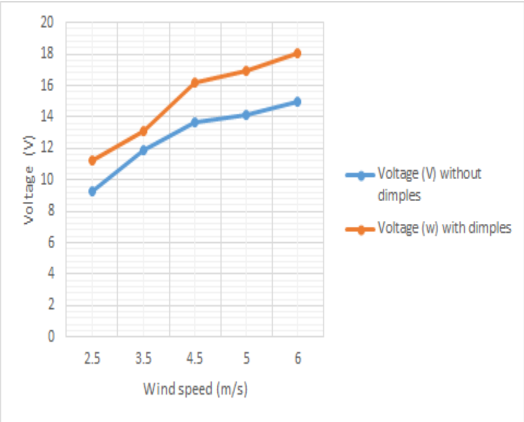

Fig.7. Variation in RPM with wind speed with and without Dimples

Conclusion

The lift enhancement of the dimpled surface has been studied both computationally and experimentally and the results are plotted and discussed based on the computational results, the dimples have been formed to have better performance and it was developed as a work model and the computational results were evaluated experimentally. It clearly shows that the experimental results do not show much variation with computational results. The difference in the result was found within the range 0-5% only.

In this work following concepts have been introduced and tested experimentally

● A performance Comparison between the turbine with dimples without dimples done.

● A concept of using dimple structures has been introduced.

Following can be concluded from the experimental results:

● Vertical axis wind turbine with dimples performs better at lower wind speeds , compare to without dimples turbine,

- The results obtained show that the dimple structures gave higher output power.
- The results obtained show that the dimple structures gave higher RPM and torque.

Innovative design and development of vertical axis wind turbine with dimples for given power output has been accomplished. The combination of these concepts in design show much promise to lower the cost to manufacturers with enhanced performance which may give a viable solution to green energy production.

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