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Performance Analysis of Wind Farm Model using Savonius VAWTs with Various Alignment having Different Diameter and Different Heights

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Abstract—*Wind power is the fastest growing renewable energy resources as fossils fuels going to be depleted in coming years. Vertical Wind Axis Turbines are less popular than Horizontal axis wind turbines because of their less power production capability. But, their use in micro-power generation is quite helpful for rural areas. In this paper, Wind farm design consists of two bladed Savonius VAWTs having different height and diameter has been studied. In this wind farm, turbines are placed in array of 3x2 matrix form. Two types of turbine are placed having blade diameter 8 cm and 6 cm and having heights are 21 cm and 15cm respectively. These turbines are put in alternate way to reduce the wake effect between them. Experiment has been performed in front of centrifugal blower RIG in open environment in free stream velocity at 15 m/s, 17.5 m/s. Cluster of wind turbines are put at 0°,5°,7.5°, 10° clockwise and anti-clock direction with respect to blower Rig's axis. After experimental investigations, concluded results shows that maximum average Cp and power output are obtained at an alignment 5° in anticlockwise direction with respect to Rig blower's axis.*

Keywords: *Wind power, VAWT, Savonius VAWT, Wind Farm, Rig Blower.*

1. INTRODUCTION

Over the past decades, the world has been concerned over the issues like climate change and depletion of fossil fuels [1]. However, depletion of fossil fuels is very far but its usage affecting the environment in worst manner and, its dominant effect declines [2]. Recently, pollution caused by fossil fuels power generation have garnered everyone's attention towards the importance of clean energy by using renewable energy. Many findings by the researchers concluded that wind and solar power are main potential sources of free, clean and inexhaustible energy [3]. Wind power alone generate 3% world's total electricity and is increasing at exponential rate with optimization of turbines and power generation related processes [4]. Wind energy is known to be the fastest growing renewable energy resource in the world with an annual growth rate of 30% [5]. Power from wind can extract with the help of wind turbine. A wind turbine is a machine that can convert the kinetic energy of the wind into mechanical power. Then by the help of generator, this mechanical power is converted into electricity. The actual conversion processes include dynamics of blade movement in air. An aerodynamic force is applied on shaft due to rotating blades. This aerodynamic force is generated a positive torque on shaft, which connected to generator [6]. Wind turbine are classified in two types:

- Horizontal Axis Wind Turbine (HAWT)
- Vertical Axis Wind Turbine (VAWT)

HAWTs are more popular than VAWTs because of their higher efficiency. In absence of power grid, their use in micro-power generation is quite helpful.

VAWTs are also classified in two types; drag type and lift type which are mainly Savonius rotor and Darrieus rotor. This study is confined to Savonius VAWTs [7].

Savonius rotor is given by the Finnish engineer S. J. Savonius in 1931, is kind of drag type VAWT. The cross-section of rotor resembled the letter 'S'. Savonius also did some experimental work on rotors. After many studies in front of wind tunnel and natural wind, he found that best model give a maximum efficiency of 31% [8].

Blackwell also studied two and three bucket Savonius rotor by varying torque and power characteristics as a function of tip Speed ratio (TSR) for different overlap ratio. Maximum C_p obtained as 0.27 for two bladed Savonius rotor at an overlap 10% for TSR 1.0. On other hand, for three blade rotor maximum C_p obtained 0.18 at an overlap ratio of 10% for TSR = 0.8 [9].

Sivasegaram used symmetrical straight walled concentrator on upstream side of rotor to study augmented power output of Savonius VAWT. By putting straight walled concentrator with different duct angles, he found a maximum C_p of 0.21 and maximum C_t of 0.31 with a duct angles 40° with power augmented factor 1.5 [10].

Kamoji et al. studied experimental work on single stage, double stage and three stage Savonius at different Reynolds numbers. He found that C_p and C_t increase with increase in Reynolds number for all rotor for same aspect ratio and by increase the number of stage aspect ratio decreases, the performance deteriorates in terms C_p and C_t [11].

Gupta et al. studied two bladed Savonius turbine by varying overlap ratio and they found 16.2% overlap condition showed maximum power extraction among all overlap ratio [12].

Morshed studied on three bladed Savonius rotor with different overlap ratio for different Reynolds number. Model with no overlap ratio showed better torque coefficient for lower Re and better power coefficient at higher Re with increase in TSR [13].

Biswas et al. did experiment work on three bladed Savonius rotor with various overlap ratio in front of sub-sonic wind tunnel with blockage effect. Results showed that the maximum power coefficient was found 47% without blockage correction with no overlap ratio and 38% with blockage correction at 20% overlap [14].

Ghatage and Joshi have done study on Savonius rotor by changing its shape. They studied both regular and twisted shape of blades. Results concluded twisted blade have better power characteristics than regular shaped blade. Among all given twisting angles, 30° give better power coefficient. Because twisted blades have higher drag on their surface [15].

2. MOTIVATION OF RESEARCH

The air coming out from industrial outlets generally has a constant wind speed. So we can use this wind for running blades of wind turbine. To find out best alignment of this wind farm design for maximum power extraction.

3. GOVERNING EQUATIONS

$$C_P = 0.5\left(1+\frac{V_0}{V}\right)\left(1-\left(\frac{V_0}{V}\right)^2\right)$$

$$TSR = \frac{\omega D}{V_\infty}$$

$$C_T = \frac{C_P}{TSR}$$

$$A = D.H$$

$$P_0 = \frac{1}{2}\rho A V^3 C_p$$

Where,

C_p = Coefficient of power

V = Upstream velocity at the entrance of rotor blade

V_0= Downstream velocity at the entrance of rotor blade

C_t = coefficient of torque

TSR = tip speed ratio

P_o = Power extracted by rotor

A = Swept Area of rotor

N = Revolution per minute

ω = Rotational Speed

D = Overall rotor diameter

H = Height of rotor

4. METHODOLOGY

Six different model of two bladed Savonius wind turbines are placed in direction of wind blower. Total area occupied by six model is 75 m × 45 m. Spacing between two successive rotors in horizontal direction is 30 cm and in vertical direction is 15 cm. The dimensions of rotor blade are d = 8 cm and d = 6 cm in diameter. Length of shaft is 48 cm and diameter is 1.5 cm. So overall rotor diameter is D = 14.5 cm and D = 10.5 cm.

Wind farm is at alignment 0° with respect to blower's axis is shown in **Fig. 1**.

First, anemometer is applied at the exit of blower to measure free stream velocity of wind, V∞. Then the same is used at inlet and outlet of rotor to calculate the intensity of wind hitting its blades. After taking the value of air velocity at the rotor inlet and outlet, tachometer is used to measure the speed of rotor in rpm. The experiment is preceded by measuring the rotor rpm up to final model of wind velocity which is 17.5 m/s. After taking reading at 0° alignment, wind farm is being put at 5°, 7.5°, 10° anticlockwise and clockwise direction w.r.t. Rig blower's axis.

As changing alignment causes change in amount of wind grasp by rotors, so it also changes their power characteristics. To analysis this effect on wind farm certain readings are taken by changing the alignment of turbine cluster.

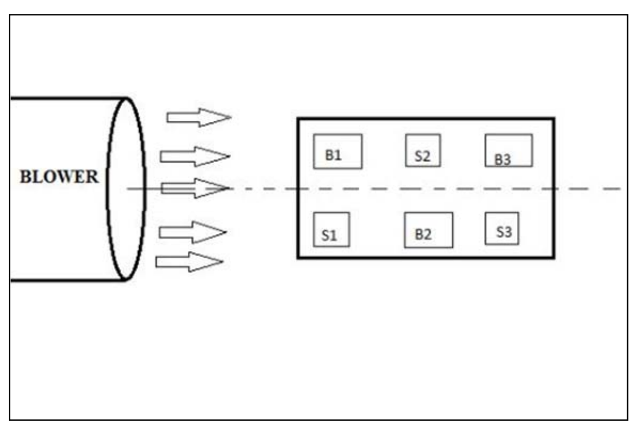

Fig. 1: Two bladed Savonius wind turbines in wind farm at 0° alignment

5. RESULTS AND DISCUSSION

Wind farm is being put in front of Rig blower at various alignment to study the effect of alignments against concentrated wind from Rig blower. Here six turbine are placed, three large sized turbine have more influence in power output than small sized turbine. But wind grasp by these turbine can also play important role in producing power. As seen in **Fig. 1**, at 0° alignment B1, B2 AND S1 rotor drive more power than any other turbine. But as change in alignment their contribution to power generation is reduce as that of others is going to increase. So rotor-wise discussion on power coefficient is illustrated through following graphs. All graphs have been plotted at free stream velocity V∞ = 17.5 m/s. All graphs have abscissa as TSR and ordinate as C_p. '+' sign indicates anticlockwise direction and '-' indicates clockwise direction.

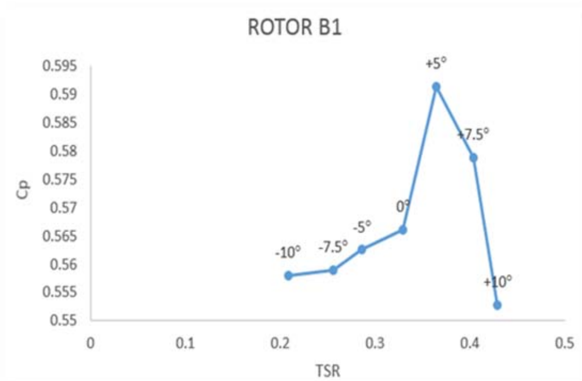

Fig. 2 Rotor B1 at 17.5 m/s

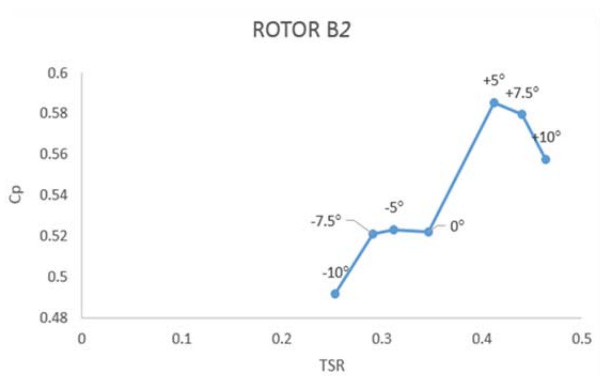

Fig. 3 Rotor B2 at 17.5 m/s

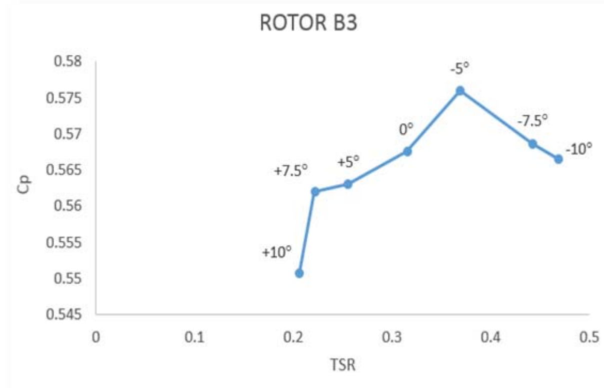

Fig. 4 Rotor B3 at 17.5 m/s

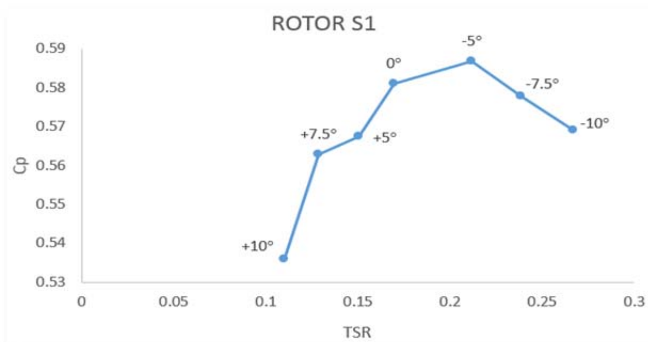

Fig. 5 Rotor S1 at 17.5 m/s

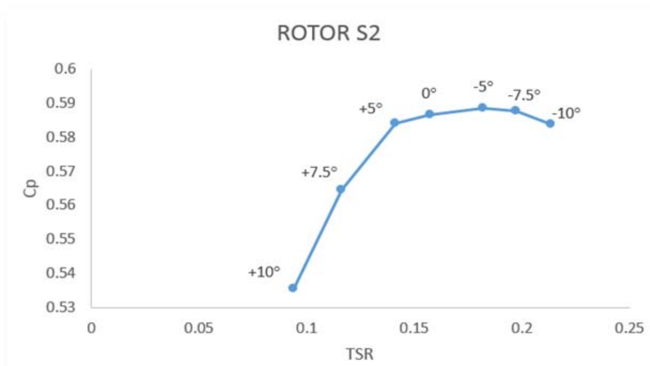

Fig. 6 Rotor S2 at 17.5 m/s

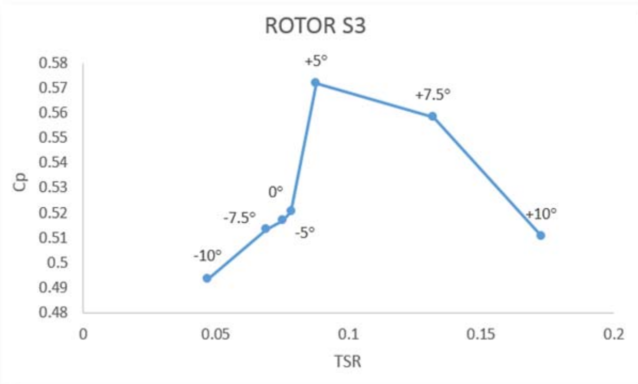

Fig. 7: Rotor S3 at 17.5 m/s

As graph illustrated B1, B2 and S3 have highest Cp at 5° anticlockwise direction. On other hand B3, S1 and S2 have highest Cp at 5° clockwise direction. Since B1, B2 and B3 are major contributor to total wind farm's power output. By the calculation, we obtained highest power output from wind farm at 5° anticlockwise direction.

6. CONCLUSION

From the experimental results it has been found that at alignment 5° anticlockwise shows maximum average C_p of wind farm model.

7. FUTURE SCOPE

- The more correct we can obtain, if we get correct position of rotor in particular area. If we applied optimization and genetic algorithm method.
- More useful result can be obtained if we put a combination of HAWT and VAWT in particular area.

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