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Performance Study of Four – Bars Linkage Continuously Adjustable Blade Angle Vertical Axis Wind Turbine

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Abstract

Drag based vertical axis wind turbine likes conventional savonius rotor suite for low wind speed but it has low power coefficient. Therefore, the present research aims to propose the resultant of improvement drag based vertical axis wind turbine by the four-bars linkage continuously adjustable blade angle. This type of wind turbine was built in lab-scale and tested in open jet wind tunnel. The linkage components were made of the aluminium. The rotor diameter is 0.8 m and 0.6 in height. To study of its performance, effects of rotor solidity, rotor tip speed ratio, statics torque and wind speed on power coefficient are investigated. At wind speed about 3.3 – 5.9 m/s and rotor solidity 0.39 - 0.8 were condition of testing. The testing results showed that this turbine have power coefficient 40% at wind speed 3.9 m/s, rotor solidity 0.8. It revealed that higher rotor solidity was higher static torque. Obviously, This type of wind turbine is suitable and useful for low wind speed conditions.

***Keywords**:* Vertical wind turbine; Four-bars linkage; Blade angle adjustable; Rotor solidity.

1. Introduction

Key world energy statistics 2015 reveals that the global power sector relies heavily on fossil fuel which consequence of global warming and climate change. Exploitation from renewable energy source to meet world's energy demand is an option to mitigate this issue. Wind power is indirect form of solar power which has rather high potential compared to others form. The technical potential of onshore wind energy is very large 20,000 x 10^9 – 50,000x 10^9 kWh per year while annual world electricity consumption of about 15,000 x 10^9 kWh [1]. The global wind power industry installed 12,105 MW in the year 2015 and increase in total installed generating capacity of nearly 20%. The cumulative global wind power capacity has grown to 432,419 MW. The countries with the highest total installed wind power capacity are China 145,104 MW, United State 74,471 MW and Germany 44,947 MW. Figure 1 shows the growing world capacity released by The Global Wind Energy Council -GWEC 2015[2].

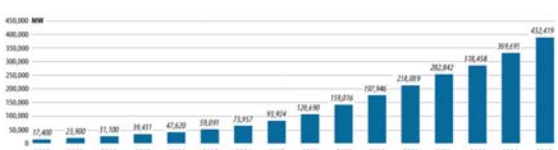


Fig. 1 Global cumulative installed wind capacity

There is no emission of CO_2 over the complete life-cycle of wind power plants [3]. Recent, according to its performance the large scale of wind power industries, horizontal axis wind turbine, HAWT is more popular these days than vertical axis wind turbine, VAWT. For the point of view decentralized power generation in micro-scale level and in low wind speed condition site the VAWT is more suitable than HAWT. Disadvantage of VAWT is low performance [4]. Currently, there are many inventors interesting to improve VAWT efficiency. Development two-bladed Savonius-style wind turbine can achieve higher maximum power coefficient of 34.8% [5]. There are some investigations used of a curtain, deflector plate or used an obstacle shielding the returning blade for improving Savonius rotor [6-8]. Using guide box tunnel is once method to enhance the Savonius rotor performance [9] also the twisted blade can provide smooth running higher efficiency and self-starting capability of Savonius rotor [4].

2. Experimental setup

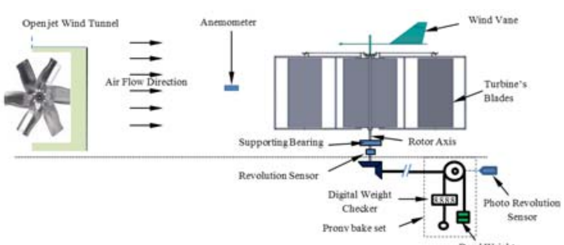
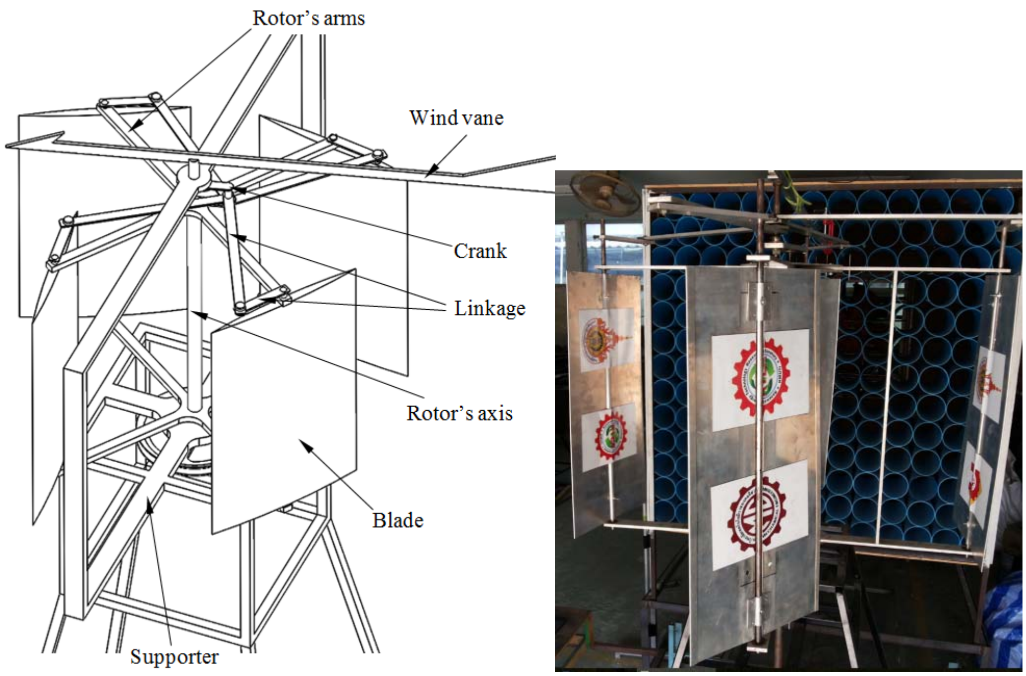


Fig 2. Schematic diagram of the experimental setup

Fig. 2 shows the schematic view of the experimental apparatus, open jet wind tunnel and four-bars linkage continuously adjustable blade angle vertical axis wind turbine (FBVAWT). The outlet cross sectional area of the open jet wind tunnel is 1.45 m X 1.45 m. The wind speed at the tunnel exit could be varied from 2.5 to 7 m/s. A prony friction bake was used to measure the torque, while a digital tachometer measured the rotational speed (RPM) of the rotor. An accuracy of digital tachometer is ±0.05%. A propeller probe anemometer with an accuracy ± 0.1 m/s was used to measure the wind speed and its station is 0.45 from the tunnel exit. The wind turbine consisted of four blades which made from 1mm thickness aluminum sheet. All of turbine blade attached to individual vertical alignment metal pivot that was supported by rotor arms. The length of rotor arm is 0.4m and rotor height is 0.58m. The rotor arms attached to vertical main rotor axis which supported by bearings in fixed bed. The main rotor axis was kept at a distance of 1.05m from the tunnel exit and was elevated height about the middle of the tunnel exit. The torque of rotor was measured by prony fiction bake which was connected to main rotor axis with right angle gear box to change shaft direction. The photos of test rotors are shown in fig. 3. The static torque was measured at 0, 30, 45 and 60 degrees of rotational rotor angle as the main rotor axis was fixed by the friction of prony bake. The dynamic torque and rotational speed were measured about 2 minutes (steady state of rotational shaft speed) after adding weighed load on prony friction bake. Three difference of rotor solidity (with changing rotor blade size) were carried out at given wind speed (3 to 6m/s).

Generally the performance of the turbine is often measured in terms of power coefficient(Cp) and static torque (Ts) which are expressed by the following equations:



(a) (b)

Fig. 3. Shows (b) components of four-bars linkage wind turbine and (a) photo of tested model

$$C_p = \frac{P_{turbine}}{P_{available}} = \frac{\tau\omega}{0.5\rho A V_\infty^3} \quad (1)$$

$$RTSR = \frac{R\omega}{V_\infty} \quad (2)$$

$$\sigma = \frac{Nb}{2\pi R} \quad (3)$$

Where ρ is the density of air(kg/m^3), V_∞ is the free stream wind speed(m/s), A is the swept area of the turbine(m^2), *RTSR* is the rotor tip speed ratio, R is the radius of rotation of the turbine(m), ω is the angular velocity of the turbine(rad/s), $P_{turbine}$ is the power produced by turbine(W), $P_{avialable}$ is the power available in the free stream wind(W), T is the dynamic torque on the turbine(Nm), N is the number of turbine's blade and b is the width of the blade(m), respectively.

3. Results and discussions

Experimental model is tested at wind speed of 3.3-5 .9 m/s to examine the power coefficient (C_p) and static torque (T_s). With the change of load at rotating conditions the C_p is calculated with respect to rotor tip speed ratio RTSR. Whereas the T_s is obtained at various turbine's axis angular positions ($\theta = 0^\circ$, 30°, 45° and 60°) with respect to wind direction as shown in the Fig 2.

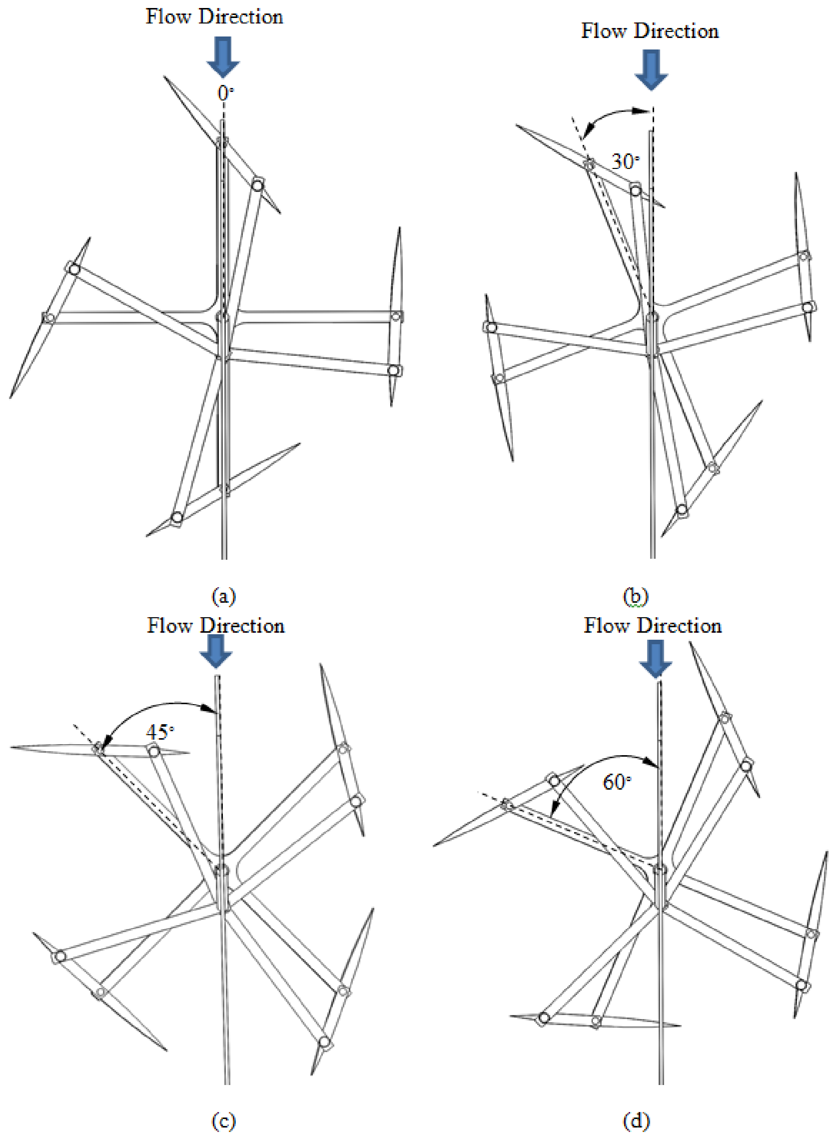


Fig 4. Rotor rotational angle of four-bars linkage wind turbine
(a) Rotor rotational angle 0° (b) Rotor rotational angle 30°
(c) Rotor rotational angle 45° (d) Rotor rotational angle 60°

3.1 Effect of rotor solidity on power coefficient

Initially, effect of rotor solidity on power coefficient was examined for various the wind speed as shown in fig. 5. The experimental results reveal that the higher rotor solidity value leads to the higher power coefficient at all wind speed conditions. At the rotor solidity = 0.8, four-bar linkage wind turbine achieve the highest power coefficient of 0.4 at *RTSR* = 0.5 for wind speed is about 3.9 m/s. Lesser rotor solidity reduces power coefficient of turbine. This was basically due to at the higher rotor solidity had more effective blade area to receive the drag force exertion from wind stream. The variations of power coefficient respect to *RTSR* was shown in fig. 6 for study effect of wind speed at various of rotor solidity = 0.8, 0.47 and 0.39. In all the case, the power coefficient increases with increase of *RTSR* up to a certain maximum value, beyond which it decreases with further increase in *RTSR*. This is mainly caused by the gradual loads applied to the turbine shaft, which in turn, reduce the turbine rotational speed.

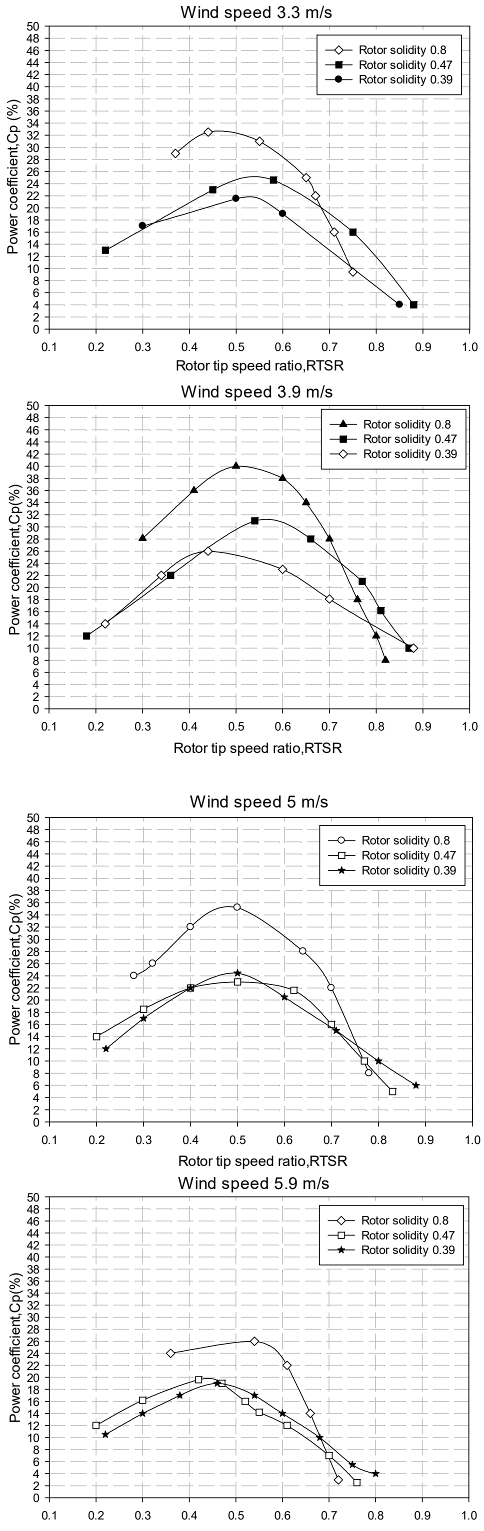


Fig 5. Shows effect of rotor solidity on power coefficient

3.2 Effect of wind speed on power coefficient

A comparative study was carried out for wind speed = 3.3, 3.9, 5 and 5.9 m/s respectively. In all the case, at the wind speed of 3.9 m/s shows the highest value (0.4) in the power coefficient as compared to the other wind speed conditions. Beside at wind speed = 3.9 m/s, the obtained power coefficient for four-bars linkage wind turbine gradual decrease. From this point of view, this type of wind turbine is preferred low wind speed condition.

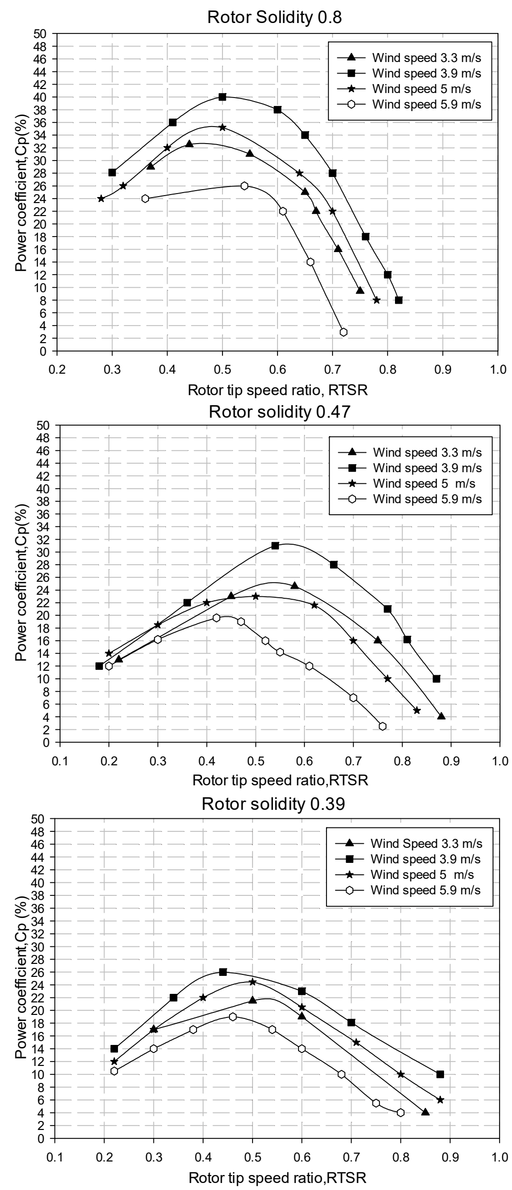
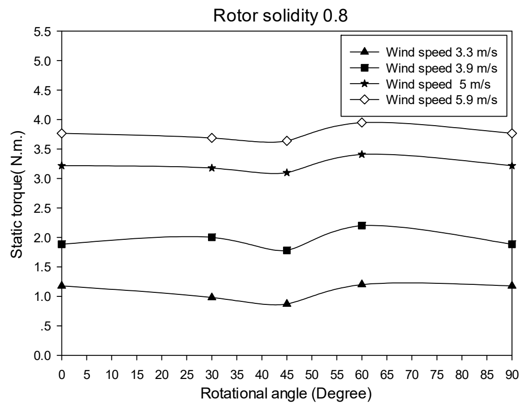


Fig. 6 Illustration of the effect of wind speed on power coefficient

3.3 Effect of wind speed on static torque

Fig. 7 demonstrates the effect of wind speed on static torque. It can be seen that the static torque value increase with the increase in the wind speed. The peak starting performance is seen at shaft rotational angular position = 60° whereas the maximum static torque is obtained. The negative static torque were not found for all tested condition case. Similarly, fig 8 shows obtained higher static torque value with the higher in rotor solidity.



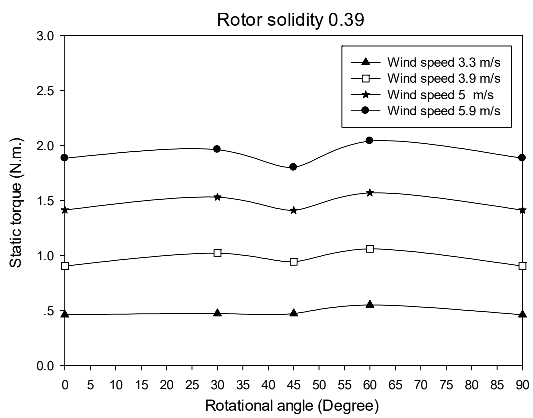


Fig. 7 demonstrates the variation of static torque for various shaft rotational angular

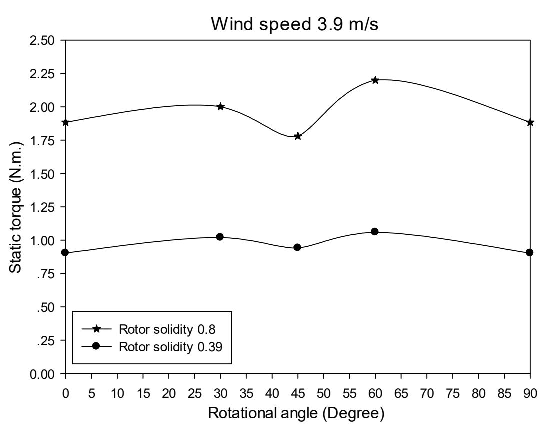


Fig. 8 demonstrates the effect of rotor solidity on static torque for various shaft rotational angular

4.Conclusions

The drag based type rotor is a promising concept for small-scale wind energy devices. However, it suffers from a rather poor efficiency. To improve the performance of the wind turbine, there for the, four-bars linkage continuously adjustable blade angle vertical axis wind turbine (FBVAWT) was proposed. The resulting of using the principle of the four-bars linkage mechanism leads to higher efficiency and better self-starting capacity. The study results could be concluded as follows:

- FBVAWT, a noticeable improvement in the maximum power coefficient is achieve of 40% at *RTSR* = 0.5 and at wind speed = 3.9 m/s.
- FBVAWT provides the results which indicate that had not be seen negative torque in all rotor rotational angular position, thus FBVAWT has better self-starting prospect.
- FBVAWT tested model, the power values are experienced at an optimum rang of *RTSR* = 0.45-0.55 for all tested conditions.

5. Acknowledgement

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