IOP Conf. Series: Materials Science and Engineering **732** (2020) 012054 doi:10.1088/1757-899X/732/1/012054

Study of comparison of tail wind turbines in wind power plants

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Abstract. The windmill tail that is widely used is a single tail that has a performance of a large zero offset. This study is to get a windmill tail pattern with a fast response and good direction stability. The aim of this study is to obtain a windmill tail pattern with the most stable direction stability under load conditions and changing wind direction by comparing the stability of several alternative windmill tail patterns. The process of data collection is done by comparing the performance of 3 types of windmills: single tail, semi-differential tail, and differential tail. The variables are speed of wind direction, speed of change of wind direction, differential angle of zero offset error, speed of change of direction, and torque produced. The material obtained from the test results was transcribed and analysed. The results of the analysis are used to design windmill tail prototypes. From the analysis results show that the swing torque at the differential windmill tail is proportional to the sinusoidal swing angle, the differential angle gives the effect of the torque scale in a cosine manner. Whereas on a single pinwheel produces torque proportional to the sine squared with respect to the swing angle. The differential tail has performance with better speed and stability, but produces vertical vibrations so it is preferable to use a semi-differential pinwheel with a differential angular size tuned in the system.

1. Introduction

The power generated by windmills depends not only on the wind speed, but also on the wind profile. This variability can be caused by atmospheric stability, which affects the average profile of wind speed, direction, and turbulence across the rotor disk [1,2]. Wind turbulence can be caused by blade rotation, blade angle, but can also be caused by changes in wind direction that form irregular three-dimensional patterns resemble the flow of water in a river [2]. Although the wind direction is in a three-dimensional pattern, the vertical direction is not a mainstay energy source unless it is only a disturbance. Only the resultant horizontal wind speed or the average movement of the wind is ready to be converted into kinetic energy inside the turbine shaft. To get optimal power, windmills need to be equipped with a horizontal resultant wind direction tracking device. To deal with wind direction, small wind turbines use mechanical systems in the form of tails [3]. In some types of windmills are equipped with a windmill tail as a wind tracker. There are several types of use of the windmill tail model, some are active as well as passive. Some form of passive pinwheel tail, some are made in 2 dimensions, also three dimensions. Two-dimensional shapes include [3]: rectangular, trapezoidal and triangular shapes and three-dimensional shapes include [4]: 1) vane shape, 2) fan shape, 3) cone shape.

In certain areas, the wind direction can be considered fixed, so the windmill is positioned in a certain and fixed direction. Although in general, the ever-changing wind direction causes windmill turbines to always move in the direction of the wind [5]. But for simplicity and convenience, wind tracking is not used with the consequence of decreasing effectiveness in energy conversion.

In large windmills, the movement of the windmills is controlled by electronic devices as active tracking [3], but for small windmills it is sufficient to use mechanical windmills as wind direction guides [6]. There are many forms of windmill tails applied, but technically the two-dimensional shape with the shark's dorsal fin pattern as shown in Figure 1 is widely applied. This shark's dorsal fin pattern which we later call a single tail type. Allegedly, the single tail type has a wider and most unstable area, that is, in conditions that have been in the direction of the wind direction, there is no longer a force that maintains its position. The presence of unstable areas causes greater offset errors and controls become less stable, and is predicted to reduce efficiency, and can mechanically shorten service life.

A single tail system can be developed into a differential tail system. The differential tail system is made to resemble the pelvic fins and shark pectoral fins. This fin consists of two parts, namely the left side and the right side, each of which forms a differential circuit. This differential model is expected to minimize the offset error, but is forced to sacrifice its torque on a large deviation error. In this model, every small error move will produce feedback twice the swing force of a single tail type. The swing torque characteristic settings can be adjusted via its differential angle. Because of this three-dimensional pattern, symmetry and sturdy construction must be made, asymmetry of the tail causes a vertical directional movement which can reduce the wear mas of the turbine. This technique is offered in this study to display its flagship characteristic, namely it’s zero offset error (steady state error) which is much smaller.

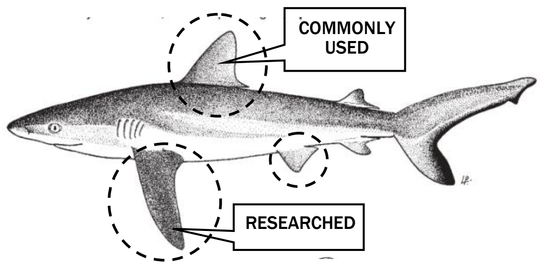


Figure 1. Sharks [4].

2. Literature review

2.1. *Wind energy*

The potential of the wind is sufficient to provide the supply of its energy needs and can even be predicted to have a capacity three times greater than its needs [7]. There are two kinds of seasonal winds, namely west monsoons and east monsoons. The west monsoon moves from Asia to Australia, the east monsoon moves from the Australian Continent to the Indian Ocean. Local winds occur in a particular place, which can be distinguished: 1) sea winds, 2) land winds, 3) mountain winds, and 4) valley winds. Fohn's wind is the wind that comes down from the mountain slope [8].

In a large scale, it appears that the wind pattern is quite flat, but when examined at various points, it turns out that the direction of wind motion is very uneven, moving turbulence. The distribution of the wind direction (windrose) is the dominant wind direction that occurs, so that the energy distribution can be calculated based on the distribution of the wind direction. The distribution of wind direction is not necessarily its energy potential [9], so not all wind can be extracted into power in a windmill, and for detailed power calculations it becomes very difficult except by taking the assumption of a constant called the power coefficient. The energy obtained from wind power is the kinetic energy of time unity [9,10]. If Aef states the cross-sectional area and V represents the wind speed, the available power (P) is expressed by equation (1) [10].

$$P = \frac{1}{2}\rho A_{ef}V^3 = 0{,}6\ A_{ef}V^3\ \left(\frac{watt}{m^2}\right) \tag{1}$$

This power is used to provide swing torque (τω) on the tail of a rotating windmill, when in a position forming an angle equation, then equation 2 applies.

$$\tau_\omega = \frac{P}{\omega} = \frac{0{,}6AV^3 Sin\theta_\omega}{\omega} \tag{2}$$

Because the effective cross-sectional area changes with every change in the position of the windmill's tail, the torque used to provide swing resistance also changes, so does the rotational speed of the windmill's tail also causes the torque to change. There are two variables that affect the amount of torque, namely changes in effective cross-sectional area and rotational speed. In a single pinwheel, if the wheel does not move then the amount of power (*P* = *F*) generated on the pinwheel, and the static torque at the angle θs is shown in equation (3).

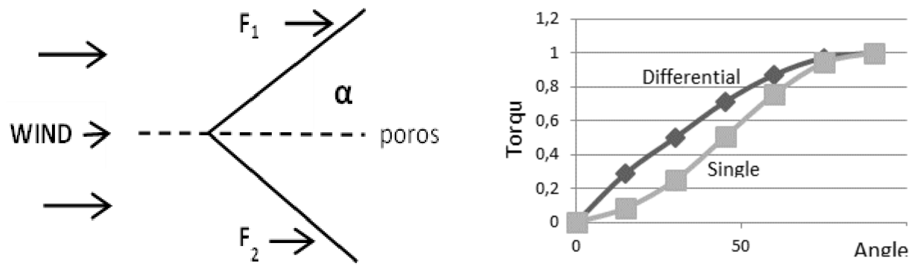
$$\tau_s = 0{,}6\ (A\ sin\ \theta_s)V^3(r \sin\theta_s) \tag{3}$$

If in the measurement, the wind direction and wind speed are not changed, the cross-sectional area (A) and arm length are also fixed, a constant k can be derived from the product of $0.6\ AV^3r$. which is referred to as a static torque constant, which affects the torque scale.

$$\tau_s \approx \sin^2\theta_s = k_\sigma sin^2\theta_s \tag{4}$$

For the tail wheel differential as shown in Figure 2, under equilibrium conditions, $F_1 = F_2 = k_\sigma sin^2\alpha$. If the tail moves its angular position by θ, then the force on one side will change to $k_\sigma sin^2(\alpha+\theta)$ and the other side becomes $k_\sigma sin^2(\alpha-\theta)$ and the resultant force becomes$k_\sigma\{sin^2(\alpha+\theta) - sin^2(\alpha-\theta)\}$.

$$F_r = k_\sigma\, cos\,\alpha\, sin\,\theta = k_{\tau DIf} \sin\theta \tag{5}$$



(a) (b)

Figure 2. Torque sketch of a full differential ferris wheel a) Direction of force / torque on differential ferris wheel b) Comparison of windmills torque.

2.2. *Windmill tail model*

Wind turbines based on the direction of rotation can be divided into two types, namely: 1) horizontal axis or Horizontal Axis Wind Turbine (HAWT), and 2) vertical axis or Vertical Axis Wind Turbine (VAWT). In HAWT usually requires a windmill tail that serves as a tracking wind direction [11].

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2.2.1. Passive wind counter swinging model. In general, small-scale windmills use a single tail pattern, which is made to resemble the shark's dorsal fin. Its characteristic is that it has a large torque at a large intersection, but has a small torque at a small intersection, causing a greater steady error. In figure 3, several windmill tail models are shown. In the fan model windmill, the tail of the windmill moves to pull the wheel to the correct position. Because fan rotation is caused by wind, this fan also becomes ineffective if the wind direction does not match the direction of the fan. The conical tail model is made to rely on the characteristics of a very small zero offset, but ignores torque at large drift errors. If there is a change in wind direction that is large and fast, then the response is slower due to the low torque under these conditions.

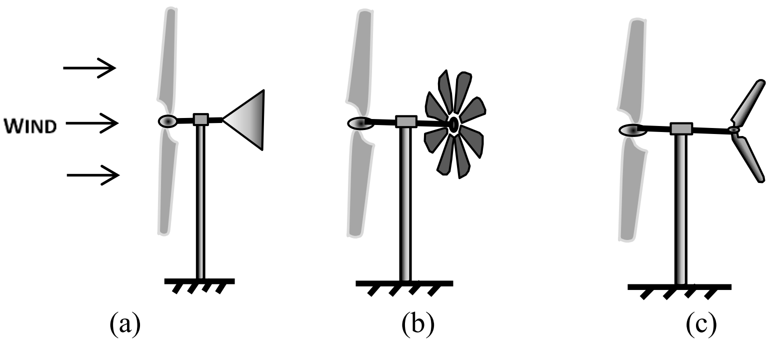

Figure 3. Several passive windmill tail models [11] a) single swinging tail, b) Fan swinging tail, c) Conical swinging tail.

Figure 4a shows the tail of a single fin model that resembles a shark's dorsal fin, and in Figure 4b it shows a tail of a differential model designed based on the shark's pectoral or pelvic fin. The pinwheel that resembles a shark pectoral or pelvic fin is called the tail of the differential wind-fighting swinging model, as shown in Figure 6b and Figure 7. This pattern has the advantage that small deviations in the wind-resisting tail have larger counter-torque compared to a single tail. But conversely, at a greater angle of drift (extrusion of 90o) it has a smaller counter torque compared to a single tail pattern. This turbidity has a smaller offset error.

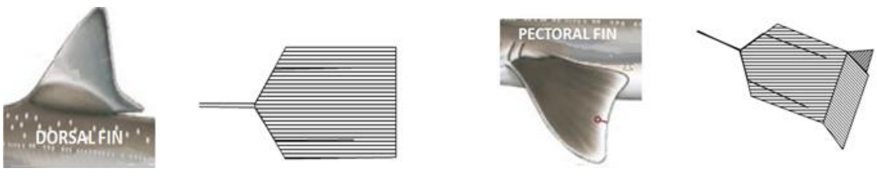

Figure 4. Comparison of (a) single tail model and (b) differential tail model.

2.2.2. Active Wind Counter Swinger Model. In the active wind-counter swing model, the tail functions as a wind direction sensor. Then electronically used to control the direction of the windmill so that it can be maintained always facing the wind direction. Therefore, in such a system a small tail wheel is needed, but to move the windmills in the right direction, a large amount of electricity is needed to supply the servomotor.

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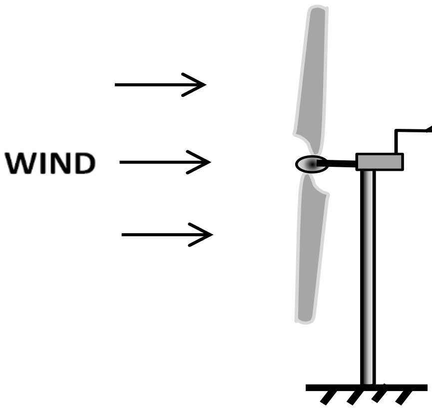
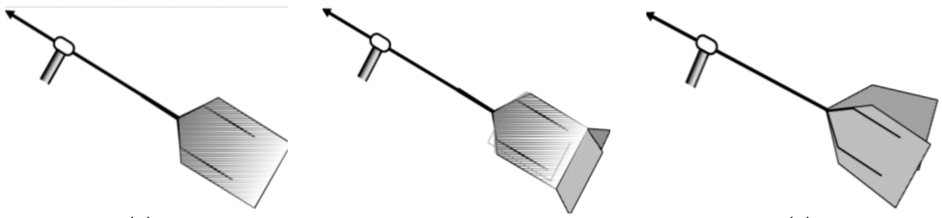


Figure 5. Active wind counter swinger model.

3. Data and methodology

3.1. Design of windmill tails

Three types of windmill tail patterns were made, each: 1) a single pinwheel, 2) a semi-differential pinwheel, and 3) a differential pinwheel. Figures 6 and 7 show the design sketch of 3 types of windmills and their implementation. Force measurements are made on the back side at the same distance for each pinwheel, to get the same moment force.



(a) (b) (c)

Figure 6. Windmills a) single, b) semi-differential, and c) differential.

Figure 7. Implementation of differential model windmills.

3.2. Static testing

The average speed of the wind on land is very dependent on the place and time of wind speed measurement. The measurement results at the measurement location of the residential area with a height of 8 meters show wind speeds ranging from 0 - 5 m/s. In September, average wind speed is close to zero in the morning and around 2-5 m/s in the afternoon. Because of the large variations in wind speed, measurements are made at times when the wind speed exceeds 2 m/s. Wind speed measuring instrument used can only measure in the perpendicular direction which is controlled by another windmill tail tracker. Three-dimensional (vertical) wind direction and turbulence are set to be as small as possible to be ignored. The size of the pinwheel that was tested had a length of 40 cm and a width of 20 cm, with the length of the pinwheel tank 40 cm, so that the total length of the pinwheel tail was 80 cm. Figure 8 shows the measurement method and the results of the measurement of torque to the wind speed are shown in Table 1.

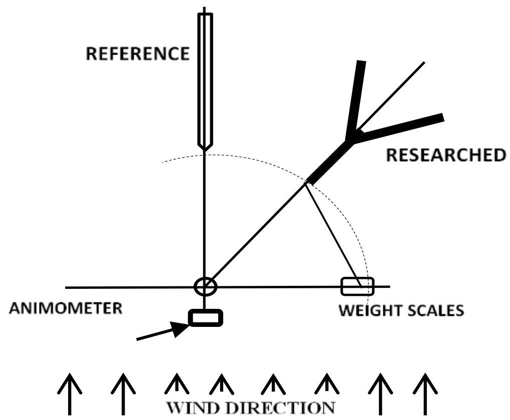


Figure 8. Static torque measurement method on windmills tail.

Table 1. Torque data at various angles.

Angle of Tail	Wind velocity (m/s)	Single Tail Torque (kgcm)	Differential Tail Torque (kgcm)
15	1.8	0.10	0.35
30	2.0	0.36	0.60
45	1.8	0.60	0.87
60	1.7	0.86	0.95
75	2.2	1.35	1.40
90	2.8	1.83	1.80

3.3. Dynamic testing

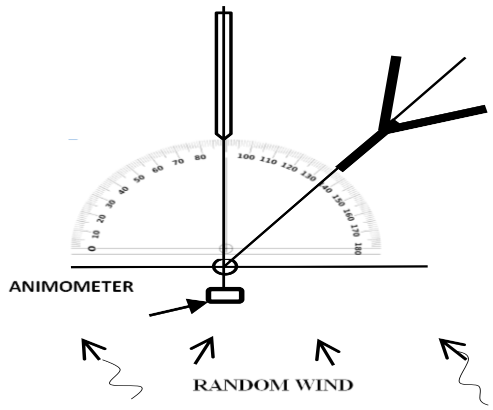


Figure 9. Method of measuring dynamic responses to windmills tails.

In Figure 9, the method of measuring the response of the windmill tails is shown. Because data retrieval uses natural wind as a result, data is obtained momentarily and this incident cannot be repeated. Data reading is taken from the ploter indicator. Figure 10 shows two examples of the movement of the windmill tail to natural wind changes. The swinging motion of each tail is compared to the reference point, the angle of intersection towards the reference and recorded to determine the difference in response. In testing it cannot be done in the same position at the same time, but it should be tried as close as possible, that is, a distance of 30 cm measured from the pivot point of the two pinwheels.

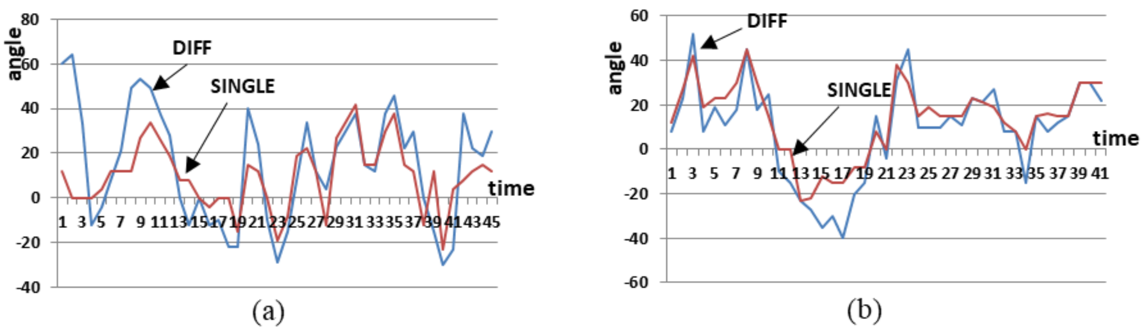


Figure 10. Response of windmill tails to natural winds

4. Results and discussions

4.1. Static

It is impossible to take measurements at the same natural wind speed. But it is known that the torque generated is proportional to the wind speed, therefore by using a comparison the torque amount can be calculated at a particular wind speed. Here to facilitate analysis can be done by means of all quantities calculated by dividing the torque of the measurement results to the wind speed when the measurement so that the unit torque is obtained (ie: torque at wind speed 1 m / s). The obstacle found in measurements using natural wind is the tail that is always moving, so the value of the measurement results also always change quickly. The movement of the tail will produce a beat to the gauge. The response of the torque gauge to the torsion of the torsion is still questionable. Waves such as flags on the tail of a windmill are very difficult to convert to static torque values, so this method of measurement still needs to be reconsidered.

4.2. Dynamic
At low wind speeds below 3 m / s, the distribution of wind flow away from the direction of straight motion, this event can be observed from the position and movement of the two tails compared, the difference in the angle of intersection can reach 45o in more than 3 seconds. But at wind speeds of more than 3 m / s, the positions and movements of the two tails move in the same direction although it is very rare to find a stable point for a long time. The two windmills always move like a flag fluttering. The tail swing always happens, this shows the importance of implementing the windmill tail with the right design. The dynamic response curve shows that the differential tail is more responsive than the single tail, too. Every swing movement, the differential tail always precedes the single tail movement, also with a larger deviation of about 1.5 times the deviation that occurs in a single tail, faster movement is not overshot because one side of the pinwheel generates a fast swing torque, while the side others provide good attenuation when the swing angle is smaller. In Figure 10a, the average wind speed is around 5 m / s, and in Figure 10b the average wind speed is around 3 m / s. It appears that the wind speed is greater, the differential pinwheel is more responsive, and the lower the responsiveness the more down, but still not lower than the response of a single pinwheel. The steady state was never achieved because the wind direction always changes. Testing with focused wind is not done because it will not be able to tell anything.

5. Conclusions
The differential response of the pinwheel is faster and the swing is about 1.5 times greater than that occurs in a single pinwheel. The amount of swing torque produced by the differential tail is proportional to the sine of the swing angle, whereas the swing torque at the single tail is proportional to the square of the swing angle. In the differential tail, as long as the swing angle is smaller than the differential angle it produces a greater swing torque compared to the torque generated in the single tail. The torque curve of the differential tail can be adjusted by adjusting the differential cutting angle and differential angle in obtaining the swing torque that suits your needs.

Acknowledgments
The author would like to thank Director and UPT P2M, Malang State Polytechnic who have given us the opportunity to carry out this research.

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