Сучасний напрямок розвитку вітрових турбін більше направлений на горизонтальні типи вітрових турбін завдяки їх ефективності, що перевищує ефективність вертикальних вітрових турбін. Однак існують деякі переваги вертикальних вітрових турбін у вигляді масивних і малогабаритних турбін. У даній статті основна увага приділяється розробці вертикальної вітрової турбіни між турбінами Савоніуса і Дар'є, що має подвійний вал на одному вітроенергетичному агрегаті.

Вертикальна конструкція турбіни з двома близько розташованими турбінними валами призначена для підвищення ефективності турбіни і збільшення питомої потужності. Однак така конструкція також впливає на всенаправлений характер вертикальної одновальної турбіни.

У даній роботі досліджується зміна всенаправленого характеру гібридної вертикальної двовальної турбіни і вплив моделей лопаті для відновлення властивостей всенаправленої турбіни. Також проводиться оцінка продуктивності прототипу з використанням направляючих лопатей і без них.

Всенаправлений характер є однією з переваг вертикальних турбін, проте в конструкції з двома осями всенаправлений характер змінюється та може впливати на загальну продуктивність вертикальної турбіни.

Результати експерименту показують, що вертикальні гібридні турбіни як і раніше володіють всенаправленими властивостями, а використання лопатей збільшує значення TSR (окружна швидкість кінців лопатей) щодо швидкості вітру, підвищує Cp (коефіцієнт потужності) вітротурбіни і механічний енергетичний потенціал турбіни

Ключові слова: гібридна вертикальна вітрова турбіна, направляюча лопать, TSR, Cp, продуктивність

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PERFORMANCE INVESTIGATION OF DUAL SHAFT HYBRID VERTICAL TURBINES USING DIRECTIONAL FINS

Erwin Erwin
Assistant Professor*
E-mail: erwin@Untirta.ac.id

Tresna Priyana Soemardi
Professor**
E-mail: tresna.p.soemardi@gmail.com

Adi Surjosatyo
Professor**
E-mail: adisur11@gmail.com

Sakti Nurfuadi*
E-mail: sakti16nurfuadi@gmail.com

Slamet Wiyono
Assitant Professor*
E-mail: maswie@Untirta.ac.id

*Department of Mechanical Engineering
Universitas Sultan Ageng Tirtayasa
Jl. Jenderal Sudirman Km 3, Kotabumi, Kec. Purwakarta, Kota Cilegon, Banten, Indonesia, 42435

**Department of Mechanical Engineering
Universitas Indonesia
Jalan Kampus UI, Kukusan, Beji, Kukusan, Kecamatan Beji, Kota Depok, Jawa Barat, 16424

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1. Introduction

The development of research in vertical wind turbines is not as fast as the development of horizontal turbines, but vertical turbines have several advantages over horizontal turbines, namely better power density, shorter wake effect than horizontal [1, 2].

Investigation of the suitability of wind turbine types in the tropical country shows that vertical wind turbines of small size are more appropriate than horizontal wind turbines [3].

Improvement of hybrid vertical wind turbines with two turbine shafts in one turbine unit is aimed at improving turbine performance and efficiency [4], intended for wind hybrid renewable energy generation and biomass gasification [5]. New problems arise with the changing omnidirectional nature of single shaft turbines to dual-shaft turbines.

Vertical hybrid turbines have been developed by the authors to be combined with thermal biomass [5]. The wake effect that arises in farm array has also been investigated by using computational fluid dynamics [6].

2. Literature review and problem statement

The results of the research are given in [1]. Vertical turbines have great potential to be used as farm arrays, but the questions connected with turbine performance with changes in wind direction remained unresolved. The reason for this may be because the focus of the investigation at that time was to increase efficiency in the turbine position adjustment system towards the most significant average wind direction throughout the year. An option to improve the corresponding may be on the improvement of wind turbine structures.

It is this approach that fins were used in horizontal [7]. However, it still does not improve the omnidirectional nature of vertical turbines.

All this allows us to argue that it is advisable to conduct a study on the analysis of changes in vertical wind turbine performance using directional fin.

The first development of fins for wind turbines and the response of the steering fin to yawn [8]. Previous research has analyzed the standard form of the steering fin. On the yaw response experiment has been carried out on several standard types of the steering blade such as rectangular profiles, triangles, and others. The Delta wing profile results give better results than rectangles and squares, but the difference in the resulting performance is not too significant. The difference is not greater than the standard deviation of rectangle and square [7–9].

In other studies, a wing or directional fin with an aspect ratio of 0.5 to 0.7 is better than a fin that has a higher aspect ratio [10].

The use of fins in vertical turbines has also been done but is intended to direct angina to the Savonius turbine [11].

Fin development studies on vertical turbines have not been carried out. Single shaft vertical turbines have omnidirectional properties, but research on vertical turbine designs with dual shafts to improve the performance of vertical turbines [2] causes changes in omnidirectional properties. In addition, the construction of the bottom seat which is the foundation of the double shaft has a weight, moment and must be able to rotate on its axis to drive this double shaft turbine.

3. The aim and objectives of the study

The study aims to restore the omnidirectional nature of the vertical hybrid turbine when two shafts become one wind turbine unit at a close shaft distance.

To achieve this aim, the following objectives are accomplished:

– to test and analyze the turbine performance which is locked in the upper triangle rotating shaft support;

– to test and analyze the turbine that is not locked in the upper triangle rotating shaft support;

– to test and analyze the turbine that is not locked and using a directional fin;

– to sum up the amount of directional fin effect on improving vertical turbine performance.

4. Formulation of the problem

Steering fins are usually found in HAWT wind turbines that function to direct the turbine in the direction of the incoming wind, installation of these fins will increase overall turbine efficiency.

The conventional single shaft VAWT turbine does not use a directional fin because of its omnidirectional nature, no matter where the direction of wind comes from, the efficiency will be the same. The change from a single shaft as usual in a VAWT turbine to a double axle VAWT can cause changes in the omnidirectional nature of the turbine. In the preliminary test, the VAWT dual shaft turbine showed that the two shafts can still rotate on the axis of the stand following changes in the direction of the coming wind (yaw).

Some fundamental differences between the vertical wind turbine and horizontal wind turbine are that the vertical wind turbine blade rotates on an axis perpendicular to the direction of the wind, with the mechanism of motion leading to the wind occurring on the same axis. Whereas in the horizontal wind turbine, the blade rotation occurs perpendicular to the mechanism of movement towards the wind (Fig. 1).

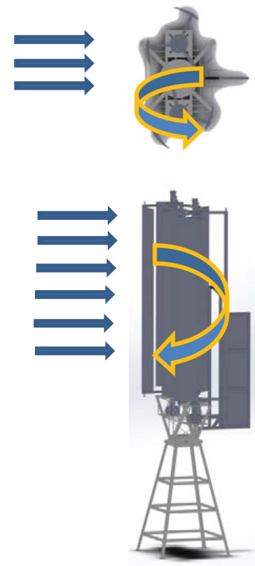

Fig. 1. Rotating axis for vertical turbine and horizontal turbine

But in certain positions of the vertical wind turbine, such as the two shafts are in one line with the direction of the incoming wind, this turbine cannot rotate, and because the position of the second shaft is very close to the first axis. This condition causes the second shaft to experience a wake effect which can reduce the performance of the second shaft. From this condition, it needs a device as directional fins to help the turbine rotate to facing the direction of the coming wind, as is usually installed on horizontal turbines.

The purpose of designing and manufacturing the directional fins is to restore omnidirectional properties and increase the performance of this dual shaft turbine. The experiment will be carried out by comparing the TSR graph VS wind speed, and TSR and *Cp* charts. With the order of testing on double shaft that cannot rotate, a double shaft turbine that can turn without fins, and a double shaft turbine that can rotate with the directional fins.

5. Investigation of omnidirectional behavior in double shaft

Initial investigations of double shaft vertical turbines have been tested for turbine TSR with the shaft bottom bracket locked so that it cannot rotate and with the bottom bracket being unlocked to rotate. The results of TSR versus wind speed can be seen in Fig. 2.

From Fig. 2, TSR for loose bottom rotations at wind speed 2 m/s TSR is lower than fixed turbine type, but up to 4 m/s wind speed, TSR starts to move to its peak where the fixed TSR type starts coming down. This shows that loose type can convert more wind energy compared to fixed type.

Noting this result, if the directional fins assist the turbine, the converted energy can increase. And if it can increase, to what optimum limit and at what dimension is the optimum directional fin.

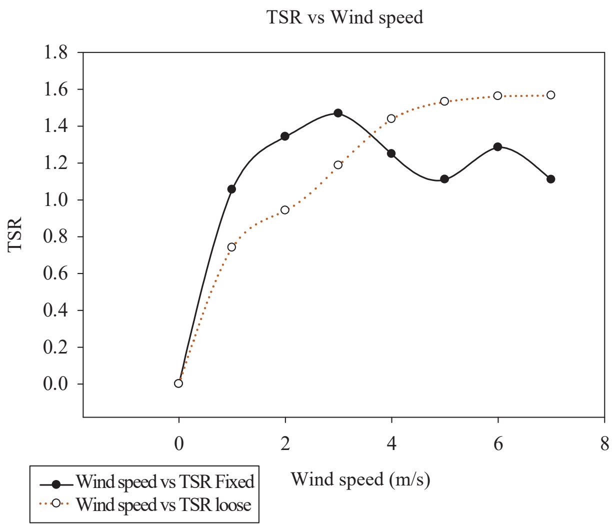

Fig. 2. Comparison of TSR with wind speed between the turbine and bottom seat can rotate and cannot rotate

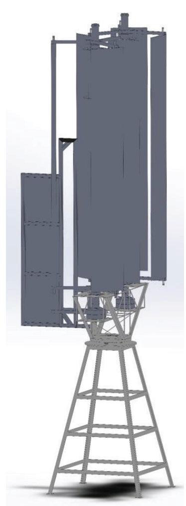

Fig. 3. Hybrid vertical wind turbine Savonius Darrieus double shaft

Initial investigations of dual shaft vertical turbines have been tested for turbine TSRs with the shaft bottom bracket locked so that it cannot rotate and with the bottom bracket being locked so that it can turn. The value of TSR vs wind speed can be seen in Fig. 2.

In Fig. 2 TSR for a loose base that can rotate (loose) at wind speed 2 m/s TSR is lower than fixed turbine type, but until wind speed, 4 m/s TSR starts to move to its peak where the fixed TSR type starts coming down. This shows that the bottom triangle that is not locked can convert more wind energy compared to the kind of bottom triangle that is closed.

Reviewing these results, then if the turbine is assisted by a steering fin to direct the turbine perpendicular to the direction of the incoming wind, it will potentially increase the amount of energy converted.

The implementation of steering fins on vertical turbines has not been done much because of a single shaft vertical turbine. Tail fin is not needed because of the omnidirectional nature of the vertical turbine. In the case of dual shaft turbines at several angles of the wind direction, the omnidirectional nature is reduced. In order to improve turbine performance, it is necessary to implement the directional fins to help the double shaft turbine move to face in the direction of changes in the coming wind.

The shape of the steering fin that will be used is a standard rectangular shape, and this is to facilitate the manufacturing process and consideration of insignificant differences in performance between the best profile and other profiles.

From the calculations, Table 1 below is obtained for the size of the fins that are possible to make.

Table 1

Recapitulation of the dimensions of the directional fin

X_0, m	A, m^2	Y_0, m	X, m	Y, m	X_A
1	0.021804511	0.005451	2	0.010902	1.33
0.5	0.034939759	0.01747	1	0.03494	0.83
0.45	0.037179487	0.020655	0.9	0.041311	0.78
0.4	0.039726027	0.024829	0.8	0.049658	0.73
0.35	0.042647059	0.030462	0.7	0.060924	0.68
0.3	0.046031746	0.03836	0.6	0.07672	0.63
0.25	0.05	0.05	0.5	0.1	0.58
0.2	0.054716981	0.068396	0.4	0.136792	0.53
0.15	0.060416667	0.100694	0.3	0.201389	0.48
0.1	0.06744186	0.168605	0.2	0.337209	0.43

After obtaining an ideal cross-sectional area based on the above manual recapitulation calculations, I got several variants of area based on the values of X and Y. To choose the perfect minimum area value, then compared through the aspect ratio. According to Matsumiya [10], fins with an aspect ratio of 0.5–0.7 have better properties compared to the fins that have a greater aspect ratio.

Based on Table 2, directional fin dimensions with aspect ratios ranging from 0.5 to 0.7 are fins with a cross-sectional area of 0.06 m^2, and an aspect ratio of 0.67 is the best among the data tables above.

Table 2

Dimension and ratio aspect

X, m	Y, m	A, m^2	Aspect Ratio
2	0.01	0.02	0.01
1	0.03	0.03	0.03
0.9	0.04	0.04	0.05
0.8	0.05	0.04	0.06
0.7	0.06	0.04	0.09
0.6	0.08	0.05	0.13
0.5	0.10	0.05	0.20
0.4	0.14	0.05	0.34
0.3	0.20	0.06	0.67
0.2	0.34	0.07	1.69

Table 2 shows the dimensions of height, length, area, and aspect ratio of fins, here we explore which dimensions are included in the required aspect ratio. From this table, a length of 0.3 m is obtained, height is 0.2 m with an area of 0.06 m^2, and an aspect ratio of 0.67.

Dimensions of these fins will be used in manufacturing the vertical turbine directing fins.

6. Weibull Distribution of Wind Speed

Naturally, wind speed continues to vary, to be able to predict the production of wind turbine power, it is needed to know precisely how often the wind blows strongly. According to the IEC standard [11], wind is measured with an anemometer and wind speeds are made average every 10 minutes. This data can be sorted into wind speed classes with a range of 1 m/s. This frequency distribution can then express the energy present in the wind at a particular location.

Weibull distribution is often the right approach for wind speed distribution, has been implemented in [12].

$$f(v)=\frac{k}{A}\left(\frac{v}{A}\right)^{k-1}\left(-\left(\frac{v}{A}\right)^{k}\right). \quad (1)$$

A is the Weibull scale parameter in m/s; size for characteristic wind speed distribution. *A* is proportional to average wind speed. The value of *k* is the Weibull form parameter. This value determines the shape of the Weibull distribution and takes values between 1 and 3. A small amount for the value of *k* signifies a very variable wind, whereas a higher *k* value characterizes constant wind. Experiment with predicting wind potential in Nepal throughout the year by using the Weibull distribution for wind speed [12], the calculation method follows the IEC standard [11].

The initial stage of investigating the wind speed profile at the test site, a graph of the frequency of wind speed is presented in Fig. 4. Because wind varies in speed and direction, and wind turbines are made to harness the energy that the wind carries with it. For a wind turbine to maximize its energy conversion, the turbine must face directly towards the coming wind. And to activate the position of the wind turbine appropriately, the directional fins are mounted directly at the end of the blades for automatic steering.

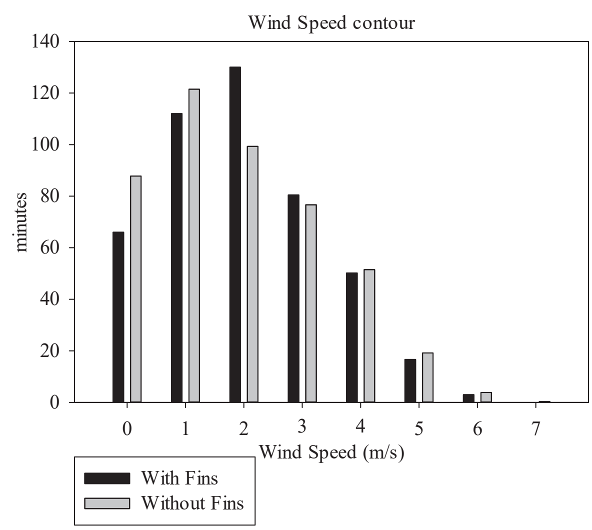

Fig. 4. Weibull distribution of wind speeds with and without directional fin

From Fig. 4 it can be seen that wind speeds 1 and 2 m/s have the highest frequency of occurrence during 8 hours of data collection, and wind speeds of 3–8 m/s have almost the same occurrence frequency, which is 125.667 minutes. And the wind speed with the lowest occurrence frequency is 6 and 7 m/s, with a rate of 0.5 minutes or 30 seconds and is not detected on a Weibull system with an average of 10 minutes.

7. Approbation of research results

The performance of the turbine without the directional fins is compared with the performance of the turbine with the directional fins to analyze the effect of improved performance by using the directional fin with the bottom triangle unlocked.

Tip speed ratio (λ) is the ratio between the translational speed of the turbine rotor and the wind speed. Several types of Darrieus airfoils were tested including the S1046, in his experiment, the speed ratio and *Cp* ratio were used to show the performance of vertical turbines [13, 14]. In this study, the fin performance test was carried out by comparing the TSR value generated by the Savonius Darrieus double-axis hybrid vertical turbine obtained from Turbines with directional fin, and Turbines without directional fins. From the test results, Table 3, 4 are obtained.

Table 3

Table of results of calculation and data grouping based on wind speed performance of turbines without directional fin

Wind speed, m/s	Time, minutes	λA	λB	*cp A* 0.36	*cp B* 0.36	*Cp A* 2.34	*Cp B* 2.34
0	87.83333	0.00000	0.00000	0.00000	0.00000	0.00	0.00
1	121.50000	0.77340	0.70797	0.05700	0.05342	0.347	0.326
2	99.33333	0.95957	0.92463	0.03684	0.03921	0.235	0.249
3	76.66667	1.15835	1.21502	0.03046	0.03582	0.199	0.234
4	51.50000	1.38569	1.49121	0.02644	0.02782	0.167	0.183
5	19.16667	1.45816	1.60632	0.02367	0.02942	0.155	0.192
6	3.83333	1.50034	1.62368	0.02377	0.02690	0.154	0.175
7	0.33333	1.51076	1.62164	0.03063	0.03788	0.199	0.246

Table 4

Table of results of calculation and data grouping based on wind speed performance of turbines with directional fin

Wind speed, m/s	Time, minutes	λA	λB	*cp A* 0.36	*cp B* 0.36	*Cp A* 2.34	*Cp B* 2.34
0	66.000	0.000	0.000	0.000	0.000	0.000	0.000
1	112.000	0.734	0.858	0.057	0.080	0.429	0.371
2	130.000	0.942	1.155	0.041	0.051	0.341	0.307
3	80.500	1.314	1.512	0.040	0.054	0.347	0.306
4	50.167	1.436	1.638	0.036	0.044	0.284	0.258
5	16.667	1.533	1.711	0.037	0.043	0.277	0.259
6	3.000	1.512	1.651	0.036	0.038	0.244	0.240
7	0.167	1.601	1.692	0.056	0.022	0.145	0.255

To obtain the results as in Table 3, 4, from this table graphs of wind speed vs. λ (TSR) are made in Fig. 5 for rotor *A* and Fig. 6 for rotor *B*.

Based on Fig. 5, 6, it is known that the highest TSR value marked with a red line on the chart both on rotor A and rotor B is obtained by a turbine that uses a directional fin.

The value of Turbine TSR with the directional fin on rotor *A* is 1.6 at wind speed 7 m/s, and on rotor *B* is 1.7 at wind speed 5 m/s. Whereas on the turbine without the highest TSR directing fin on Rotor *A*, the value of 1.5 at wind speed 7 m/s is obtained, and on Rotor *B* is 1.6 at 7 m/s speed.

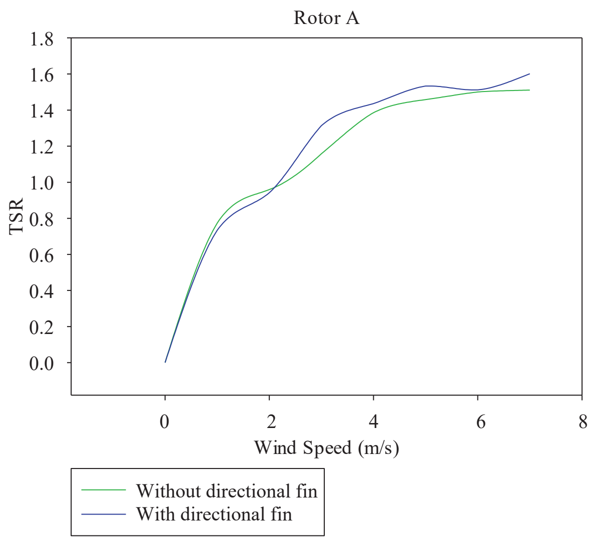

Fig. 5. TSR vs wind speed turbine with directional fin and without directional fin on rotor *A*

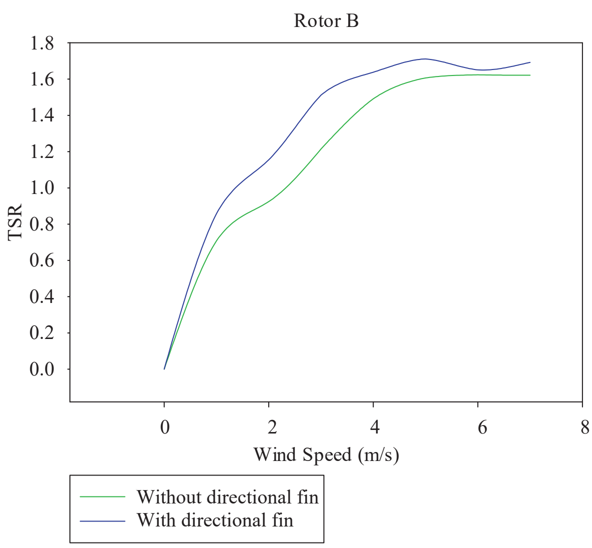

Fig. 6. TSR vs wind speed turbine with directional fin and without directional fin on rotor *B*

The maximum *Cp* obtained at 38.9 % at TSR 0.89 is shown in Fig. 7, from the maximum *Cp* of Darrieus S1046 blades which is a maximum of 40.51 %, the decrease in *Cp* is due to design changes combined with Savonius turbines. But with Savonius this hybrid turbine can spin itself at wind speeds of 3 m/s, whereas the Darrieus turbine itself cannot spin alone.

Based on the two graphs above, it is known that the value of *Cp* in turbines with fins is more significant than turbines without fins on all TSR values of the experiment. This result shows that the use of fins can significantly improve turbine performance. The research focused on tail fin design shows its function for turbine safety and improving turbine performance [7]. The shape of the delta wing in the form of the directional fin which has the best performance among the other types of the directional fin investigated [10].

Comparison of power curves to wind speeds of 7 m/s can be seen in Fig. 8. The Aeolos turbine has the best performance, followed by the Sunilly turbine and the Savonius Darrieus dual shaft hybrid turbine.

Savonius Darrieus dual shaft hybrid turbines have performance that is close to the performance of the Sunilly turbine and with advantages in power density, which according to investigations with CFD show that turbines can be arranged at x/D=4 distances while horizontal turbines are arranged at x/D=distance 15 [6, 15].

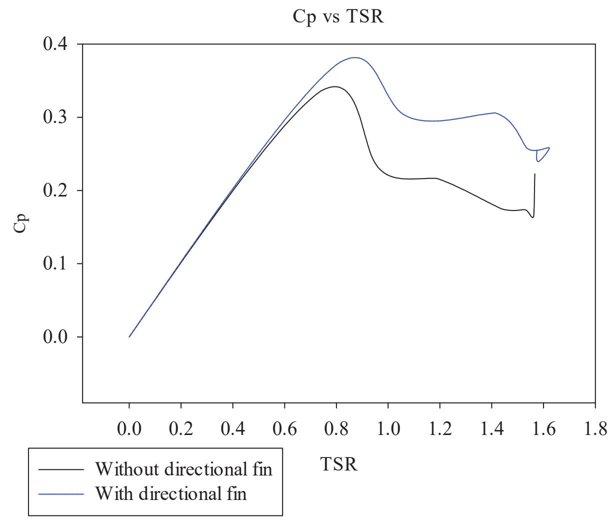

Fig. 7. Comparison of TSR and *Cp* values between Turbines with Directional fin and Turbines without Directional fin

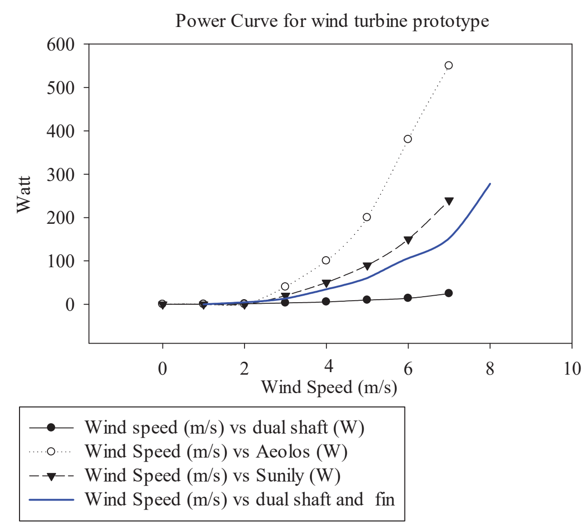

Fig. 8. Comparison of power curves between Aeolos 500, Sunily 600 and Savonius Darrieus dual shaft hybrid vertical turbines

8. Discussion of experimental results

Research on the use of directional fin on vertical wind turbines shows the phenomenon that there is an increase in kinetic energy performance, explained in detail below.

The design change to a double shaft (Fig. 3) raises the question of whether the vertical turbine omnidirectional nature will change, but the initial testing of the double shaft in Fig. 2 shows that the turbine can rotate facing perpendicular to the direction of the wind. But the response to changes in wind direction still needs to be improved. In horizontal wind turbines to improve the ability to face perpendicular to the direction of the wind, the directional fin was used [10]. The use of fins in double shaft vertical turbines in Fig. 7 shows an increase in turbine performance, which means improving the ability of the vertical turbine facing perpendicular to the direction of the incoming wind. The use of double shafts on one turbine to get the vortex effect of airflow has been researched where this effect increases the performance of each shaft [2].

The limitation and disadvantage of this study are that the performance of the turbine is represented by the potential kinetic energy of the turbine (Table 3, 4), not yet the power coming out of the turbine generator, but the potential kinetic energy has shown a significant increase. To eliminate this drawback, the following tests can be carried out using wind turbine generators and performance is measured by the electrical power coming out of the generator.

Further development can optimize the size and shape of the fin so that the energy produced can be even better. This result is related to yawn performance, the dumper effect, and the strength of the fin structure.

9. Conclusions

From the experiments that have been carried out, it can be concluded that the result of the experiment is as described below.

1. Experiment and analysis of the turbine which is locked in the upper triangle shaft rotating support show the quantitative indicators of the results having the lowest power generated only 7 watt, an unlocked fin vertical wind turbine generates 38 watt compared with Aeolos turbine producing about 400 watt and sunnily turbine producing 200 watt of all test schemes.

2. Experiment and analysis of the turbine that is not locked in the upper triangle rotating shaft indicating the turbine still has the ability to spin and face perpendicular to the incoming wind direction, this is concluded from the TSR value of 1.6 unlocked and the type of locked TSR 1.2.

3. Experiment and analysis of the turbine that is unlocked and using a fin indicate minimum 10 % overall improvement in performance compared to the locked turbine and unlocked turbine without the fin.

4. Summing up of directional fin gives a significant effect about 30 % of *Cp* after TSR 0.8 to TSR 1.5.

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