Design and Early Development of Solar-Integrated Darrieus-Savonius Hybrid Wind Turbine

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***Abstract*—Many of the vertical axis wind turbines (VAWT) work well at low Wind Power Density (WPD) areas. At lower WPD, wind tends to be in lower speed and most of the time, intermittent and turbulence in nature. Although such condition may seem to provide less energy resources, if tapped correctly, there will be adequate amount of energy to power the necessities that may occur. Hence, VAWT technology requires high performances and optimal self-starting to ensure maximum power is gained from such scarce environment. To compliment this, this paper presents a concept of an integration of solar photovoltaic (PV) thin film onto a hybrid Darrieus-Savonius VAWT. The hybrid Darrieus-Savonius, which combines the Savonius blade type that performs well in low wind speed which improves the self-starting for the turbine, and Darrieus blades that perform well in higher wind speed, which ensure wider range of wind speed application for the turbine. The solar PV on the other hand, will be able to harness energy from sunlight, whenever it is available. This paper looks into the suitability of several types of Savonius blades, within the hybrid turbine, along with symmetrical airfoil for Darrieus blades, including the shape, angles between the two blade types, aspect ratio and a few others, both in terms of performance and structurally. The optimum area for solar PV thin film is also studied and the suitable location of installation within the VAWT is identified.**

Keywords— solar wind turbine; hybrid wind turbine; Darrieus, Savonius, wind energy, solar energy, urban energy system

I. Introduction

Wind turbines are devices that convert kinetic energy from the wind into electrical energy through rotational motion that can be used for many applications. Wind turbines provide clean solution for energy generation as they produce little to no pollution during operation. The sizes of these wind turbines are largely affected by the application of them. For high wind speed region, large wind turbines are preferred, and similarly, for lower wind speed region, smaller wind turbines are more effective in tapping the wind energy.

Generally, wind turbines are categorized based on its axis of rotation; horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). VAWTs are the preferred design type for smaller wind turbines and deemed more suitable for urban application and closer to consumer type of devices. Among the reasons are it can operate within omni-direction of wind, more silent during operation, and in fact, safer in terms of safety, due to its small size and less complicated structures.

On the other hand, solar energy is another source of renewable energy that is widely utilized, especially in regions that have substantial amount of sunlight throughout the year. Nowadays, many have looked into integrating both solar and wind turbine technologies to provide steady and undisturbed power for small and medium application [1]. This integration is popular as the resources are readily available: sunlight and wind. Solar energy can be harvested during the day when the sun is up, and wind energy can be harvested throughout day and night, as long as wind is available. These two sources and technologies complement each other and would be one of the best solutions for low-powered application, for example street lightings.

This paper describes the design and early development of solar integrated Darrieus and Savonius wind turbine, which is a multi-hybrid device. The first type of hybrid is the wind turbine hybrid. Darrieus and Savonius are two types of wind turbines (lift and drag types) that are combined into a wind turbine. While solar panels (or films), in this project is integrated onto the wind turbine surfaces which make the turbine another layer of hybrid (wind turbine and solar). The design allows harvesting of wind and sun energy throughout the day and night, whenever sun and wind are available.

II. Design Description of The Solar-Integrated Darrieus-Savonius Hybrid Wind TUrbine (Wind Turbine)

This section describes the general anatomy of the wind turbine of the Solar Integrated Darrieus-Savonius Hybrid Wind Turbine. Fig. 1 depicts several views of the design, which was filed for an intellectual property of Universiti Kebangsaan Malaysia (UKM) in 2018 (Filing number: UKM IKB/108/2/1804). The structure of this section is arranged as follows. The types of blades will be described, both Darrieus and Savonius types. This include types of blades, shape of blades, configuration of the blades and its solidity.

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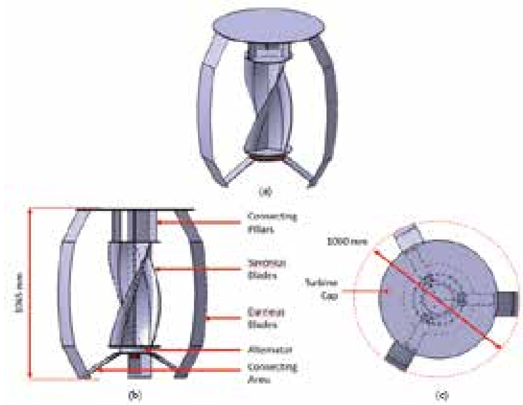

Fig. 1. Isometric view of the solar-integrated hybrid wind turbine (a), and its general parts from side view (b) and top view (c).

A. Darrieus Blades

Darrieus blades traditionally consist of airfoil cross section, similar to aircraft wings. At certain angle of attack, the blades with certain airfoil profile are able to improve their rotation performance, or widely known as tip-speed-ratio (TSR) in wind turbine field. It has been suggested that symmetrical airfoil shapes are able to improve the turbine's TSR. In fact, as Darrieus blades are naturally 'heavy', i.e., relatively poor in self-starting the turbine rotation, the symmetrical blades may assist in improving the self-starting [2]. NACA 0012, a symmetrical airfoil profile, with adequate chord thickness to exert the bending forces of the blade, is chosen as the profile for the wind turbine's blade. Fig. 2 illustrates the profile of the airfoil.

It is known that rotor solidity greatly influences the power coefficient of the wind turbine. Solidity for VAWT depends on the number of blades, chord length of the blade profile and radius of the blade. Increasing the solidity will increase the aerodynamic efficiency while decreasing the solidity will improve the controllability of the wind turbine rotation [2]. The solidity, σ can be calculated by the following equation;

$$\sigma = \frac{N_b\, c}{R} \tag{1}$$

where N_b is the number of blades, c is the chord length, and R is the radius of the wind turbine. It is good to balance between the aerodynamic efficiency and controllability of the wind turbine. Therefore based on [3], it is suggested to maintain the solidity less than 0.5, possibly as low as 0.3. In this paper, the blade solidity is 0.45.

Reference [3] also suggested to have a sufficient aspect ratio to ensure steady performance of the wind turbine. Generally, it is suggested that the lower the aspect ratio, the lower the Reynolds number is and therefore improves the wind turbine efficiency. Aesthetical matter is also taken into consideration, as much lower aspect ratio may not be too appealing for the eyes. Therefore, balance between performance and aesthetic views are considered, and the aspect ratio for the wind turbine discussed in this paper is 1.065.

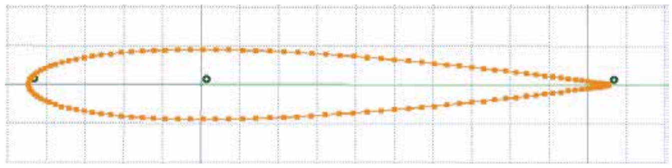

Fig. 2. NACA 0012 airfoil profile selected for Darrieus blades.

On the other hand, the turbine shape described in this paper also ressembles phi-type rotor blades, or egg-beater wind turbine. Phi-type rotors are inspired from a troposkien type of blade which ressembles the jumping rope that can endure high centrifugal forces. This shape can also be manufactured relatively easy and uses lighter material [4]. Utilization of helical blades has been proven to improve the performance of the wind turbine, however, producing helical blades require high manufacturing cost and premium facilities. Therefore, straight blades are chosen for the wind turbine described in this paper. The final shape of the Darrieus blades is illustrated in Fig. 3. The summary of the details of the Darrieus blade used for the wind turbine is listed in Table 1.

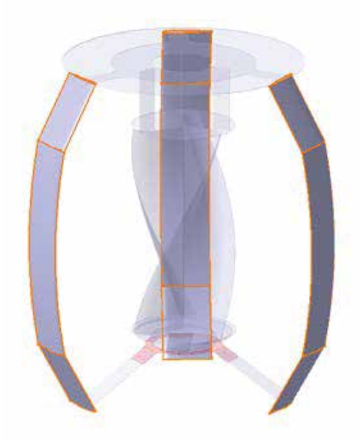

Fig. 3. Darrieus blades of the wind turbine (highlighted).

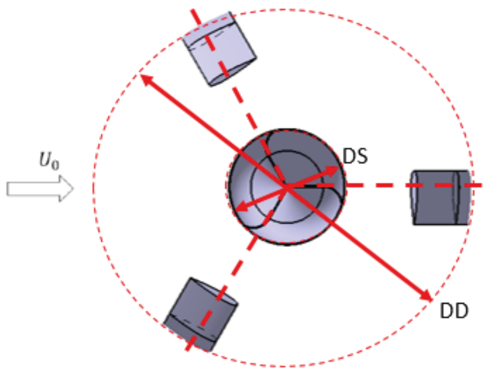

Fig. 4. Attachment angle between Darrieus blades and Savonius blades (dotted lines) and diameter of both Darrieus and Savonius blades (DD and DS), U_0 is the depiction of wind direction example.

B. Savonius Blades

The number of blades for Savonius is determined to be the same as the number of blades of the Darrieus blades, which is three. This is achieved through the consideration of attachment angle between both types of blades. Reference [5] suggested that the attachment angle to be 0°, i.e., the Savonius blades and Darrieus blades are aligned, as shown in Fig. 4. Fig. 4 also illustrates the diameter of Darrieus blades (DD) and diameter of Savonius blades (DS) in determining the ration of the two types of blades. It is suggested by [5], the best diameter ratio to be less than 0.5, with 0.25 being the optimal ratio with regards to the power coefficient of the wind turbine. The diameter ratio for the wind turbine discussed in this paper is 0.3.

As for the profile of the Savonius blade, there is a number of profiles that can be considered, flat, cup (semi-circular) and Bach profiles. Bach profiles, as suggested by [6], is a novel Savonius profile which produce higher power coefficient when compared to other types of profiles (especially bucket type blades). Bach profile consist of a straight profile at the root, and a quarter-circular shape at the tip of the blade, as illustrated in Fig. 4. Bach profile is selected due to its relatively ease of manufacture and high performance, compared to other types of profile.

Another consideration in designing the Savonius blades is the overlap ratio. Overlap ratio is the ratio of the blade length to the distance of the overlapping blades, as illustrated in Fig. 6. Reference [7] found that overlap ratio of 0, i.e., no overlap, produces the maximum power coefficient compared to other sets of overlap ratios. In fact, Bach profile has inherently no overlap as each of its root is a flat profile, hence overlap is unachievable here.

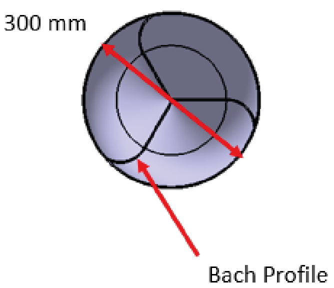

Fig. 5. The Savonius Bach profile and the diameter of the Savonius blades.

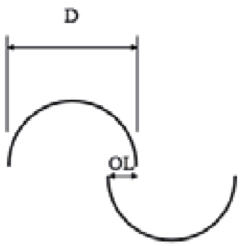

Fig. 6. Overlap between two Savonius blades.

There are also arguments with regards to the performances of helical versus straight Savonius blades. Reference [8] performed an experiment on 180° twisted Savonius blades and compared to straight Savonius blades. It is found that the helical blades develop an average torque that is greater than torque created by conventional blades. In this paper, the Savonius blades are designed to have a 120° helical profile. The final shape and design of the Savonius blades is illustrated in Fig. 7.

The final part of the Savonius blade design is the integration of end plates on top and bottom parts of the blades. Reference [9] has provided an insight of the end plates. Several configurations of end plates have been tested on a helical bucket-type Savonius wind turbine. Fig. 8 lists all of the configurations tested in the experiment. It is found that End Plate #4 (Circular Plate) has increased the power coefficient of the wind turbine by 36% compared to the one without end plate. Therefore, circular plates are utilized on top and bottom of the Savonius blades in the wind turbine. The summary of the details of the Darrieus blade used for the wind turbine is listed in Table 1.

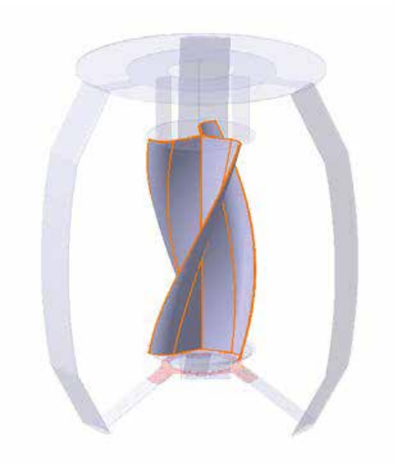

Fig. 7. Savonius blades of the wind turbine (highlighted).

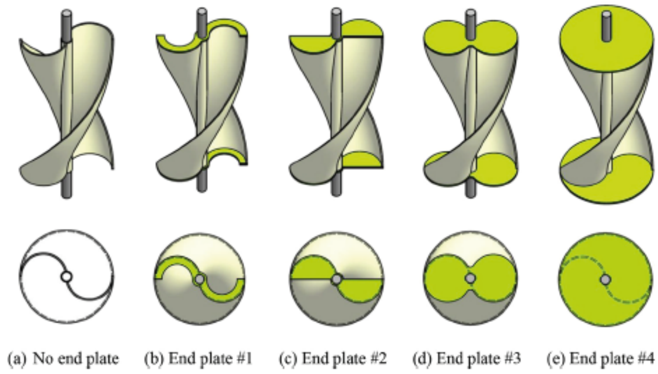

Fig. 8. Configurations of end plates tested on the Savonius blades. [9]

TABLE I. SUMMARY OF DARRIEUS AND SAVONIUS BLADE DETAILS

Darrieus Blades	
Details	***Types***
Airfoil Profile	NACA 0012
Chord Length	0.15 m
Solidity	0.45
Aspect Ratio	1.065
Savonius Blades	
Blade Profile	Bach
Attachment Angle	0°
Diameter Ratio	0.25
Helical Twist Angle	120°

III. DESIGN DESCRIPTION OF THE SOLAR-INTEGRATED DARRIEUS-SAVONIUS HYBRID WIND TURBINE (SOLAR)

This section describes the general anatomy of the solar part of the Solar Integrated Darrieus-Savonius Hybrid Wind Turbine. The structure of this section is arranged as follows. This section mainly focuses on the surface area determination for solar as well as types of solar panel used for the device. This also includes a brief discussion on solar power transmission issues and its mitigation suggestion.

A. Solar Film

The wind turbine has substantial amount of surface area. This includes the surface area of the Darrieus blades as well as the helical Savonius blades. It is proposed that these surfaces to be integrated with solar film that is able to harvest energy from the sunlight, while the wind turbine is operating.

For curved surfaces, like the Darrieus blade surfaces, solar film is suggested for the solar integration. For the three available Darrieus blade surfaces that are facing outwards (facing outward as this is the area that will be dominantly facing the sun light), there is an area of 0.45 m^2.

To add to this solar area, a thin circular plate is introduced and positioned at the top of the turbine. This circular plate provides another 1.77 m^2 of area for solar thin film to be integrated to. This will in the end, total up to 2.22 m^2 for the overall surface area of the wind turbine that is available and suitable for solar film integration.

There is a number of potential types of solar film available in the market. Among the considerations that need to be taken into account when selecting the solar thin film are the solar film is modular, i.e. able to be tailored to specific dimensions (for example to be fit to the Darrieus blade chord length), the solar thin film's ability to be folded, lightweight, durable and as high efficiency as possible. One of durable solar thin film manufacturer is Flisom from Switzerland. Fig. 9 is a screengrab of Flisom's product brochure, depicting one of the solar thin films available and its general specifications. Fig. 10 illustrates the 3D rendering example of solar thin film integration on the wind turbine.

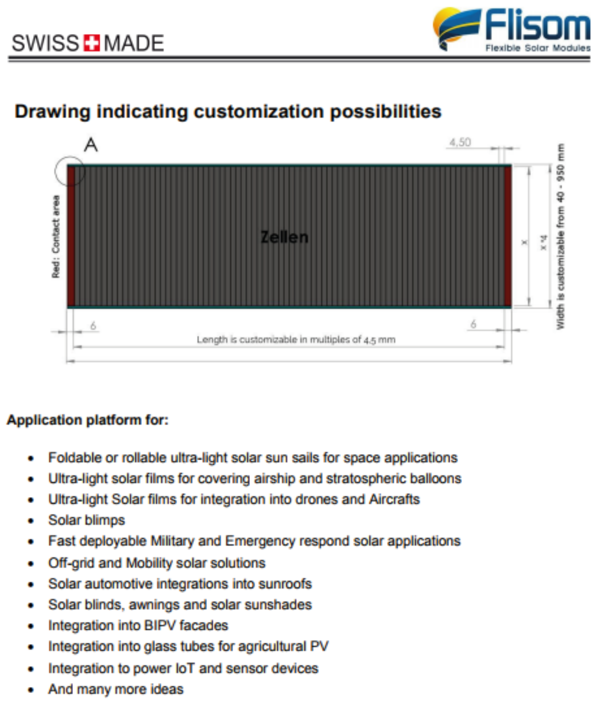

Fig. 9. Screen grab from Flisom product brochure, depicting the flexible thin film, as an example film suitable for this turbine.

Fig. 10. 3D model rendering of solar thin film integrated to the Darrieus blades and to the thin circular plate on top of the wind turbine.

B. Solar Area Calculation

General and basic solar panel/film area calculation is presented in this section. As described in previous section, a total area of 2.22 m^2 is available within the turbine structural part for solar thin film integration. For the sake of general calculation, it is deemed that this device will be used for street lighting application. Typical street lighting that utilizes energy saving LED lights uses approximately 130W of electrical power, which gives a total of 1,560 Wh/day if the usage of the lamp is 12 hours per day.

Since this device is a hybrid of two types of devices; wind and solar, it is expected that the sources for the electrical energy are coming from both wind and solar. As of the early development of this device, it is assumed that solar and wind will produce the energy at a 70:30 ratio. Therefore, at 70% of total Watt-hour, the solar will need to produce at least 1,092 Wh per day. Table 2 lists all the information of Malaysian weather and brief and rough calculation of the solar area required. The calculation used the basic equation on solar area calculation based on basic physics;

$$Total\ Solar\ PV\ Area = \frac{Total\ Watt - hour\ per\ day}{PV\ efficiency\ \times Solar\ Intensity\ \times Hour\ of\ Intensity} \quad (2)$$

Based on the rough calculation, the solar panel area required is 1.82 m^2, less than what is available as calculated previously (2.22 m^2). Therefore, it is deemed that the solar area on the device is sufficient, although further thorough investigation, calculations and validation are required for future development.

TABLE II. SOLAR PANEL AREA ROUGH CALCULATION

Solar Panel/Film Area Calculation	
Details	***Values***
Total of Watt-hours per day	1,092 Wh
Solar Intensity in Malaysia	800 W/m^2
Hours of Intensity	5 hrs
PV efficiency (assumption)	0.15
Solar Area Required	**1.82 m^2**

IV. CONCLUSION

Solar integrated Darrieus-Savonius wind turbine provides a platform for the future of small hybrid energy generation devices. It is able to tap to multiple natural energy sources, i.e. solar and wind, while leveraging on two types of wind turbines; Darrieus and Savonius, which are able to capture energy from a wider range of low wind speed. The study is limited to a review of design strategies for various types of wind turbine and solar panel parts. Therefore, flow and aerodynamic analysis, solar power evaluation, as well as wind tunnel testing to study the turbine's performance are necessary for future development. Furthermore, the solar panel/film area also needs to be revisited using actual parameters and needs to be validated. Solar power transmission within the device is also needs to be designed for future development.

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