Design of small wind turbines to produce electricity for low wind speed in Thailand

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Abstract
This work studied the design of small Vertical Axis Wind Turbine (VAWT) S Shape and Leaf Shape which are appropriate for low wind speed in Thailand. The theory of Overlaps Ratio ($\beta$), End Plates and Blade Areas which effect to wind turbines operation were analysed. The turbines were tested in a wind tunnel and connected to permanent magnet generator under wind speed conditions close to the real wind speed. The starting up wind speed and Power Coefficient of Leaf Shape were 0.81 m/s and 0.011 and the starting up wind speed and Power Coefficient of S Shape were 0.63 m/s and 0.038, respectively. The results showed that the S-Shape performance was better than Leaf Shape. The results from this study can be applied for developing and improving the small turbine for the application at the low wind speed area in Thailand

Keywords: Vertical Axis Wind Turbine, Permanent Magnet Generator, Low Wind Speed in Thailand

1. Introduction
Nowadays, global warming crisis such as greenhouse effect, melting ice at the north and the south pole since the use of energy from fossil such as petroleum, coal, natural gas that affected to environment and in the future, all of these energies will be exhausted. Therefore, the research of renewable energy such as solar energy, hydropower energy, and wind energy were made to solve this problem. Wind energy is alternative energy because of the cleanliness and no pollution. The wind turbine is the device which converted the mechanical energy from the wind to electrical energy. Most of research studied on large Horizontal Wind Turbines (HAWT) which require high wind starting up speed for the operation, but wind speed is low in the most part Thailand especially in the northern Thailand. Another wind turbine that can handle low wind speed is a Vertical Axis Wind Turbine (VAWT). It can also receive the wind in all directions. Thus, Vertical Axis Wind Turbine Savonius type was selected for this study [1]
2. Researching and Methods

2.1 Wind Speed data
Abdul Latif Manganhar et al. [2] performed a design and comparison of vertical axis wind turbine test between 2 types which were Three Blade Savonius and gap between blades (WAG-RH, Wind Accelerating and Guiding Rotor House) by testing inside the wind tunnel and testing outside area. The results showed that the wind turbine Power Coefficient was 0.125 while wind turbines with a gap between blades Power Coefficient was 0.218 by tested at the same at wind speed 5 m/s. It was founded that the gap between of blade influenced to operation of wind turbine with increased efficiency and the use of a program model could help improve the performance by improving the relevant parameters as well.

Jae-Hoonlee et al. [3] analyzed twist angle of Savonius wind turbine by test Tip Speed Ratio at angles of 0, 45, 90 and 135 degrees. The numerical method of the air flow through the wind turbine at each twisted angle was performed to find out which parameters involved, to construct and to test the turbine in wind tunnels. The wind tunnel tests were, then, used to compare and to analyse the results. From the numerical flow simulation and the wind tunnel flow test found that the highest Power Coefficient was 25.5 percent at the angle 45 degree and the lowest at the shape was at a twist angle of 135 degree.

Abdullah Al-Faruk and Ahmad Sharifian [4] studied the operation of a two blade Savonius wind turbine by hot air from utilizing industrial waste heat. The test was derived from the exhaust of jet engine installed in the laboratory and could adjust the wind speed and temperature and installed the turbine in the wind tunnel. Numerical method on air flow in conjunction with the actual test was performed. The actual test results and simulation tests were compared and analyzed to determine the parameters and to improve wind turbine performance. The results showed that the relevant parameters were propeller gap and propeller torsion angle, with the appropriate values after improvement, the gap between the blades was 16 mm and the propeller torsion angle was 195 degrees and the Power Coefficient was increased 24.12 %.

Keum Soo Jeon et al. [5] studied the shape of vertical axis wind turbine which affected performance of wind turbine by using a two blade Savonius wind turbine with a twist angle of 180 degrees. The top and bottom of the wind turbines were in total of 4 types ordered from small area to large area and tested in a wind tunnel. The Power Coefficient data were recorded. The results showed that the highest area and Power Coefficient was type 4 or circular flap which up to 36% compared to type 1 (without a top cover). The research team concluded that the top end plate reduced wasteful airflow deflection and increase torque.

Jean Luc Menet and Nachida Bourabaa [6] studied the increase performance of Savonius wind turbine by using numerical methods for selected and adjusted relate parameter. After improving relate parameter, this research suggested ones to use two blade Savonius wind turbine by putting top and bottom end plate. The height of the wind turbine should be twice of its diameter and the overlap ratio must be between 0.15 and 0.3.

From literature review, the concept was applied in this research. The design new turbine with end plate top and bottom which had difference area with the same height with the overlap ratio between 0.15 and 0.3 of wind turbine blade and tested the turbine in wind tunnel and compared result between 2 turbine types.

2.2 Wind Speed data
According to the wind speed data from Chiang Mai Meteorological Station in Thailand, the maximum and minimum average wind speed in past 10 years of Chiang Mai were in May and December consequently. Table 1 and 2 show the maximum, minimum and average wind speed of Chiang Mai, Thailand in the past 10 years (2008 to 2018) in May and December (Source: Chiang Mai Meteorological Station).
Table 1. The maximum and minimum average wind speed in the past ten years in May

| Maximum Wind Speed (m/s) | Minimum Wind Speed (m/s) | Average Wind Speed (m/s) |
|--------------------------|--------------------------|--------------------------|
| 17.505                   | 3.089                    | 7.650                    |

Table 2. The maximum and minimum average wind speed in the past ten years in December

| Maximum Wind Speed (m/s) | Minimum Wind Speed (m/s) | Average Wind Speed (m/s) |
|--------------------------|--------------------------|--------------------------|
| 10.773                   | 2.052                    | 4.542                    |

The wind energy assessment in Chiang Mai was analysed by the wind power divided by the number of seasons in Thailand (3 seasons- Winter Summer and Rainy). The calculation showed that the highest and lowest wind power were in summer and winter as shown in Figure 1.

Figure 1. Wind power assessment in Chiang Mai province by season.

The real wind speed was measured for collecting the wind speed data for designing the wind turbine. The wind speed data from meteorological stations cannot be used for designing wind turbines because the measurement of maximum wind speed of each day was not suitable for estimating the wind energy in each season. The wind speed was measured by Anemometer as shown in Figure 2.
2.3 System Design

The design of wind turbine begins by selected shapes from research of interest, Leaf-Shape wind turbines [7] and S-Shape wind turbines [8] and overlap theory were used for the redesigning [9] then adding End Plate of the wind turbine at the end for increasing the efficiency [5] as shown in equation (1).
\[ \beta = \frac{e}{d} \]  

(1)

When

- \( \beta \) is Aspect Ratio
- \( e \) is Overlap Distance (m)
- \( d \) is Chord Length Rotor (m)

**Figure 4.** Displays the vertical axis wind turbine from the designing by using overlap theory and average wind speed data from the measurement.

![Figure 4](image)

**Figure 4.** (a) Leaf Shape wind turbine and schematic diagram of design (b) S Shape wind turbine and design schematic diagram

The input power can be calculated by the Equation (2) [10].

\[ P_a = \frac{1}{2} \rho A v^3 \]  

(2)

Where

- \( P_a \) is Wind Power (W)
- \( A \) is Blade Swept Area (m²)
- \( \rho \) is Density of Air (1.225 Kg / m³)
- \( v \) is Wind Speed (m/s)

The output power (electrical power) can be calculated by Equation (3) [11].

\[ P_e = IV \]  

(3)

where

- \( P_e \) is Electrical Power (W)
- \( I \) is Current (A)
- \( V \) is Voltage (V)

The parameter indicates the efficiency of wind turbine is Tip Speed Ratio (TSR) (\( \lambda \)). Tip Speed Ratio increase with the increasing of efficiency which can be calculated by Equation (4) [12].
\[ \lambda = \frac{(RPM \times \pi \times D)}{60 \times v} \]  

(4)

Where

\( \lambda \) is Tip Speed Ratio (TSR)

\( RPM \) is Round Per Minute

\( D \) is Diameter of Wind Turbine (m)

\( v \) is Wind Speed (m/s)

The efficiency of wind turbine can be determined by Equation (5) [13].

\[ C_P = \frac{P_e}{P_a} \]  

(5)

Where \( C_P \) is Power Coefficient

### Table 3. Data of system wind turbine test

| Device                  | Specification                              |
|-------------------------|--------------------------------------------|
| Leaf Shape Wind Turbine | Turbine Diameter(D) = 0.25 m, High(H) = 0.3 m, e = 0.04 m, Overlap Ratio(\( \beta \)) = 0.276, Area of Turbine = 0.0589 m², Material = Aluminum |
| S Shape Wind Turbine    | Turbine Diameter(D) = 0.3 m, High(H) = 0.3 m, e = 0.04 m, Overlap Ratio(\( \beta \)) = 0.253, Area of Turbine = 0.09 m², Material = Aluminum |
| Generator               | Permanent Magnet Generator: Power = 10 W, Voltage = 12V |
| Load                    | Light Bulb: 5 W, 12V |

### 3. Experimental

Schematic of wind turbine system test diagram in wind tunnel is shown in Figure 5 and component of measuring tools and wind turbine testing presents in Figure 6.
Figure 5. Wind turbine test system in wind tunnel

![Diagram of wind turbine test system]

The experiment started by turning on the wind tunnel fan. The wind turbine power can be calculated by Equation (2) which is input power. The anemometer measured and recorded the wind speed data. The turbine speeds (RPM) were measured and recorded by Tachometer for determining the Tip Speed Ratio (TSR) which can be calculated by Equation (4).

Figure 6. (a) Schematic diagram of the experiment, (b) Measuring wind speed (c) RPM speed measuring, (d) Generator and device during the electric measurement. The device and measuring tools shown as follows 1. Wind Tunnel Fan 2. Anemometer 3. Wind Tunnel 4. Wind Turbine 5. Tachometer 6. Generator and Electric Measuring Tools 7. Control Panel of Wind Speed Adjust
shaft to generator and spin to produce the electric power. The electrical power was measured by Voltmeter and Ammeter. The Output Power can be determined by Equation (3). The tests were repeated by adjusting wind speed in the wind tunnel started from 0 m/s then increased gradually to 6 m/s.

4. Result and Discussion
The results showed that the starting up wind speed and average starting up wind turbine speed of S Shape were 0.63 m/s and 48.31 RPM respectively and the average starting up wind speed and starting wind turbine speed of Leaf Shape were 0.81 m/s and 28.32 RPM consequently. Figure 7 displays Tip Speed Ratio (TSR) of S Shape and Leaf Shape wind turbine.

![Figure 7. Tip Speed Ratio of S Shape and Leaf Shape.](image)

According to Figure 7, Tip Speed Ratio of S Shape were higher than Leaf Shape wind turbine also output power of S Shape were higher than Leaf Shape as shown in Figure 8. The Power Coefficient of S Shape was higher than Leaf Shape as displayed in Figure 9.

![Figure 8. Output power of S Shape and Leaf Shape.](image)
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Figure 9. Power Coefficient of S Shape and Leaf Shape.

At wind speed range 3 to 6 m/s, Tip Speed Ratios of the S Shape wind turbine were higher than Leaf Shape wind turbine as displayed in Figure 7. The output power increased with the increasing of wind velocity as well as Tip Speed Ratio as shown in Figure 8. For the Leaf Shape wind turbine, Tip Speed Ratio was almost constant because the output power and Power Coefficient were lower than the S Shape wind turbine due to the S Shape wind turbine Overlap Ratio was lower than Leaf shape wind turbine as shown in Table 3. The starting up speed of S Shape was lower than Leaf Shape because the Chord Length of S Shape was longer than Leaf Shape. Thus, S Shape wind turbine blade area and swept area were more than Leaf Shape wind turbine. The Power Coefficient of S Shape wind turbine was more than Leaf Shape wind turbine due to S Shape wind turbine plate area end plate and wind catchment area were more than Leaf Shape wind turbine.

5. Conclusion.

From this study S Shape wind turbine starting up speed was lower than Leaf Shape wind turbine. The starting up speed of S Shape and Leaf Shape were 0.63 and 0.81 m/s and starting of turbine speed S Shape and Leaf Shape were 48.31 RPM and 28.32 RPM respectively. The S Shape wind turbine Tip Speed Ratio increased with the increasing of wind speed, but the Tip Speed Ratio of Leaf Shape was almost constant because S Shape wind turbine Power Coefficient was higher than Leaf Shape wind turbine. The Power Coefficient of the wind turbine increased with increasing of Overlap Ratio and End Plate. The wind turbine performance increased with the increasing of the Chord Length Rotor, Swept Area and End Plate Area. It can be concluded that, there is a possibility for the operation of S Shape wind turbine at low wind speed area in winter season in northern part area of Thailand.

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