Building Module Calculation Power Coefficient And Manufacture Vertical Axis Wind Turbine

Cao Anh Khoa
Institute of Civil Engineering
Ho Chi Minh City University of Transport
Ho Chi Minh City, Vietnam
khoa.cao@ut.edu.vn

Abstract **- First of all, the purpose of this paper is to develop a computational module of vertical axis wind turbine power coefficient based on multiple stream tube theory of Habtamu Beri and Glauert empirical relation with MATLAB language and called as CP-VAWT. Then, the design parameters of the vertical wind turbine are proposed with the support of CP-VAWT for maximum power coefficient of a turbine. Finally, manufacturing turbines following design parameters are proposed, to serve energy needs for families in Vietnam.**

Keywords-Vertical axis wind turbine, power coefficient, multiple stream tube theory, manufacture turbine.

I. INTRODUCTION

Before the gradual disappearance of fossil energy sources, people looked for alternative energy sources. Wind energy is increasingly concerned with sustainability and being environmentally friendly. With over 3,000 km of the coastline, located in the area of tropical monsoon climate, Vietnam has a geographical location relatively favorable to wind power development. According to data of wind potential in Vietnam collected from 150 meteorological stations, annual wind speed measures at these stations range from 2m/s to 3m/s on land. Coastal areas are higher wind speeds, ranging from 3m/s to 5m/s. In the island region, average wind speed of 5m/s to 8m/s [1]

There are generally two types of wind turbine: horizontal axis and vertical axis. Research topic focus vertical axis wind turbine (VAWT) because it advantages in comparison with horizontal axis wind turbine, such as VAWT is not affected by the direction of the wind, WAWT can be significantly less expensive to build…VAWT suitable for installation in rural areas where an electrical grid is not covering, suitable for low power energy use, serve energy needs for families in Vietnam. VAWT developed by Sandia National Laboratories Center (USA) in 1980. Since then there has been much research in the world on VAWT. The models are used to research on VAWT: single stream tube model, multiple stream tube model, double multiple stream tube model, vortex model. Typical topic: "Double Multiple Stream Tube Model and Numerical Analysis of Vertical Axis Wind Turbine" of Habtamu Beri and Yingxue Yao [2], this paper uses double multiple stream tube theory to modeling of unsteady flow analysis through NACA 0018 of VAWT, analytically calculated results are compared with CFD simulation results, but not compared with experimental results, not manufacture. The Darrieus with turbine: Proposal for a new performance prediction model based on CFD of Marco Raciti Castelli, Alessandro Englarom and Ernesto Benini, this paper presents a CFD model for the evaluation of energy performance and aerodynamic forces acting on VAWT, then propose the parameters for VAWT with three blades, NACA 0021 profile, not manufacture. This paper builds module calculation power coefficient of VAWT by analytical methods, using multiple stream tube of Habtamu Beri and Glauert empirical relation, using Matlab program. Then, manufacture turbine from parameters of the program proposed.

II. THEORETICAL BASIS

A. Blade element momentum theory

The empirical relationship developed by Glauert

$$\begin{cases} C_{T1} = 4a(1-a) & \text{a} < 0.4 \\ C_{T1} = \dfrac{(a-0.143)^2 + 0.55106}{0.6427} & \text{a} \geq 0.4 \end{cases} \quad (1)$$

Where CT1 is thrust coefficient, a is axial induction factor.

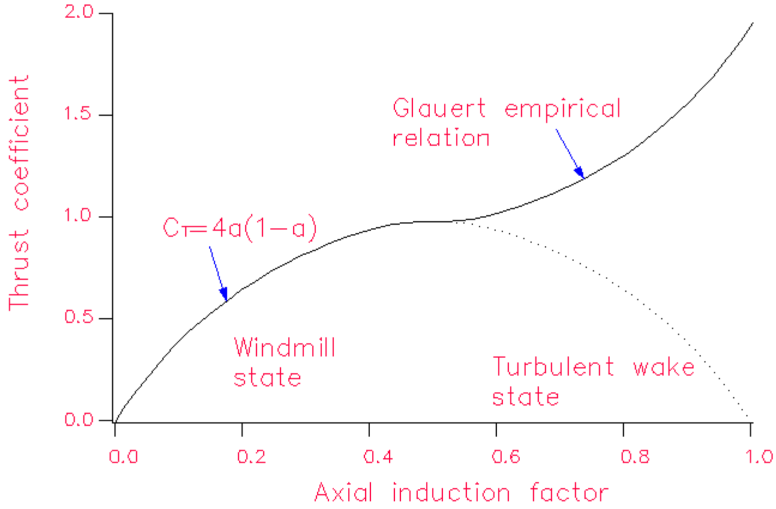

Figure 1. The relationship between a and C_T.

B.Theory of single stream tube

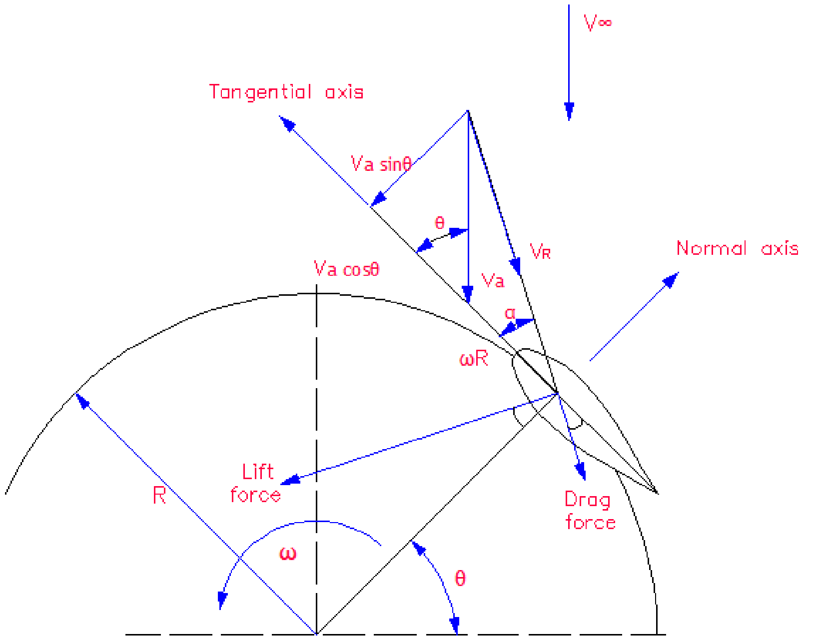

Figure 2. Airfoil velocity and force diagram.

From figure 2 the relative velocity component V_R is calculated:

$$V_R = \sqrt{(V_a \sin\theta)^2 + (V_a \cos\theta + \omega R)^2} \qquad (2)$$

Where is the axial flow velocity through the rotate, is the rotational velocity, *R* is the radius of the turbine and is the azimuth. We have:

$$\frac{V_R}{V_\infty} = \sqrt{\left(\frac{V_a \sin\theta}{V_\infty}\right)^2 + \left(\frac{V_a \cos\theta + \omega R}{V_\infty}\right)^2} \qquad (3)$$

$$\frac{V_R}{V_\infty} = \sqrt{((1-a)\sin\theta)^2 + ((1-a)\cos\theta + \lambda)^2} \qquad (4)$$

Where *a* is axial induction factor, tip speed ratio of the turbine, and stream wind velocity.

Referring figure 2, angle of attack can be expressed as:

$$\tan\alpha = \frac{V_a \sin\theta}{V_a \cos\theta + \omega R} \qquad (5)$$

$$\tan\alpha = \frac{\frac{V_a}{V_\infty}\sin\theta}{\frac{V_a}{V_\infty}\cos\theta + \frac{\omega R}{V_\infty}} \qquad (6)$$

$$\alpha = \tan^{-1}\left(\frac{(1-a)\sin\theta}{(1-a)\cos\theta + \lambda}\right) \qquad (7)$$

The normal and tangential coefficients can be expressed as:

$$C_n = C_l \cos\alpha + C_d \sin\alpha \qquad (8)$$

$$C_t = C_l \sin\alpha - C_d \cos\alpha \qquad (9)$$

The instantaneous thrust force ( ) is one single airfoil at certain is:

$$T_i = \frac{1}{2}\rho V_R^2 (hc)(C_t \cos\theta - C_n \sin\theta) \quad (10)$$

Where "h " is blade height and "c " is blade chord length. The instantaneous torque ( ) on one single airfoil at certain is:

$$Q_i = \frac{1}{2}\rho V_R^2 (hc) C_t R \quad (11)$$

C. Theory of multiple stream tube

The flow velocity within the stream tube was assumed to be uniform. Wilson and Lissaman assumed a sinusoidal variation in inflow velocity across the width of the turbine to account for non-uniform flow. In order to account for this effect more fully, Strickland extended the model so that the flow through the turbine is divided into multiple independent stream tubes as shown in Figure 3. The momentum balance is carried out separately for each stream tube, allowing an arbitrary variation in inflow. The averaged thrust force acting in a stream tube by *N* blades:

$$T_a = N \times T_i \times \frac{\Delta\theta}{2\pi} \quad (12)$$

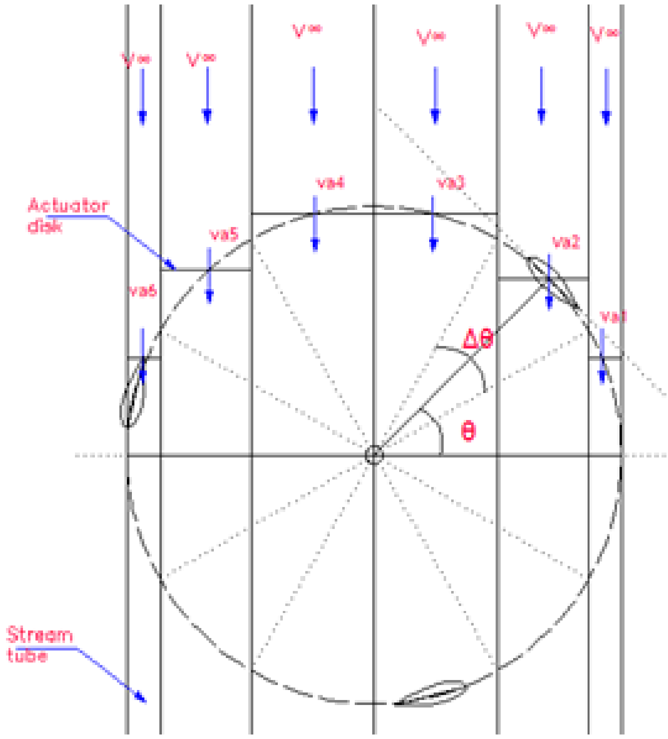

Figure 3. Multiple stream tube model.

The average aerodynamic thrust can be characterized by a non-dimensional thrust coefficient:

$$C_{T2} = \frac{T_a}{\frac{1}{2}\rho V_\infty^2 (hR\Delta\theta \sin\theta)} \quad (13)$$

$$C_{T2} = \left(\frac{Nc}{2R}\right)\left(\frac{V_R}{V_\infty}\right)^2 \frac{2}{\pi}\left(C_t \frac{\cos\theta}{\sin\theta} - C_n\right) \quad (14)$$

The instantaneous torque on a single blade is given in equation (11). The average torque Q_a on rotate by *N* blades in one complete revolution is then given as:

$$Q_a = N \sum_{i=1}^{2m} \frac{\left[\frac{1}{2}\rho V_R^2 (hc) C_t \times R\right]}{2m} \quad (15)$$

Where *m* is the number of stream tubes. The torque coefficients C_Q and power coefficients (C_P) are given as:

$$C_Q = \frac{Q_a}{\frac{1}{2}\rho V_\infty^2 (2Rh) \times R} \quad (16)$$

$$C_Q = \left(\frac{Nc}{2R}\right) \sum_{i=1}^{2m} \frac{\left[\left(\frac{V_R}{V_\infty}\right)^2 \times C_t\right]}{2m} \quad (17)$$

$$C_p = \lambda C_Q = \lambda\left(\frac{Nc}{2R}\right) \sum_{i=1}^{2m} \frac{\left[\left(\frac{V_R}{V_\infty}\right)^2 \times C_t\right]}{2m} \quad (18)$$

III. CALCULATE POWER COEFFICIENT

A. Algorithm

- Step 1: Define the parameters of turbine include $\lambda,\ \sigma,\ R,\ V_\infty,\ NACA\ (airfoil\ shape)$;
- Step 2: Divide the flow area of the turbine into *m* stream tube;

• Step 3: Define induction factor *a* of each stream tube by step as diagram figure 4.

In the diagram figure 4, we will first choose induction factor a, V_R, α , C_t,C_n , C_{T1} , C_{T2} calculated according to the formula (4), (7), (8), (9), (1), (14), and investigated Reynolds number [1].

• Step 4: From induction factor *a* is determined in step 3, power coefficient of the turbine calculated according to formula (18).

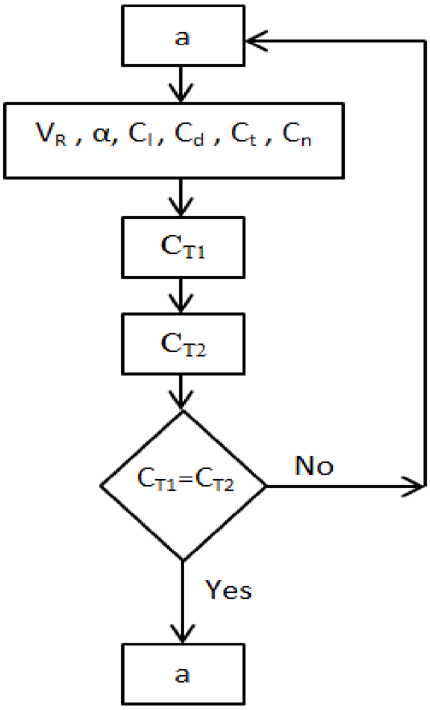

Figure.4. Diagram determine *a* for a stream tube.

B. Check the MATLAB program

1) A packed program

This program is packed with user interface and run directly on operating Window system, this module is named CP-VAWT.

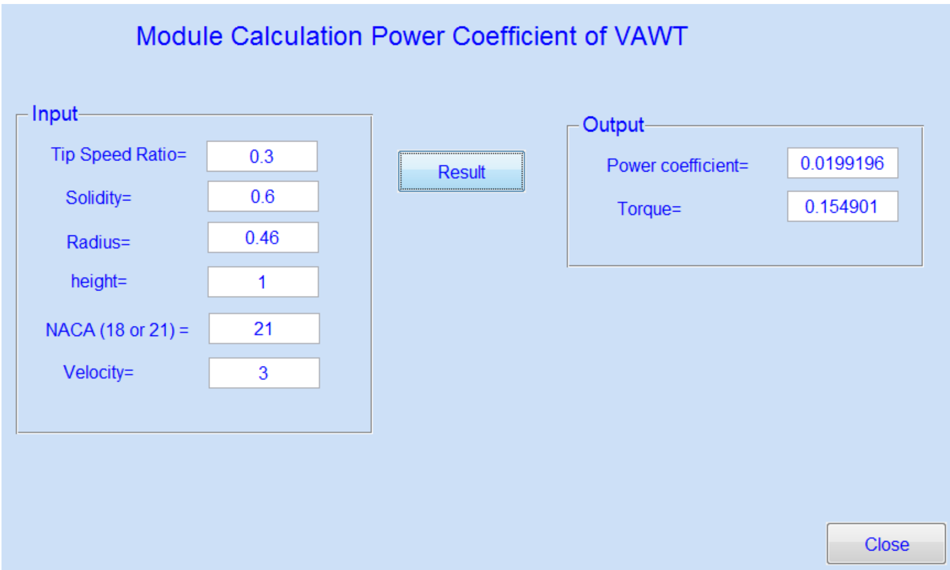

Figure 5. A packed program with user interface.

2) Compare with theoretical results

The result of power coefficient by CP-VAWT will be compared with the theoretical results "Double Multiple Stream Tube" (DMST) of Habtamu Beri, Yingxue Yao [2] for the same wind turbine.

Table I. WIND TURBINE PARAMETERS [3].

Airfoil shape	Wind speed	Blade chord	Number of blades	Radius
NACA 0018	*v* = 4 m/s	*c* = 0.2 m	*N* = 3	*R* = 2 m

Table II. RESULTS OF POWER COEFFICIENT.

λ	DMST	CP-VAWT	Error
1	0	-0.0085	0%
2	-0.045	-0.0486	8%
3	0.075	0.0779	3.86%
4	0.350	0.3806	8.74%
5	0.245	0.2534	3.42%
6	0.080	0.0991	23.87%

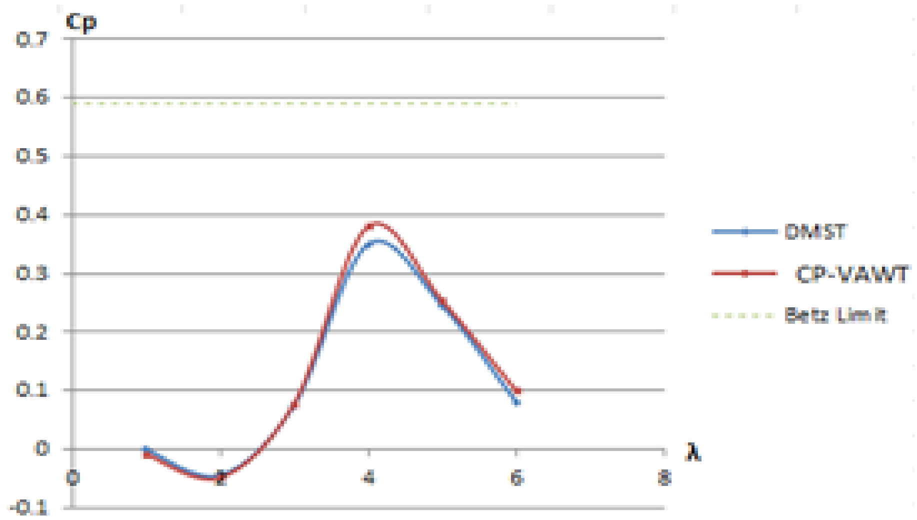

Figure 6. The graph compares CP-VAWT results with theoretical.

Comment: The results of power coefficient between CP-VAWT and theoretical almost coincide. Therefore, in terms of algorithm, CP-VAWT has proven to be correct.

3) Compare with experimental results

The result of power coefficient by CP-VAWT will be compared with experimental results from the 12 KW straight bladed vertical axis wind turbine of J. Kjellin [3].

TABLE III. WIND TURBINE PARAMETERS

Airfoil shape	Wind speed	Blade chord	Number of blades	Radius
NACA 0021	v = 12 (m/s)	c = 0.25 (m)	N = 3	R = 3 (m)

TABLE IV. RESULTS OF POWER COEFFICIENT.

λ	Experimental results	CP-VAWT	Error
2	0.080	0.0667	16.62%
2.5	0.185	0.1830	1.08%
3	0.275	0.4160	51.27%
3.5	0.295	0.4716	59.86%

λ	Experimental results	CP-VAWT	Error
4	0.250	0.4166	66.64%
4.5	0.150	0.3029	101.93%

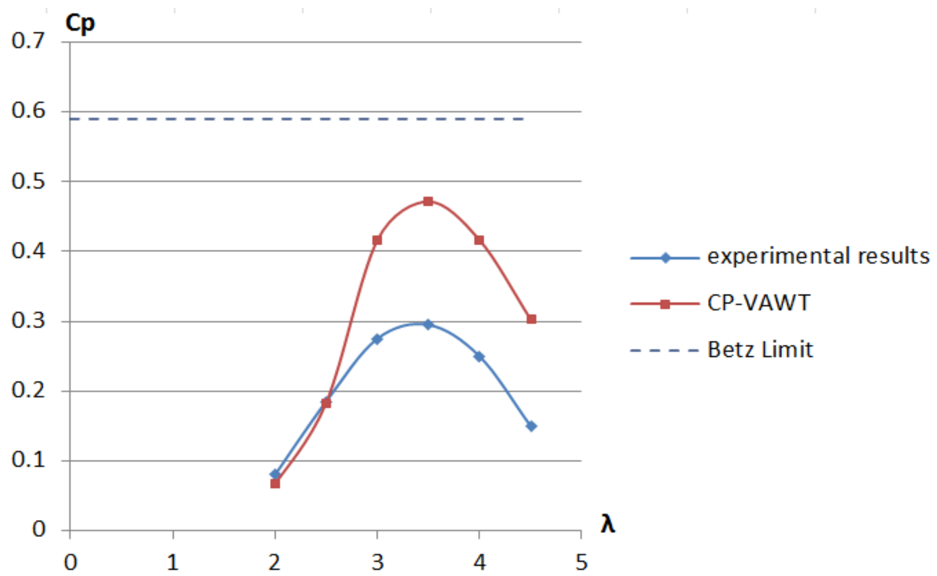

Figure 7. The graph compares CP-VAWT results with experimental.

Comment: Result of using CP-VAWT similarity with the experimental about. shape of power constant variation versus tip speed ratio. Two results for the same tip speed ratio values corresponding maximum power coefficient. In figure 7, the CP-VAWT result and experimental measurements show wind turbines for maximum power coefficient when tip speed ratio is about 3.5. So CP-VAWT has been tested and has reliable results. However, the result of CP-VAWT for power coefficient higher than reality (power coefficient value is still Betz limit).

Cause of error: Accurately determine the power coefficient of the turbine with multiple stream tube theory, we have to consider dynamic-stall effect and secondary effect [7]. CP-VAWT ignores this effect. It's one of the causes of errors with experimental data.

C. Results

From figure 8 to figure 13 draw relationships C_p, λ, σ are calculated by CP-VAWT.

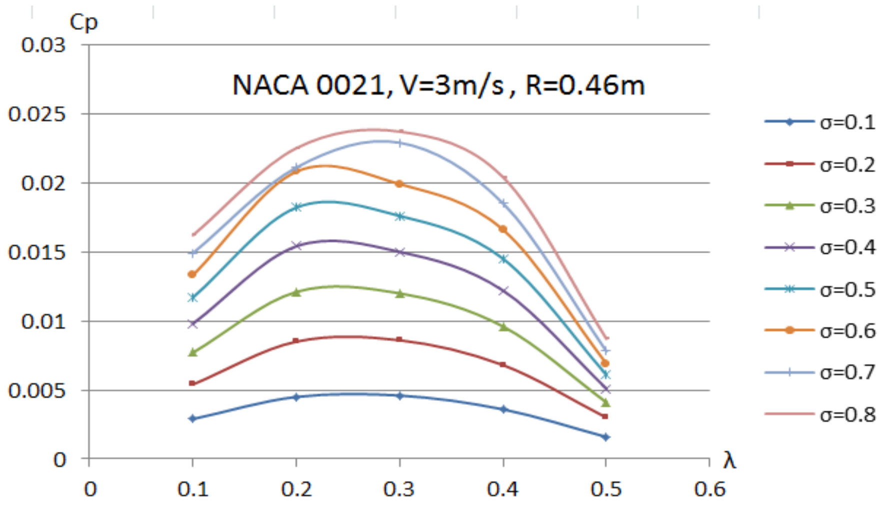

Figure 8. Relationship *Cp, λ, σ* with airfoil NACA 0021, *v* = 3 m/s, *R* = 0.46 m.

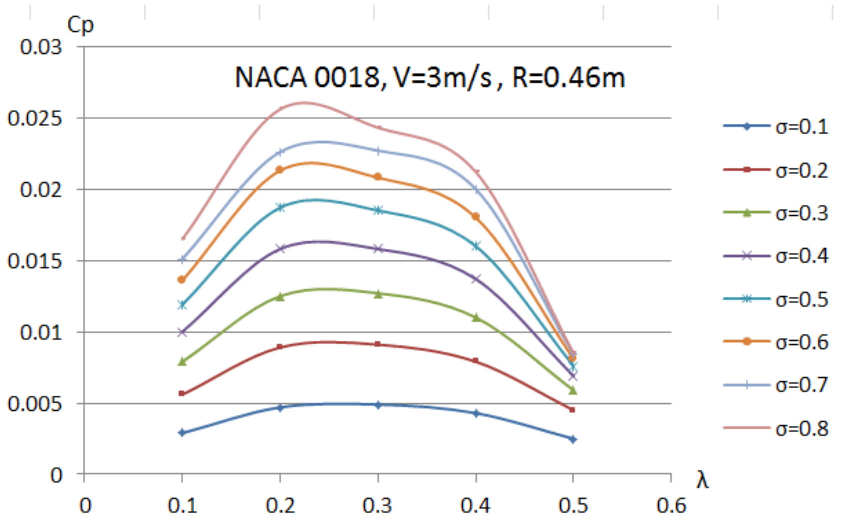

Figure 9. Relationship *Cp, λ, σ* with airfoil NACA 0018, *v* = 3 m/s, *R* = 0.46 m.

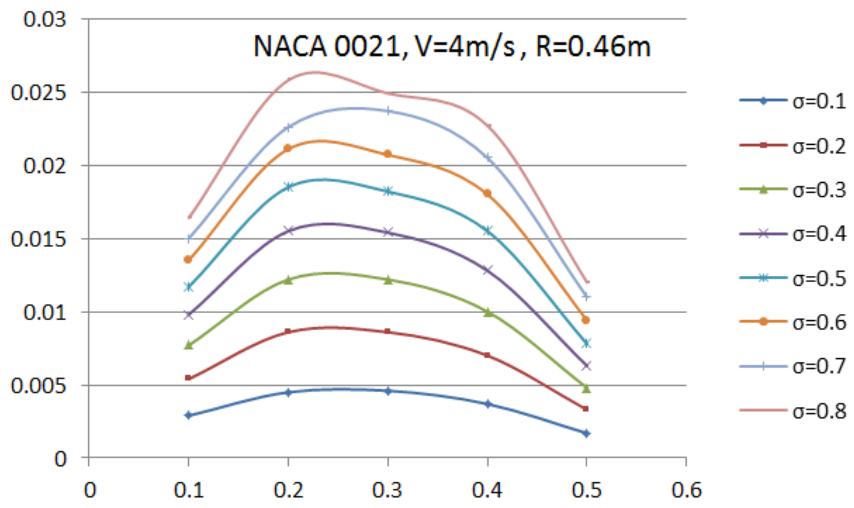

Figure 10. Relationship *Cp, λ, σ* with airfoil NACA 0021, *v* = 4 m/s, *R* = 0.46 m.

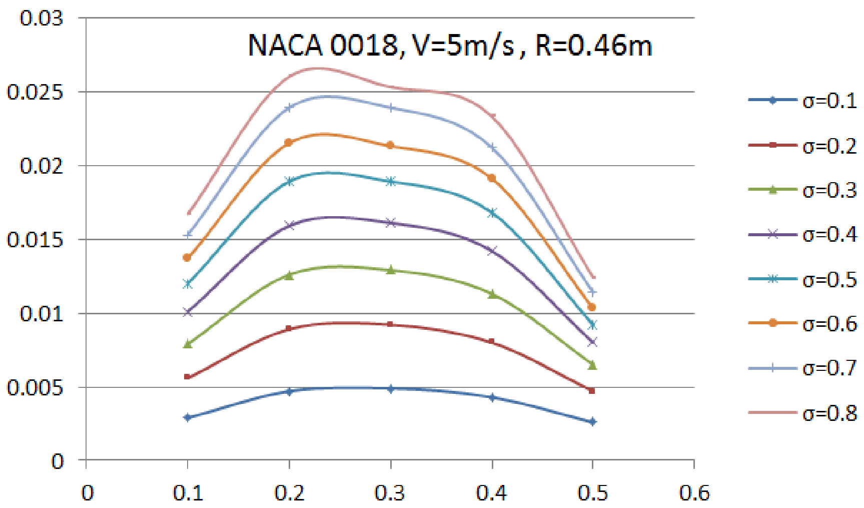

Figure 11. Relationship *Cp, λ, σ* with airfoil NACA 0018, *v* = 4 m/s, *R* = 0.46 m

IV. RECOMMEND DESIGN PARAMETERS

Based on the calculated result from CP-VAWT, authors propose parameters for maximum power coefficient of VAWT.

TABLE V. PARAMETERS OF A RECOMMENDED TURBINE.

Number of blades	3
Airfoil shape	NACA 0021
Radius	0.46m
Blade height	1m
Blade chord	0.21m
Solidity	0.32
Tip speed ratio	0.68

V. MANUFACTURE WIND TURBINE

A. Stator of the turbine

Stator is the most important part of the wind turbine. We wrap coils in the form of three phase generators. With a 12 V generator, we use copper wire diameter 1.1 mm. Stator include nine coils, use the star connection.

Figure 12. The coil is placed in stator.

B. Roate of the turbine

We need two disc magnets to rotate of the turbine. Each disc has 12 magnets divided equally. For the highest performance turbine, we use rare earth magnets.

Figure 13. Rotate of turbine.

C. Blade of the turbine

Blade of the turbine built as table V. Airfoil shape: NACA 0021. Blade height: 1 m. Blade chord: 0.21 m. Number of blades: 3. Radius: 0.46 m.

Figure 14. The overall turbine.

Figure 15.Blade profile of turbine

D. Output voltage

Table VI. OUTPUT VOLTAGE FOLLOW ROTATIONAL SPEED OF ROTATE.

Rotational speed of rate	**Output Voltage**
15 rpm	2.5V
20 rpm	3.5V
30 rpm	6V
50 rpm	12V

VI. CONCLUSIONS

In this paper, the module calculation power coefficient of VAWT is established, using multiple stream tube theory of Habtamu Beri and Glauert empirical relation. This program is packed with a user interface and run directly on the operating Windows system and is named CP-VAWT. We use CP-VAWT to determine tip speed ratio and solidity for maximum power coefficient of the turbine, optimal design. Finally, manufacturing turbines and testing the following design parameters is proposed.

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