# Optimization Twist Angle of Darrius Wind Turbine with Computational Fluid Dynamics (CFD) Simulation for Highway Area Application

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# Optimization Twist Angle of *Darrius* Wind Turbine with Computational Fluid Dynamics (CFD) Simulation for Highway Area Application

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**Abstract.** The research conducted to analyze and optimization of *Darrius* wind turbine based on air velocity and twist angle blade which can influence of turbine torque, turbine rotation speed and turbine power capacity. The method of research uses three steps that is the air velocity observation, wind turbine design, and simulation of wind turbine design. The twist angle as a variable parameter has degree angle of 0° and 30°. The result showed that the *Darrius* wind turbine with the twist angle of 30° which has chosen has the torque value is 0.285 N m that capable to increase the rotation speed is 6.42 rpm, and generate the turbine power capacity is 0.221 W. The research will be continuing to data validation with the result of pilot scale experiment.

**Key words:** *Darrius* wind turbine, power capacity, rotation speed, torque, twist angle.

## 1 Introduction

The street lighting is an important factor to help the transportation activity in the night-time, where it has the primary function that is to keep the person safety, and reduce hazards by illuminating objects in the roadway [1]. Today, street lighting uses solar cell technology that can absorb solar radiation by utilizing silicon materials that can transform solar radiation into electrical energy that is generally applied in highways area. Unfortunately, solar cells still have a weakness factor that is the increase of solar radiation absorbed by solar cells requires more silicon thickness, and silicon purity processes still have a high price [2]. The wind energy can be an alternative energy to complement solar energy, where wind energy has a high potential to be utilized, especially in highway areas. Highway wind energy potential of the high-speed vehicle movement produces strong disturbance to the air

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and transmits its energy to local wind energy form [3]. Highway wind energy potential depends on large mileage and high traffic flow [4].

Research on the utilization of wind energy using wind turbines has been previously done [3–6]. In previous research, wind energy is managed by vertical axis wind turbines (VAWT), where the VWAT working principle is based on the drag force in appropriate with high-speed vehicles movement that produces high torque in the wind turbines [7]. The VAWT has two types turbine that is *Darrius* wind turbine and *Savonius* wind turbine [8]. *Darrius* wind turbine type have power coefficient and minimum velocity flow greater than the *Savonius* wind turbine, where have the power coefficient (Cp) between 0.2 to 0.4; while the minimum wind velocity to rotate of wind turbine between (3 to 7.5) m $s^{-1}$ [6]. This research conducted to analyze and optimization of *Darrius* wind turbine which produce the turbine torque that can influence of power capacity and rotation speed. The basic parameters that influence *Darrius* turbine performance are air velocity, turbine blade numbers, twist angle of turbine blade, and air density. The analyze of basic parameters use the Computational Fluid Dynamics (CFD) simulations has the aims to produce the optimal of *Darrius* turbine performance with generate the turbine torque to influence the rise of power capacity, which can influence the high of electric energy production that transform from wind energy that collected in the turbine blade.

## 2 Method

This research conducted to analyze and optimization of *Darrius* wind turbine use Computational Fluid Dynamics (CFD) simulations. This research has the three steps that is the observation of air velocity, create of wind turbine design, and wind turbine simulation. Air velocity, air density, turbine blade numbers, and the twist angle of wind turbine can be the basic parameters to simulate of wind turbine. The observation of air velocity and design *Darrius* wind turbine has been done [9].

### 2.1 Observation of air velocity

The observation of air velocity has been held in the daytime and nighttime, where the nighttime air velocity has a greater value rather than air velocity in the daytime that caused by the rises of air to take the high temperature [10], beside the high transportation activity in the nighttime. The result of air velocity and air direction also depended by the height of rotor turbine that has four position areas based on the standard point [650 mm (1$^{st}$ position), 1 000 mm (2$^{nd}$ position), 1 350 mm (3$^{th}$ position), and 1 700 mm (4$^{th}$ position)], where the position can be shown in Figure 1. The results of observation can be shown in Table 1.

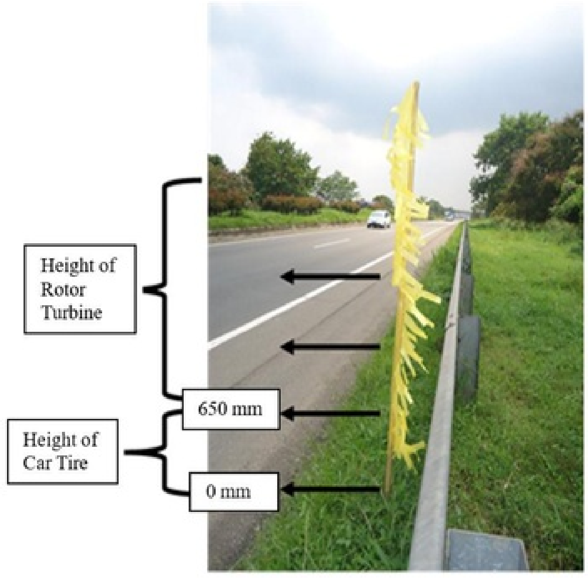



**Fig.1.** The height of rotor turbine [9].

**Table 1.** Air velocity [9].

| No | Variable | Value |
|---|---|---|
| 1 | Data total | 80 |
| 2 | Score range | 2.87 |
| 3 | Class number | 7 |
| 4 | Class length | 0.41 |
| 5 | Average of air velocity with the high-speed vehicle | 2.10 m |
| 6 | Average of air velocity without the high-speed vehicle | 0.95 m $s^{-1}$ |
| 7 | Deviation Standard | 0.909 |
| 8 | Minimum frequency distribution | 1.7 m $s^{-1}$ |
| 9 | Maximum frequency distribution | 3.43 m $s^{-1}$ |

## 2.2 Wind turbine design

Based on the observation results [9] can be seen that the average of air velocity with the high-speed vehicle is 2.10 m $s^{-1}$, and the great value of air velocity has been occur in the height of 1 700 mm ($4^{th}$ position). The results can be basic parameter to design of *Darrius* wind turbine. The design results can be shown in the Table 2.

**Table 2.** Design of *Darrius* Wind Turbine [9].

| Parameters | Symbol | Value | Units |
|---|---|---|---|
| Average of air velocity | v | 2.10 | m $s^{-1}$ |
| Air density | ρ | 1.225 | Kg $m^{-3}$ |
| Power Capacity | $C_p$ | 0.4 | - |
| Blade numbers | B | 2 | - |
| Tip Speed Ratio (TSR) | λ | 5 | - |
| Height of rotor turbine | h | 1 700 | Mm |
| Rotor diameter | D | 700 | Mm |
| Chord width | C | 488 | Mm |
| Attack of angle | α | 8 | degree |
| Reynolds number | Re | 71 143.219 | - |
| Airfoil type | | NACA 4412 | |
| Material | | Aluminum and fiber reinforced plastic | |

### 2.3 Wind turbine simulation

*Darrius* wind turbine simulations use the continuity and momentum equation to control volume based on discrete integration equation and to reach the conversion value with the smallest error. The continuity and momentum equation can be shown in Equation 1, Eq. 2, Eq. 3, and Eq. 4 [12].

Continuity Equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho U)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho W)}{\partial z}=0 \quad (1)$$

X- Momentum equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+W\frac{\partial u}{\partial z}\right)=$$

$$\rho gx-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}\left(2\mu\frac{\partial u}{\partial x}+\lambda\vec{V}.\vec{V}\right)+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right] \quad (2)$$

Y- Momentum equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+W\frac{\partial u}{\partial z}\right)=$$

$$\rho gy-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right]+\frac{\partial}{\partial y}\left[2\mu\frac{\partial v}{\partial y}+\lambda\vec{V}.\vec{V}\right]+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right] \quad (3)$$

Z – Momentum equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+W\frac{\partial u}{\partial z}\right)=$$

$$\rho gz-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}\left[\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]+\frac{\partial}{\partial y}\left[\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+\frac{\partial}{\partial z}\left(2\mu\frac{\partial w}{\partial z}+\lambda\vec{V}.\vec{V}\right) \quad (4)$$

The *Darrius* wind turbine model use the twist angle as a variable parameter to simulate, which the result of simulation can describe that the *Darrius* wind turbine performance can collect the maximum of wind energy to convert to electrical energy, which can indicated by power capacity. The twist angle was determined by normalization power turbine graph with *Qblade* simulation. The result can be described that the twist angle can determine the estimation result of power capacity and the air flow numbers collecting. The result can be shown in Figure 2. Based on Figure 2 can be described that the twist angle of 30° has the more collect of air flow based on the surface of area blade, where the rise of air flow collected can increase the power capacity [9].

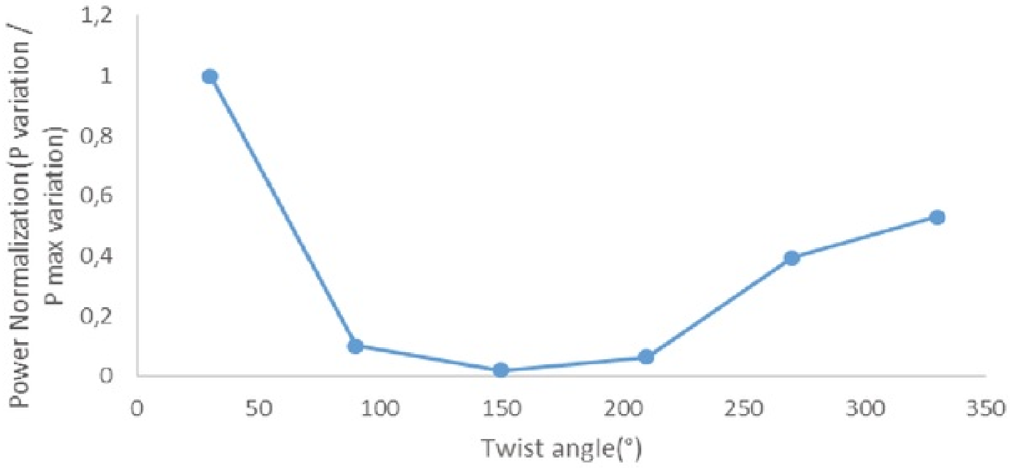
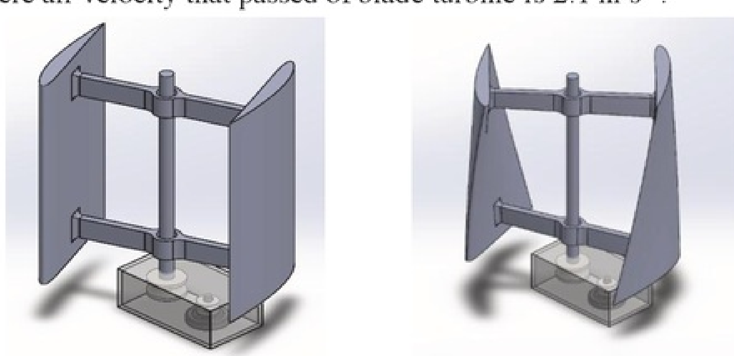



**Fig.2.** Correlation between twist angle and power normalization [9].

The twist angle that used as a variable parameter in simulation is 0°, and 30° as a result of *Qblade* simulation, where the twist angle is divided into two variants [9]. The first variant can be shown in Figure 3a, while second variant can be shown in Figure 3b. The first variant described that the *Darrius* wind turbine model has the twist angle with the value of 0°, while the second variant described that *Darrius* wind turbine model has and the twist angle with the value of 30°. The condition between the both of them has the similarity condition, where air velocity that passed of blade turbine is 2.1 m $s^{-1}$.



(a) (b)

**Fig.3.** Variant twist angle of *Darrius* wind turbine model: a) 0° and b) 30°.

## 3 Results and ddiscussion

The simulation of *Darrius* wind turbine based on twist angle variant as a variable parameter can determine the air flow collected which carry out of energy to being convert to electrical energy pass the torque of wind turbine and power capacity of wind turbine. The results simulation divide into two variant, where the first variant use the twist angle of 0°, the second variant use the twist angle of 30°, and the basic parameters simulation based on the data in Table 2. The simulation can be describe how the air flow pass of the turbine blade that can be seen in the front, side, and upper views, and giving the effect to determine the air flow type. The air flow also can determine the turbine blade rotation speed that influence of turbine torque. The result simulation of the variant of twist angle 0° and 30° can be shown in Figure 4. Based on Figure 4a which have the twist angle of 0° can be describe that the maximum air flow pass the turbine blade from front side of wind turbine that can be known with the red color has the value maximum of air velocity is 2.9 m $s^{-1}$. The second variant of *Darrius* wind turbine simulation use the twist angle of 30°, where the rise of twist angle can increase of power capacity. The result of second variant simulation can be shown in Figure 4b.

The air flow that has pass wind turbine will be generating the decrease of air velocity, caused by the collision between air flow and surface of blade area. The collision between surface of blade area and air velocity can rotate the rotor turbine that continue to being converted to electrical energy. The electrical energy can be recognized by the power capacity of wind turbine. Based on Figure 4b can described that the Figure 4b has the different view with the Figure 4a, which can be known from the different color of simulations. The wide side in Figure 4b can be described that the air flow collection that passed the surface area of turbine blade has the maximum value, when the air velocity the turbine blade is 2.9 m $s^{-1}$ and has different value with the wide side in Figure 4a where the collected of air flow in the turbine blade has the great losses. The great losses of air velocity can be known by the air velocity has been pass the turbine blade still has the high value which approach to maximum air velocity value that is 2.9 m $s^{-1}$.

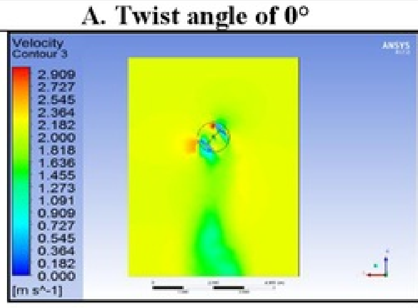
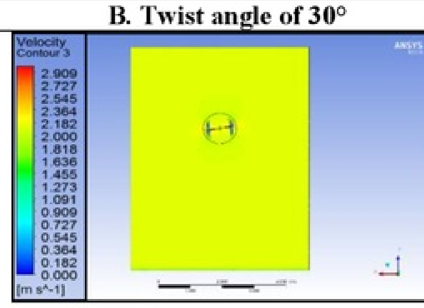
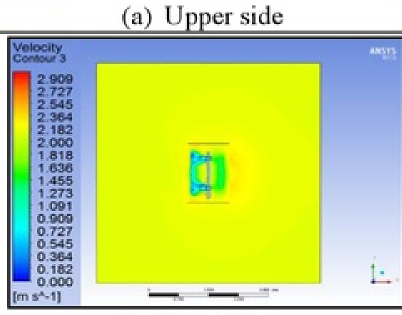
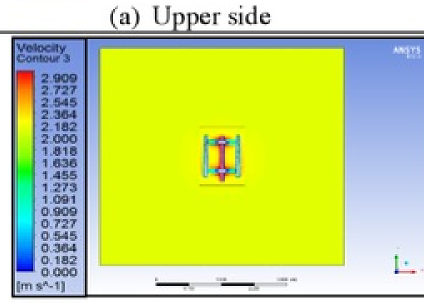
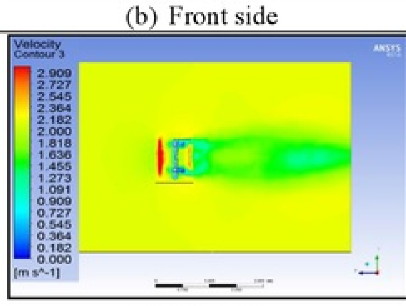
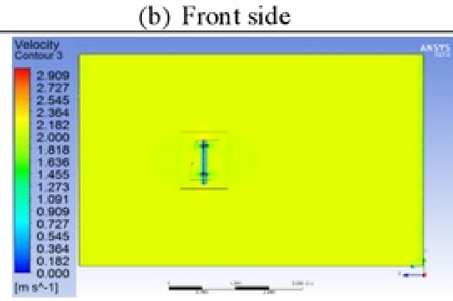
| **A. Twist angle of 0°** | **B. Twist angle of 30°** |
| --- | --- |
|  (a) Upper side |  (a) Upper side |
|  (b) Front side |  (b) Front side |
|  (c) Wide side |  (c) Wide side |

**Fig.4.** Simulation of air velocity in the *Darrius* wind turbine.

The results of data simulations also can be shown in the Table 3.

**Table 3.** Torque, rotation speed, and power capacity of *Darrius* wind turbine.

| No | Parameters | Value | | Units |
|---|---|---|---|---|
| | | **0°** | **30°** | |
| 1 | Maximum rotation speed | 234.01 | 366.46 | rpm* |
| 2 | Maximum torque | 1.21 | 0.673 | N m |
| 3 | Maximum power | 12.49 | 22.2 | W |
| 4 | Minimum rotation speed | 0.05 | 0.018 | rpm* |
| 5 | Minimum torque | 0.001 | 0.000 45 | N m |
| 6 | Minimum power | 0.000 3 | 0.000 3 | W |
| 7 | Average of rotation speed | 9.77 | 6.42 | rpm* |
| 8 | Average of torque | 0.319 | 0.285 | N m |
| 9 | Average of power | 0.357 | 0.221 | W |

*) 1 rpm = 1/60 Hz

The Table 3 the *Darrius* wind turbine simulation with the twist angle of 0° has the maximum torque is 1.21 N m and the maximum rotation speed is 234.1 rpm (1 rpm = 1/60 Hz), whereas the twist angle of 30° has the maximum torque is 0.673 N m and the maximum rotation speed is 366.46 rpm. The result can obtain that the maximum of air velocity 2.9 m $s^{-1}$ has been passing the blade turbine. Based on Table 3 also can be described that the different data between the twist angle of 0°, and 30° can be described that the increase of rotation speed turbine blade can decrease of torque and increase the power capacity, and the second variant with the twist angle of 30° has been chosen as a blade of *Darrius* wind turbine.

## 4 Conclusions

The results of *Darrius* wind turbine simulations can be concluded that the second variant with the value of twist angle is 30° have the optimum power capacity rather than the first variant with the value of twist angle is 0°. The result torque of second variant is 0.285 N m, with the rotor turbine rotation speed is 6.42 rpm can produce the power capacity is 0.221 W. The research will be continued to data validation process with the result of pilot scale experiment.

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