# Modeling and Investigation of Combined Darrieus and Vane Design Vertical Axis Wind Turbine

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# Modeling and Investigation of Combined Darrieus and Vane Design Vertical Axis Wind Turbine

by

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بسم الله الرحمن الرحيم

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ABS | Acrylonitrile Butadiene Styrene. |
| CSB-VVAWT | Combined Straight Bladed Vane type Vertical Axis Wind Turbine. |
| CFD | Computational Fluid Dynamic. |
| DWT | Darrieus Wind Turbine. |
| HAWT | Horizontal Axis Wind Turbine. |
| RES | Renewable Energy Resources. |
| SB-VAWT | Straight Bladed Vertical Axis Wind Turbine. |
| SST | Shear Stress Transport. |
| SVAW | Sistan Vertical Axis Windmill. |
| VAWT | Vertical Axis Wind Turbine. |
| VTVAWT | Vane Type Vertical Axis Wind Turbine. |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $A$ | Area | $m^2$ |
| $A_S$ | Swept Area | $m^2$ |
| $C_P$ | Power Coefficient | _ |
| $C_t$ | Torque Coefficient | _ |
| $C_d$ | Drag Coefficient | _ |
| $F_n$ | Normal Force | N |
| $F_t$ | Tangential Force | N |
| $F_l$ | Lift Force | N |
| $F_d$ | Drag Force | N |
| $C_l$ | Lift Coefficient | _ |
| $\omega$ | Angular Velocity | rad/s |
| $V$ | Wind Velocity | m/s |
| $V_t$ | Tangential Velocity | m/s |
| $H$ | Height of Turbine | m |
| $D$ | Diameter of Turbine | m |
| $R$ | Radius of Combined Turbine | m |
| $\rho$ | Air Density | $Kg/m^3$ |
| $\mu$ | Air Viscosity | $\mathrm{Pa.s}$ |
| $R_e$ | Reynold Number | _ |
| $T$ | Static Torque | N.m |
| $t$ | Thickness | m |

| | | |
|---|---|---|
| $V_{blade}$ | Blade Turbine Velocity | m/s |
| $W$ | Power | Watt |
| $\beta$ | Shadow Angle | Degree (°) |
| $\theta$ | Azimuth Angle | Degree (°) |
| $W_e$ | Electrical Power | Watt |
| $W_{wind}$ | Power Produce by Wind Turbine | Watt |
| $W_m$ | Mechanical Power | Watt |
| $W_{gen.}$ | Power Produce by Generator of Turbine | Watt |
| $W_t$ | Transmission Output Power | Watt |
| $\Delta p$ | Pressure Different | $N/m^2$ |
| $P$ | Static Pressure | $N/m^2$ |
| $N_g$ | Generator Efficiency | - |
| $N_b$ | Gearbox Efficiency | - |
| $n$ | Number of Rotate | - |
| $\lambda, TSR$ | Tip Speed Ratio | - |
| $c$ | Plate Length | m |
| $c_D$ | Darrieus Resultant Velocity | m/s |
| $\theta_1$ | Starting Wind Shadow Angle | Degree (°) |
| $C_f$ | Skin Friction | - |
| $\alpha$ | Airfoil Angle of Attack | Degree (°) |
| $C$ | Airfoil Chord Length | m |
| $u$ | Relative Air Velocity on The Blade | m/s |
| $V_{rel.D.}$ | Darrieus Relative Velocity | m/s |

| | | |
|---|---|---|
| $d$ | Airfoil Thickness | m |
| $N$ | Number of Rotor Blade | - |
| $A_{com.}$ | Area of Combined Turbine | $m^2$ |
| $W_p$ | Power of The Prototype Wind Turbine | Watt |
| $W_m$ | Power of The Model Wind Turbine | Watt |
| $N_p$ | Number of Rotate for Prototype Wind Turbine | - |
| $N_m$ | Number of Rotate for Model Wind Turbine | - |
| $r_p$ | Radius for Prototype Wind Turbine | m |
| $r_m$ | Radius for Model Wind Turbine | m |
| $T_{V_i}$ | Torque for Vane Frame (i =1,2,3) | N.m |
| $T_{D_i}$ | Torque for Darrieus Frame (i =1,2,3) | N.m |
| $T_{V_{ave.}}$ | Average Torque for Vane wind Turbine | N.m |
| $T_{Com.ave.}$ | Average Torque for Combined wind Turbine | N.m |
| $T_{D_{ave.}}$ | Average Torque for Darrieus wind Turbine | N.m |
| $T_{V.tot.}$ | Total Torque for Vane wind Turbine | N.m |
| $T_{D.tot.}$ | Total Torque for Darrieus wind Turbine | N.m |
| $T_{Com.tot.}$ | Total Torque for Combined wind Turbine | N.m |

**PERMODELAN DAN PENYIASATAN TURBIN ANGIN GABUNGAN DARRIEUS DAN REKA BENTUK RAM PAKSI MENEGAK**

## ABSTRAK


Tenaga angin adalah salah satu bakal sumber tenaga yang boleh diperbaharui kerana banyaknya ada di atmosfera. Ia boleh didapati dalam skala yang berbeza iaitu julat halaju tinggi, sederhana dan rendah. Kuasa angin adalah sumber besar tenaga yang berterusan, yang boleh dituai oleh turbin angin paksi mendatar (HAWT) dan turbin angin paksi menegak (VAWTs). VAWT boleh digunakan untuk rejim kelajuan angin yang rendah untuk melaksanakan pelbagai fungsi skala-kecil bermula dengan mengelektrikkan peralatan bangunan. Di dalam tesis ini, prestasi turbin angin paksi menegak yang baru direka untuk digunakan di kawasan bandar dibentangkan. Reka bentuk baru yang dicadangkan adalah gabungan pemutar jenis ram dan pemutar Darrieus (kerajang udara NACA 0012) berbilah-lurus menegak pada paksi yang sama. Reka bentuk ini menggabungkan kelebihan kedua-dua reka bentuk dan pada masa yang sama cuba mengurangkan kelemahan. Pemutar jenis ram mewujudkan tork yang tinggi dan mula-sendiri walaupun pada kelajuan angin yang rendah tetapi dengan kadaran relatif kecekapan-rendah. Pemutar Darrieus mempunyai prestasi yang lemah dari segi mula-sendiri tetapi mempunyai kecekapan yang lebih tinggi dari pemutar jenis ram. Gabungan kedua-dua pemutar, jenis ram dan Darrieus kerajang udara NACA 0012 berbilah-lurus meningkatkan jumlah kuasa turbin pada kelajuan angin yang lebih rendah. Gabungan pemutar turbin angin paksi menegak (VAWT) telah direka dan diuji dalam terowong angin subsonik. Reka bentuk gabungan baru yang dicadangkan meningkatkan kuasa output turbin di kawasan kelajuan angin yang rendah melebihi 4 m/s sambil menyelesaikan masalah tork mula yang rendah untuk turbin angin Darrieus. Hasil kajian menunjukkan bahawa reka bentuk baru itu boleh mencapai pekali kuasa tertinggi $C_p = 0.24$ untuk turbin angin jenis ram pada halaju angin 6 m/s dan nisbah kelajuan hujung $\lambda = 0.223$. Di samping itu, pekali kuasa untuk turbin angin yang direka bentuk bergabungan itu meningkat kepada $C_p = 0.3925$ pada halaju angin yang sama iaitu 6 m/s dan pada nisbah kelajuan hujung $\lambda = 0.75$.

**Modeling and Investigation of Combined Darrieus and Vane Design Vertical Axis Wind Turbine**


## ABSTRACT

Wind energy is one of the potential sources of renewable energy because of its abundance in the atmosphere. It is available in different scales of high, medium and low-velocity ranges. Wind power is a major source of sustainable energy, which can be harvested by Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbines (VAWTs). VAWT can be used in low wind speed regimes for performing various small-scale functions ranging from electrifying a building's equipment. In this thesis, the performance of a newly designed vertical axis wind turbine for application in urban areas is presented. The proposed new design is a combination of vane type rotor and a vertical straight-bladed Darrieus rotor (NACA 0012 airfoil) on the same axis. This design combines the advantages of both designs while attempting to reduce the disadvantages. The vane type rotor creates high torque and is self-starting even at low wind speed but with a relatively low-efficiency rating. The Darrieus rotor has poor performance on self-starting rotor but has much higher efficiency than the vane type rotor. The combination of the two rotors, vane type and straight-bladed Darrieus airfoil NACA 0012 increases the total power of the turbine at lower wind speeds. A combination of Vertical Axis Wind Turbine (VAWT) rotors was designed and tested in a subsonic wind tunnel. The proposed new combined design increases the turbine output power in low wind speed areas of above 4 m/s while solving the low starting torque problem for a Darrieus wind turbine. The results showed that the new design could achieve the highest power coefficient of $C_p = 0.24$ for a vane type wind turbine at wind velocity of 6 m/s and tip speed ratio $\lambda = 0.223$. In addition, the power coefficient for the combined designed wind turbine increased to $C_p = 0.3925$ at the same wind velocity of 6 m/s and at a tip speed ratio $\lambda = 0.75$.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Wind is an ecologically agreeable wellspring of vitality that has a huge potential for satisfying the energy needs of people and mitigating the climate change from greenhouse gasses, emitted by the burning of fossil fuels. It was assessed that about 10 million MW of energy is available in the world's wind. Starting now, the installed capacity of wind energy system in the world is 194,390 MW (Sharma, Biswas, & Gupta, 2013). The energy of the wind is related to the turbine generator in the form of rotation of the turbine blades and this mechanical form of energy is further transformed into electricity, tapping wind energy through this sequence.

Wind turbines are of two types; Horizontal Axis Wind Turbine HAWT and Vertical Axis Wind Turbine VAWT. VAWT is most reasonable for area with low wind speed where HAWT, in contrast, is exceptionally uneconomical. Further, VAWT rotors do not require any yawing control that conduct the plane of the cutting edges to the winding course, as required if there were an occurrence of HAWT.

The low-performance coefficients, is the main disadvantage of VAWT. Subsequently, there is a scope for major research on VAWT rotors to improve their performance. The present work is based on VAWT rotor combined Darrieus wind turbine with a flat plate as a drag device with movable vanes to expand the starting torque for a Darrieus wind turbine.