TRANSIENT ANALYSIS OF BIO-INSPIRED VERTICAL AXIS WIND TURBINE

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MASTER OF SCIENCE

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Penuaian tenaga menandakan perkembangan pertumbuhan industri dan kuasa ekonomi dan sosioekonomi di rantau ini. Penggunaan bahan api fosil tanpa peraturan yang betul mengakibatkan kenaikan gas rumah kaca. Bilah turbin angin semasa direka untuk memenuhi persekitaran khusus, lokasi geografi dan beban angin. Oleh itu, ini mengakibatkan prestasi buruk dan tidak mencukupi di kawasan beban angin yang tidak konsisten seperti Malaysia. Oleh itu, pengubahsuaian reka bentuk sedang dilakukan pada morfologi bilah turbin angin untuk menyesuaikan diri dengan pelbagai persekitaran beban angin.Tujuan kajian ini adalah untuk mengkaji prestasi tiga turbin angin biofuel yang dicadangkan. Berdasarkan kelajuan angin yang tidak konsisten di Malaysia disebabkan oleh pengaruh cuaca bermusim. Oleh itu, reka bentuk pisau baru dicadangkan untuk menampung potensi kelajuan angin di Malaysia. Reka bentuk yang dicadangkan adalah produk hibridisasi reka bentuk yang diilhami oleh unsur alam. Oleh itu, penyiasatan dinamik bendalir komputeran teori turbin yang dicadangkan dijalankan relatif dalam 2D dan berdasarkan andaian teori. Kaedah isipadu terhingga disesuaikan untuk menganalisis turbin yang dicadangkan di bawah konfigurasi grid tidak konformal. Turbin yang dicadangkan disimulasikan di bawah konfigurasi pengiraan yang sama; formulasi berangka; konfigurasi pemecah. Penyiasatan adalah berdasarkan ‘Unsteady Reynolds rata-rata Persamaan Navier-Stokes’ yang tidak stabil dan dua model persamaan pengangkutan bergolak persamaan. Turbin dianalisis dari segi pekali pengekstrakan kuasa (C_p), berbanding dengan batas Betz sebagai penanda aras. Untuk kesederhanaan turbin yang dicadangkan dilabelkan sebagai Reka Bentuk 1; Reka bentuk 2; Reka bentuk 3. Reka bentuk 1 dimodelkan dalam dua skala yang besar dan mikrosek. Sementara itu Reka Bentuk 2 dan Reka Bentuk 3 dimodelkan dalam mikroskop. Turbin ini disimulasi di bawah pengaruh kelajuan freestream 8 m/s seperti yang dipotong laju untuk turbin. Reka bentuk 1 disimulasikan pada lima nisbah kelajuan hujung rendah yang berbeza. Keputusan menunjukkan bahawa turbin bertindak balas dengan baik pada λ = 0.2 dan λ = 0.3 dengan pekali kuasa positif C_p = 0.029 dan C_p = 0.025 masing-masing yang relatif rendah berbanding dengan turbin seretan yang konvensional. Sementara itu, nisbah kelajuan hujung, λ = 0.4, λ = 0.6 dan λ = 0.9 menunjukkan ketidakstabilan yang tinggi dalam penjanaan momen dan pengekstrakan kuasa negatif yang tinggi. Hasil yang dihasilkan menunjukkan pekali kuasa negatif yang memberi kesan kepada prestasi turbin. Rongga rongga mengalami tekanan buruk yang tinggi kerana geometri penjuru yang tajam dalam mengembalikan bilah yang mengakibatkan putaran bilah memajukan. Oleh itu, disimpulkan bahawa, penambahbaikan reka bentuk perlu dilakukan pada geometri rongga rongga untuk memastikan kelancaran putaran sementara tanpa bilah yang mempengaruhi satu sama lain. Sedangkan untuk Design 2 pada λ = 1.3 ayunan berangka stabil selepas 480° dengan nilai puncak stabil stabil iaitu C_m = 0.32. Purata pekali momen keseluruhan adalah C_m = 0.1886. Sementara itu, pada λ = 1.7 turbin menghasilkan nilai pekali momen purata C_m = 0.153991 dan menunjukkan corak tingkah laku hampir sama seperti λ = 1.3 dalam pengekstrakan tenaga angin. Keputusan menunjukkan bahawa turbin yang dicadangkan dengan empat bilah yang terdiri daripada AoA aerofoil NREL S819 tetap dilakukan dengan baik pada λ = 1.3 dan λ = 1.7 dengan menghasilkan purata pekali kuasa purata stabil iaitu C_p = 0.245 dan C_p = 0.262. Tambahan pula, magnitud kepusaran bagi setiap nisbah kelajuan hujung dianalisis. Ia telah diperhatikan bahawa, kesan bangun yang diakibatkan oleh tepi trailing telah mempengaruhi prestasi pisau berikut. Sementara itu, keputusan Reka bentuk 3 menunjukkan bahawa reka bentuk S-4 menunjukkan kestabilan numerik relatif kepada konfigurasi pengiraan dan keputusan pekali momen yang lebih baik berbanding dengan turbin angin Savonius. Pada λ = 0.59, turbin angin yang dicadangkan menunjukkan peningkatan sebanyak 7.2% dan mengurangkan kepada 4% pada λ = 0.94. Berdasarkan analisis dinamik bendalir komputeran morfologi yang dicadangkan menunjukkan bahawa pelaksanaan desain melalui bioinspirasi adalah bertanggungjawab tetapi memerlukan analisis lebih lanjut dan penyelidikan eksperimental untuk alat penuaian angin yang efisien dan adaptif.

ABSTRACT

Energy harvesting signifies the development of industrial and power growth of economy and socio-economy in a region. The use of fossil fuels without proper regulation resulted in rise of greenhouse gases. Current wind turbine blades are designed to cater specific environment, geographical location and wind load. Hence, this resulted in poor and inadequate performance at inconsistent wind load regions such as Malaysia. Hence, design modification is being done on wind turbine blade morphology in order to adapt to various wind load environment. This aim of the present study is to investigate the performance of three proposed novel bioinspired wind turbine. Based upon the inconsistent wind speed in Malaysia due to the seasonal weather influence. Hence a novel blade design is being proposed to accommodate the wind speed potential of Malaysia. The proposed design is the product of design hybridization inspired by elements of nature. Thus, the theoretical computational fluid dynamic numerical investigation of the proposed turbines was conducted relative in 2D and based on theoretical assumption. Finite volume method approach was adapted to analyze the proposed turbines under non-conformal grid configuration. The proposed turbines are simulated under the similar computational configuration; numerical formulation; solver configuration. The transient numerical investigation is based on Unsteady Reynolds-averaged Naiver-Stokes equation and two equation turbulent transport numerical model. The turbines are analyzed in terms of power extraction coefficient (C_p), relative to Betz limit as benchmark. For simplicity the proposed turbines are labeled as Design 1; Design 2; Design 3. Design 1 is modelled in two scales which is large and microscale. Meanwhile Design 2 and Design 3 is modelled in microscale. The turbine is simulated under the influence of freestream velocity of 8 m/s as cut in speed for the turbines. Design 1 is simulated at five different low tip speed ratios. Results shows that the turbine responded well at $\lambda = 0.2$ and $\lambda = 0.3$ with positive power coefficient of $C_p = 0.029$ and $C_p = 0.025$ respectively which is relatively low in comparison to conventional drag driven turbines. Meanwhile, tip speed ratio, $\lambda = 0.4$, $\lambda = 0.6$ and $\lambda = 0.9$ indicated high instability in moment generation and high negative power extraction. Generated result indicates negative power coefficient which has impacted the performance of the turbine. The cavity vane experiences high adverse pressure due to its sharp cornered geometry in returning blade which consequently impacted the rotation of the advancing blade. Therefore, it is concluded that, design improvement needs to be done on the cavity vane geometry to ensure smooth transient in rotation without the blade affecting one another. As for Design 2 at $\lambda = 1.3$ the numerical oscillation stabilizes after 480° with an average stable peak value of $C_m = 0.32$. The average of total moment coefficient was $C_m = 0.1886$. Meanwhile, at $\lambda = 1.7$ the turbine generated an average moment coefficient value of $C_m = 0.153991$ and showed almost similar behavior pattern as $\lambda = 1.3$ in wind energy extraction. The result showed that the proposed turbine with four blades composed of fixed AoA aerofoil NREL S819 performed well at $\lambda = 1.3$ and $\lambda = 1.7$ by generating a stable average power coefficient value of $C_p = 0.245$ and $C_p = 0.262$ respectively. Furthermore, the vorticity magnitude of each tip speed ratio was analyzed. It was observed that, wake effects induced by the trailing edge had affected the performance of the following blade. Meanwhile, Design 3 result shows that, design S-4 displayed numerical stability relative to the computational configuration and improved moment coefficient result compared to Savonius wind turbine. At $\lambda = 0.59$, the proposed wind turbine shows an improvement of 7.2% and reduces to 4% at $\lambda = 0.94$. Based on the computational fluid dynamic analysis of the proposed morphology indicates that design implementation via bioinspiration is liable but requires further analysis and experimental investigation for efficient and adaptive wind harvesting device.

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LIST OF SYMBOLS

A.R	Aspect ratio
S_A	Swept area
C_{pr}	Pressure coefficient
C_p	Power coefficient
C_m	Moment coefficient
C_d	Drag coefficient
C_l	Lift coefficient
C_t	Torque coefficient
D	Diameter
D_r	Rotor diameter
D_h	Hydraulic diameter
ε	Rate of dissipation of kinetic energy
E	Energy
F_l	Lift force
F_D	Drag force
I	Turbulent intensity
K	Turbulent kinetic energy
K_E	Kinetic energy
l	Turbulent length scale
M	Moment
ω	Specific rate of dissipation of kinetic energy
ω_r	Angular velocity
μ_t	Turbulent dynamic viscosity
μ	Laminar dynamic viscosity
u_f	Frictional velocity
Y^+	Y plus wall function
ρ	Density
P_w	Power
P	Pressure
U_∞	Free stream velocity
Re	Reynolds number

μ	Dynamic viscosity
O	Rotor hub diameter
σ	Standard deviation
T	Torque
V_m	Mean velocity

LIST OF ABBREVIATIONS

BEM	Blade element momentum
CFD	Computational fluid dynamics
COUPLE	Pressure velocity coupling scheme
DES	Detached Eddy Simulation
DMS	Double multiple streamtube
DNS	Direct Numerical Simulation
ERF	Explicit Relaxation Factor
FiT	Feed in Tariff
FSM	Fractional Step Method
GRI	General Richardson Extrapolation
Gg	Gigagrams
HAWT	Horizontal Axis Wind Turbine
LES	Large eddy simulations
NGO	Non-Government Organization
NACA	National Advisory Committee for Aeronautics
NREL	National Renewable Energy Laboratory
NSE	Navier-Stokes equation
PDE	Partial differential equations
PISO	Pressure linked equation with split operators
RAM	Random access memory
RANS	Reynolds-averaged Navier-Stokes
R.E	Renewable energy
R*i*	Robustness index
RSM	Reynolds stress model
RNG	Renormalized group
RPM	Revolution per minute
SEDA	Sustainable energy development authority
SIMPLE	Semi implicit method for pressure linked equations
SIMPLEC	Semi implicit method for pressure linked equations consistent
SST	Shear stress transport
SSM	Single streamtube model

PIV	Particle image velocimetry
TSR	Tip speed ratio
TUI	Text user interface
UDF	User defined function
URF	Under relaxation factor
ORF	Over relaxation factor
URANS	Unsteady Reynolds-averaged Navier-Stokes
VAWT	Vertical axis wind turbine
VOS	Voluntary observation ship

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