AN INVESTIGATION OF SQRT 2 CONJECTURE INSPIRED DRAG INDUCED VERTICAL AXIS WIND TURBINE BLADE

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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 Doctor of Philosophy.

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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

Kerajaan dan agensi penyelidikan menyediakan sokongan dan sumber untuk memudahkan pertumbuhan sektor tenaga boleh diperbaharui. Hari ini turbin angin adalah bentuk tenaga boleh diperbaharui yang terkenal untuk penuaian tenaga langsung. Dalam kajian ini konfigurasi turbin angin dipacu seret iaitu turbin angin Savonius diadaptasi untuk pembinaan reka bentuk yang dicadangkan. Aliran proses penyelidikan diasingkan kepada empat fasa yang menyatakan strategi yang digunakan untuk menjalankan penyiasatan iaitu bio-hibridisasi, dinamik bendalir eksperimen, dinamik bendalir pengiraan dan pengoptimuman. Didapati bahawa turbin angin Savonius tradisional memerlukan pengubahsuaian reka bentuk atau ciri reka bentuk sokongan penyepaduan untuk meningkatkan sifat seretan dan prestasi keluaran kuasa. Elemen bio yang dipilih dikonfigurasikan semula dan diubah agar sesuai dengan masalah reka bentuk dan kriteria turbin angin. Memandangkan kajian melibatkan menganalisis dan mengenal pasti morfologi kompleks bio-elemen, rangka kerja berasaskan pengiraan digunakan untuk proses pengekstrakan geometri iaitu OpenCV. Turbin angin teraruh seretan yang dicadangkan adalah hasil penghibridan dua elemen bio iaitu cangkerang terkonfigurasi lingkaran nautilus dan organisma marin teritip. Matlamat peringkat utama proses reka bentuk adalah untuk membina kerangka utama bentuk bilah turbin angin yang diekstrak daripada unsur bukan aerodinamik iaitu cangkang Nautilus. Reka bentuk awal dimodelkan dengan teritip dan morfologi bilah yang diilhamkan oleh tekaan matematik tetapi tanpa plat hujung. Konjektur dan nisbah yang dicadangkan menyediakan pendekatan alternatif dalam mengira nilai parametrik sesuatu geometri berkenaan dengan $\sqrt{2}$. Nampaknya nombor tak rasional $\sqrt{2}$ adalah asas dalam penciptaan bulatan dan lingkaran. Selain itu, gabungan berbilang kelengkungan bilah juga boleh dibina dengan tekaan, nisbah dan kaedah yang baru ditemui. Sementara itu, berbanding prosedur dinamik bendalir eksperimen, sifat putaran rotor disiasat menggunakan torkmeter digital yang diselaraskan oleh Arduino. Kredibiliti torkmeter rekaan disiasat dengan membandingkan magnitud momen yang dijana dengan model berangka pengiraan yang dilaksanakan dalam komputeran bendalir dynamik. Peratusan ralat antara tork pengiraan dan instrumentasi ialah 15.6%. Bagi rangka kerja komputeran bendalir dynamik untuk penyelidikan ini, reka bentuk yang dicadangkan pada mulanya disiasat secara menyeluruh berdasarkan analisis model berangka pengiraan yang dijalankan dalam Ansys CFX. Siasatan awal menunjukkan bahawa prestasi reka bentuk awal dipengaruhi oleh ketiadaan plat hujung. Geometri teritip dan konfigurasinya memperkenalkan pergolakan awal dan seterusnya mengurangkan seretan tekanan. Konfigurasi semula reka bentuk adalah berdasarkan proses pengoptimuman yang dicadangkan. Asas teknik pengoptimuman ialah G_f yang mengawal sifat seret badan berbanding dengan aliran. Sekiranya pengkaji ingin menyiasat lebih lanjut mengkonfigurasi semula morfologi sedia ada, ia dikehendaki menentukan faktor geometri badan untuk menentukan awal keadaan seretan. Memandangkan $G_f < 1$ (isipadu negatif) dan $G_f > 1$ (isipadu positif) meminimumkan atribut seretan jika orientasi badan adalah serenjang aliran. Didapati bahawa pelaksanaan geometri teritip yang diselaraskan secara berserenjang untuk mengalir secara berkesan mengurangkan sifat tekanan. Oleh itu, teknik ini diilhamkan untuk penyingkiran geometri teritip. Didapati bahawa sekatan diperbetulkan nilai C_p puncak turbin yang dikonfigurasikan semula ialah 0.201 iaitu 15.4 % sisihan daripada keputusan komputeran bendalir dynamik yang tidak diperbetulkan. Oleh itu, data baharu C_p yang diperbetulkan digunakan untuk membandingkan dengan literatur yang ada untuk mengukur prestasi reka bentuk yang dicadangkan. Dapat disimpulkan bahawa reka bentuk yang dioptimumkan meningkatkan kualiti C_p sebanyak 19.2 % berbanding data tradisional turbin angin Savonius pada $\lambda = 0.67$. Sementara itu, penulis juga mempersembahkan reka bentuk novel dengan aci dan bilah bersambung. Didapati bahawa reka bentuk yang dioptimumkan mengatasi prestasi kedua-dua model masing-masing sebanyak 15.51 % dan 6.34 %. Oleh itu, adalah jelas bahawa pengubahsuaian morfologi bilah melalui konjektur yang dicadangkan dengan kehadiran plat hujung meningkatkan prestasi pemutar dari segi ciri putaran dan output kuasa.

ABSTRACT

Governments and research agencies are providing support and resources to facilitate the growth of renewable energy sector (RES). Today wind turbines (WT) are the prominent form of renewable energy for direct energy harvesting. It is found that traditional Savonius wind turbine (SWT) requires design modification or integration supportive design feature in order to improve the drag attributes and power output performance. Generally conventional WTs are design to operate at high wind speed ranging from 10-15 m/s. This constrains the WT to harvest adequate power at low wind speed condition. Research shows that, design configuration adjustment and optimization has improved the efficiency in C_p. Hence, in this study drag driven WT configuration namely SWT is adapted for the construction of proposed design. The research process flow is segregated into four phases specifying the strategies utilized to carry out the investigation namely bio-hybridization, experimental fluid dynamics, computational fluid dynamics and optimization. The selected bio-elements are reconfigured and altered to fit the design problem and criteria of WT. Since the study involves analyzing and recognizing complex morphologies of bio-elements, computational based framework is utilized for the geometry extraction process namely OpenCV. The proposed drag induced wind turbine (DIWT) is a result of hybridization of two bio-elements namely nautilus spiral configured shell and barnacle marine organism. The aim of primary stage of the design process is to construct the mainframe of the WT blade shape which is extracted from a non-aerodynamic element which is Nautilus shell. The initial design is modelled with barnacles and blade morphology inspired by mathematical conjecture but without endplates. The proposed conjecture and ratio provide an alternative approach in calculating the parametric values of a geometry with regards to $\sqrt{2}$. It appears that irrational number $\sqrt{2}$ is fundamental in the creation of circle and spiral. In addition, multiple combinations of blade curvatures is also possible to be constructed with the newly found conjecture, ratio and method. Meanwhile, relative to experimental fluid dynamics procedure the rotational properties of the rotor is investigated using a digital torquemeter coordinated by Arduino. The credibility of the fabricated torquemeter is investigated by comparing the generated moment magnitude with computational numerical model which is executed in CFD. The percentage of error between computational and instrumentational torque is 15.6 %. As for CFD framework for this research, the initially proposed design is comprehensively investigated based on computational numerical model analysis conducted in Ansys CFX. Preliminary investigation indicated that the performance of the initial design is affected by the absence of endplate. The barnacle geometry and its configuration introduce early turbulence and consequently reduces the pressure drag. The reconfiguration of the design is based on the proposed optimization process. The basis of the optimization technique is the G_f which governs the drag attributes of a body relative to flow. If the researcher would like to further investigate reconfigure the existing morphology, it is required to determine the body geometric factor in order to preliminary determine the drag condition. Since $G_f < 1$ (negative volume) and $G_f > 1$ (positive volume) minimizes the drag attributes if the orientation of the body is perpendicular the flow. It is found that the implementation of the barnacle geometry aligned perpendicular to flow effectively reduces the pressure attributes. Hence, the technique inspired for the removal of the barnacle geometry. It is found that the blockage corrected peak C_p value of the reconfigured turbine is 0.201 which is 15.4 % of deviation from the uncorrected CFD result. Hence the new corrected data of C_p is utilized to compare with available literature to measure the performance of the proposed design. It can be concluded that the optimized design improved the quality of C_p by 19.2 % in comparison to conventional SWT at $\lambda = 0.67$. Meanwhile the author also presented a novel design with shaft and adjoin blade. It is found that the optimized design outperformed both the models by 15.51 % and 6.34 % respectively. Hence, it is evident that blade morphology modification via the proposed conjecture with the presence of endplate improves the performance of the rotor in terms of rotational characteristics and power output.

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