Faculty of Mechanical Engineering

THE INFLUENCE OF BLADE PARAMETERS ON THE PERFORMANCE OF PROPELLER PICO HYDRO TURBINE FOR RURAL ELECTRIFICATION

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Doctor of Philosophy

2018

THE INFLUENCE OF BLADE PARAMETERS ON THE PERFORMANCE OF PROPELLER PICO HYDRO TURBINE FOR RURAL ELECTRIFICATION

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A thesis submitted

In fulfilment of the requirements for the degree of Doctor of Philosophy

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled "The Influence of Blade Parameters on the Performance of Propeller Pico Hydro Turbine for Rural Electrification" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

DEDICATION

To my beloved mother and my late father, my wife and sons

ABSTRACT

Propeller Pico hydro turbine is one of the hydro turbine schemes which is capable to produce power output up to 5 kW. This stand-alone hydro system uses the run-off-river method with the application of penstocks to deliver the necessary water flow rate to the turbine system. In Malaysia, most of the rural sites offer significant sources of river flows with annual average 100 L/s to distribute power without the need for grid. In order to ensure the propeller hydro turbine can perform as required, both head and water flow rate are the two crucial parameters that must be taken into consideration. Since propeller Pico hydro turbine is more suitable to operate under low head, the water flow rate should be high enough to ensure power output generated by the hydro turbine can reach its maximum output. However, during dry season, the level of the river water will become low and even the stream flow of the water can become slow and unsteady. This phenomenon affects the overall performance of the Pico hydro turbine. The slow flow causes the rotational speed of the blades to become slower and indirectly the generator of the propeller hydro turbine produces very little power output. Therefore, the investigation on the influence of blade parameter configurations such as the hub-to-tip ratio, number of blades, and blade angles on the performance of the propeller hydro turbine were done under these stipulated condition. In addition, the straight flat profile with constant thickness and blade width are other blade criteria which are being focused. In this particular case, in which both head and flow rate are in low conditions, the values were fixed at 2.3 m height and 13 L/s water flow rate. At the initial stage, before proceeding to the actual experiments, the implementation of CFD simulation analysis was conducted on the mentioned blade design parameter configurations to serve as a design tool and reference for a better understanding of the experimental findings. Next, a Pico hydro test rig was designed and developed for the experimental purpose. After confirmation was made with the actual experiments, all related data were compiled together to identify the influence of combination related to blade parameters. Comparison on the Cost of Energy (CoE) was conducted between the hydro turbine and the standalone fuelled generator, where hydro turbine provided better amount of CoE which was 3.77 RM/kWh. From the Life Cycle Cost Analysis (LCCA), hydro turbine provided better Return of Investment (RoI) and Payback Period (PP) compared to standalone generator which is 44% and 5 years respectively. The final results showed the maximum electrical power output generated by the hydro turbine was 17 W, while the efficiency was 45%. In conclusion, the hub-to-tip ratio contributed the most on the performance of the hydro turbine, followed by the number of blades and lastly the blade angles. The best combination of blade parameter configurations is 0.4 for the hub-to-tip ratio, with three blades at 70° angle.

ABSTRAK

Turbin bilah hidro Piko merupakan salah satu daripada skim turbin hidro yang berkemampuan menghasilkan kuasa sehingga 5 kW. Sistem turbin hidro ini melibatkan penggunaan aliran air sungai secara terus di mana sistem perpaipan diguna pakai untuk mengarahkan aliran air sungai terus ke sistem turbin hidro. Kebanyakan kawasan pedalaman di Malaysia mempunyai purata tahunan kadar aliran sungai sekitar 100 L/s sebagai sumber bekalan kuasa. Untuk memastikan turbin bilah hidro Piko ini boleh berfungsi seperti mana yang diperlukan, dua faktor penting iaitu ketinggian dan juga kadar aliran air perlu dipertekankan. Memandangkan turbin bilah hidro Piko adalah sesuai diaplikasikan di kawasan yang rendah, oleh yang demikian, kadar aliran air yang perlu dibekalkan haruslah cukup deras bagi memastikan ianya berkemampuan untuk menjana kuasa semaksimum mungkin. Walau bagaimana pun, semasa musim panas dan kering, paras air sungai akan menurun malahan kadar aliran air sungai akan turut menjadi perlahan dan tidak menentu. Fenomena ini menjejaskan keseluruhan prestasi turbin piko hidro. Daripada kajian yang telah dijalankan, ketinggian yang rendah dan kadar aliran air yang juga rendah telah menyebabkan generator turbin menghasilkan kuasa yang begitu rendah. Dalam penyelidikan ini, turbin bilah kipas (salah satu daripada jenis turbin piko hidro) telah dipilih sebagai subjek yang akan diperbincangkan. Kajian telah dilaksanakan ke atas pengaruh parameter-parameter bilah seperti nisbah hab ke hujung bilah, bilangan bilah, dan sudut bilah ke atas prestasi turbin hidro. Di samping itu, bilah yang berprofil rata dengan ketebalan dan kelebaran yang seragam adalah merupakan kriteria yang turut diberikan perhatian. Di dalam kes ini, ketinggian yang akan diaplikasikan adalah 2.3 m manakala kadar aliran airnya adalah 13 L/s. Sebelum melaksanakan eksperimen sebenar, perlaksanaan analisis simulasi CFD telah dilakukan sebagai panduan bagi mendapatkan gambaran yang lebih jelas berkenaan dengan eksperimen yang dikendalikan. Kesemua data yang berkaitan (daripada analisis CFD dan juga eksperimen) akan dikumpulkan dan dibuat perbandingan untuk mengenal pasti sejauh mana pengaruh parameter-parameter bilah yang terlibat ke atas prestasi keluaran. Perbandingan Kos Tenaga (CoE) turut dilakukan di antara hidro turbine dan generator, di mana hidro turbin mempunyai jumlah Kos Tenaga yang lebih baik iaitu 3.77 RM/kWh. Daripada Analisis Kos Kitaran Hayat (LCCA), turbin hidro memberikan pulangan yang lebih baik dalam tempoh pelaburan (RoI) dan pembayaran balik (PP) berbanding dengan jenerator di mana nilainya adalah sebanyak 44% dan 5 tahun. Keputusan akhir menunjukkan kuasa keluaran maksimum elektrik yang dijanakan oleh hidro turbin adalah 17 W manakala kuasa keluaran maksimum mekanikal adalah 37 W. Kecekapan turbin hidro adalah 45%. Kesimpulan daripada penyelidikan ini mendapati nisbah hab ke hujung bilah adalah parameter yang paling mempengaruhi prestasi turbin hidro, diikuti dengan sudut bilah dan akhir sekali adalah jumlah bilangan bilah. Kombinasi parameter bilah yang paling sesuai adalah 0.4 nisbah hab ke hujung bilah, dan 3 bilah pada sudut 70^o.

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my supervisor, Associate Professor Juhari bin Ab. Razak from the Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (FKM, UTeM) for the supervision, support, guidance, and valuable advice in all aspects throughout the completion of this research and the thesis. I also wish to express my thanks to Dato' Professor Dr. Kamaruzzaman bin Sopian from the Solar Energy Research Institute, Universiti Kebangsaan Malaysia (SERI, UKM), as my co-supervisor for sharing additional information and knowledge towards the completion of this research.

Special thanks go to my employer, Universiti Teknikal Malaysia Melaka (UTeM), and Jabatan Perkhidmatan Awam Malaysia (JPA) for their fundings.

Special thanks also go to my family, especially my late father, beloved mother, wife and sons, for their moral support and tolerance towards the completion of my thesis.

Finally, thank you to those who directly or indirectly contributed to the completion of this thesis.

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AC	-	Alternate Current
BoM	-	Bill of Materials
CoE	-	Cost of Energy
CAD	-	Computer Aided Design
DC	-	Direct Current
DIY	-	Do it Yourself
2D	-	Two Dimension
3D	-	Three Dimension
FV	-	Future Value
LCCA	-	Life Cycle Cost Analysis
PP	-	Payback Period
PV	-	Present Value
RoI	-	Return of Investment

LIST OF SYMBOLS

A	-	Area of Cross-Section
A_1	-	Cross Section of Water Flow at Inlet Rotor
A_2	-	Cross Section of Water Flow at Outlet Stator/Inlet Rotor
A_3	-	Cross Section of Water Flow at Outlet Rotor
α_1	-	Angle of Absolute Velocity at Inlet Stator
α_2	-	Angle at Outlet Stator
α_3	-	Angle of Relative Velocity at Outlet Rotor
B_a	-	Blade Angle
β_3	-	Angle at Outlet Rotor
C_f	-	Fanning's Friction Factor
C_θ	-	Circumferential Fluid Velocity
C_{x1}	-	Water Flow Absolute Velocity at Inlet Stator
C_{x2}	-	Water Flow Absolute Velocity at Outlet Stator
C_{x3}	-	Water Flow Absolute Velocity at Outlet Rotor
d_i	-	Inner Diameter of the PVC Pipe
D_1	-	Exit Diameter for Straight Draft Tube
D_2	-	Inlet Diameter for Straight Draft Tube
D_b	-	Diameter of Runner Blade
E_t	-	The Rate for Work Transferred from the Fluid to the Runner
f	-	Friction Factor for Laminar Flow
g	-	Gravitational Acceleration
H	-	Head
H_{major}	-	Major Energy Losses
H_{minor}	-	Minor Energy Losses
H_f	-	Head Loss
H_i	-	Head Loss at The Entrance of the Pipe
H_o	-	Head Loss at The Exit of the Pipe
H_{fit}	-	Head Loss due to Pipe Fittings
H_N	-	Net Head

H_T	-	Total Head Losses
H_G	-	Gross Head
I	-	Current
I_x	-	Current Gained from Experiment Activities
K	-	Coefficient of the Bend Pipe
k_f	-	Loss Coefficient of the Pipe Bend
k_i	-	Loss Coefficient at Entrance
k_o	-	Loss Coefficient at Exit
L	-	Pipe Length
m	-	Mass Flow Rate
η	-	Efficiency
η_s	-	Specific Speed
$\eta_{turbine}$	-	Turbine Efficiency
$\eta_{generator}$	-	Generator Efficiency
N	-	Rotational Speed of the Turbine In Rpm
N_{blade}	-	Number of Blade
P_o	-	Power Output
P_i	-	Power Input
P_T	-	Turbine Power
ρ	-	Density (General)
ρ_W	-	Fluid (Water) Density
ρ_1	-	Water Density at Outlet Stator/Inlet Rotor
ρ_2	-	Water Density at Outlet Stator/Inlet Rotor
ρ_3	-	Water Density at Outlet Rotor
Q	-	Flow Rate
R	-	Resistor
R_e	-	Reynolds Number
r	-	Radius
$r1$	-	Hub Radius of Propeller Hydro Turbine
$r2$	-	Blade Radius of Propeller Hydro Turbine
R_{ht}	-	Hub-to-Tip Ratio
σ	-	Standard Deviation
t	-	Time in Second
τ	-	Torque

U	-	Blade Speed
μ	-	Absolute or Dynamic Viscosity of the Fluid
V	-	Flow Velocity
V_{bucket}	-	Volume of the Bucket
V_{CFD}	-	Stream Velocity Gained from CFD Analysis Activities
V_{ave}	-	Mean (Average) Velocity of the Flow
V_{stream}	-	Stream Velocity of the Flow
V_x	-	Current Gained from Experiment Activities
ω	-	Angular Velocity in rad/s
W_2	-	Water Flow Relative Velocity at Inlet Rotor
W_3	-	Water Flow Relative Velocity at Outlet Rotor
+ve	-	Positive Electrical Point
-ve	-	Negative Electrical Point