

**MODELLING AND CONTROL STRATEGIES
FOR HYDROKINETIC ENERGY HARNESSING**

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DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG



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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

College of Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2020

ACKNOWLEDGEMENTS

Alhamdulillah, I am grateful to Almighty Allah s.w.t for the good health, His blessing, merciful and rahmah in guiding me throughout all this tenure years in completing this research.

I would like to express my sincere appreciation to my supervisors, Associate Professor Ts. Dr Mohd Rusllim Bin Mohamed and Dr Raja Taufika Bin Raja Ismail for the continuous support, motivations and immense knowledge. Their guidance is invaluable.

I would like to take the opportunity to acknowledge the Universiti Malaysia Pahang and Ministry of Higher Education Malaysia for the financial support and scholarship award during my research and study years at UMP.

I would like to dedicate my special appreciation to my beloved mother, Wan Mariam Binti Wan Sulaiman, my lovely wife, Raihan, both of my hero, Darwisy & al-Fateh and as well as my entire family for the understanding, patience, support and doa during my PhD journey.

I would also to extend my thank to my friends, colleagues and everyone who directly and indirectly who have lent their ideas, time, knowledge and energy during my difficult time. I greatly appreciate their friendship and assistance.

ABSTRAK

Harga yang tinggi dan kekurangan sumber tenaga konvensional di samping kesedaran tentang alam sekitar kerana kadar pelepasan gas CO₂ yang tinggi telah menggalakkan ramai penyelidik di seluruh dunia untuk menerokai bidang baru dalam sumber tenaga yang boleh diperbaharui. Tenaga hidrokinetic terhasil daripada sungai adalah salah satu tenaga yang berpotensi untuk memastikan kesinambungan tenaga yang bersih, boleh dipercayai dan lestari. Sistem penjanaan konvensional hidroelektrik memerlukan turbin khas, kawasan tадahan air yang luas dan isu berkaitan alam sekitar. Sebaliknya, sistem hidrokinetik berdasarkan pengaliran air berterusan adalah salah satu pilihan yang terbaik untuk menyediakan tenaga elektrik terutamanya untuk kawasan luar bandar dan tenaga berskala kecil. Walaubagaimanapun, terdapat isu dan cabaran yang perlu diberikan perhatian seperti pilihan turbin, turbin model dan juga strategi kawalan untuk sambungan grid dan bukan grid. Sekarang, usaha memanfaatkan tenaga berdasarkan teknologi hidrokinetik muncul dengan ketara. Walaupun begitu, beberapa cabaran dan masalah perlu dipertimbangkan, seperti pemilihan turbin, strategi kawalan untuk sambungan grid dan bukan grid. Sehingga kini, tidak ada maklumat terperinci mengenai turbin dan turbine model yang paling sesuai dengan ciri sungai di Malaysia untuk di aplikasikan. Selain itu, ayunan besar turut berlaku pada keluaran arus dan kuasa semasa dalam keadaan mantap disebabkan oleh variasi pengaliran air sungai yang turun naik. Disebabkan itu, tenaga yang terhasil dan kecekapan pengawal untuk sistem yang bersendirian dan bersambung dengan grid menjadi kurang. Oleh itu, kajian ini bertujuan untuk menganalisa beberapa reka bentuk turbin, menentukan model turbin dan mengkaji strategi kawalan yang berpotensi untuk tenaga hidrokinetik yang bersendirian dan bersambung dengan grid. Dalam kajian ini, tiga jenis turbin paksi menegak, iaitu H-Darrieus, Darrieus, dan Gorlov dengan dua belas hidrofil NACA dan NREL, masing-masing dianalisa menggunakan perisian QBlade dan Matlab. Kesan profil geometri simetri dan tidak simetri, ketebalan hidrofoil, dan kepejaluan turbin telah dianalisa untuk memilih turbin yang terbaik berdasarkan pekali kuasa (C_P) dan pekali tork (C_M) yang tertinggi. Selepas itu, model turbin telah dicadangkan berdasarkan karekter turbin menggunakan persamaan anggaran polinomial. Sementara itu, keadah tanpa sensor telah di gunakan untuk system sendirian sebagai strategi kawalan MPPT. Litar topologi berdasarkan penerus tidak terkawal dan DC penukar rangsangan telah di gunakan untuk mengawal voltan keluaran dari penerus melalui kitar tugas. Seterusnya, kaedah metaheuristik berdasarkan gabungan algoritma Hill-Climbing Search (HCS) dan Fuzzy Logic Controller telah dicadangkan untuk menghasilkan ukuran saiz yang berubah-ubah berbanding dengan ukuran saiz tetap dalam konvensional algoritma HCS. Tambahan pula, dinamik model untuk system bersambung grid telah dilinearisasi untuk analisa kestabilan isyarat kecil. Pendekatan berdasarkan analisa nilai eigen telah diterapkan untuk menilai kestabilan sistem disebabkan gangguan kecil. Pengawal PI dengan kaedah penelusuran nilai eigen telah dicadangkan untuk meningkatkan kestabilan sistem dengan mengurangkan frekuensi ayunan. Hasil penyelidikan menunjukkan bahawa H-Darrieus dengan NACA 0018 adalah turbin terbaik untuk mendapatkan tenaga elektrik di sungai. Selain itu, HCS-Fuzzy MPPT algoritma dapat meningkatkan tenaga yang terhasil sehingga 88.30% dan juga mengurangkan 74.47% ayunan berbanding dengan SS-HCS MPPT. Manakala, kestabilan system tenaga hidrokinetik yang bersambungkan dengan grid dapat dipertingkatkan sehingga 63.63% dengan mengurangkan frekuensi ayunan pada nilai $\lambda_{8,9,10,11}$ serta mengurangkan ayunan 40.1% arus stator penjana pada pengawal sisi pemutar (RSC).

ABSTRACT

The high prices and depletion of conventional energy resources and the environmental concern due to the high emission of CO₂ gases have encouraged many researchers worldwide to explore a new field in renewable energy resources. The hydrokinetic energy harnessing in the river is one of the potential energies to ensure the continuity of clean, reliable, and sustainable energy for the future generation. The conventional hydropower required a special head, lots of coverage area, and some environmental issues. Conversely, the hydrokinetic system based on free stream flowing is one of the best options to provide the decentralised energy for rural and small-scale energy production. Lately, the effort of energy harnessing based on hydrokinetic technology is emerging significantly. Nevertheless, several challenges and issues need to be considered, such as turbine selection for energy conversion, generalised turbine model and control strategies for the grid and non-grid connection. To date, no detailed information on which turbines and turbine model are most suited to be implemented that match Malaysia's river characteristics. Besides, a large oscillation has occurred on the output current and power during dynamic steady state due to the water variation and fluctuation in the river. Hence, reducing the energy extraction and controller efficiency for stand-alone and grid-connected systems, respectively. Therefore, the study aims to analyse the different turbine's design, proposed the turbine model, and propose the potential control strategies for stand-alone and grid-connected hydrokinetic energy harnessing in the river. In this work, three types of vertical axis turbines, including the H-Darrieus, Darrieus, and Gorlov with twelve different NACA and NREL hydrofoils, were analysed using the QBlade and MATLAB software, respectively. The effect of symmetrical and non-symmetrical geometry profiles, hydrofoils thicknesses, and turbine solidities have been compared to choose one of the best option turbines based on the highest power coefficient (C_P) and a torque coefficient (C_M), respectively. Subsequently, the turbine power model generalised equation has been proposed to represent the hydrokinetic turbine characteristic using a polynomial estimation equation. On the other hand, the MPPT control strategy is employed for the off-grid system using the sensorless method. The circuit topology based on an uncontrolled rectifier with the DC boost converter is implemented to regulate the rectifier output voltage through duty ratio. Subsequently, the metaheuristic method based on the combination of the Hill-Climbing Search (HCS) MPPT algorithm and the Fuzzy Logic Controller has been proposed to produce a variable step size compared to the fixed step size in conventional HCS algorithm. On the contrary, the dynamic model of the grid-connected hydrokinetic system has been linearised for small-signal stability analysis. The eigenvalues analysis-based approached has been applied to evaluate the system stability due to the small disturbance. The PI controller with the eigenvalues tracing method has been proposed to improve the system stability by reducing the oscillation frequency. The research outcomes indicated that the H-Darrieus with NACA 0018 was the best turbine for energy conversion in the river. Besides, the HCS-Fuzzy MPPT algorithm improved the energy extraction up to 88.30 % as well as reduced 74.47 % the oscillation compared to the SS-HCS MPPT. The stability of grid-connected hydrokinetic energy harnessing was improved up to 63.63 % by removing the oscillation frequency at states of $\lambda_{8,9,10,11}$ as well as reducing 40.1 % oscillation of the generator stator current at the rotor side controller (RSC).

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