Faculty of Engineering

Development of Axial-Flow Hydrokinetic Turbine Systems for Shallow Tropical Rivers

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Development of Axial-Flow Hydrokinetic Turbine Systems for Shallow Tropical Rivers

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DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

Currently, the majority population of the world without access to electricity are countries in the tropics. Although Malaysia was among the tropical country listed to achieve 100 % accessibility in 2015, the state of Sarawak still has about 5 % of its population that does not. Due to the uneconomical grid connection, the state government has implemented small-scale conventional Micro-Hydropower (MHP) and Solar Energy Systems (SES) because of their abundant resources. However, despite being the preferred choice, small-scale MHP is inapplicable in the area where the topography does not favour it. In the meantime, the off-grid rural communities rarely have the purchasing power to acquire expensive equipment manufactured in high-cost countries. Besides, few commercially available small-scale Hydrokinetic Turbines (HKT) were developed specifically for shallow rivers (less than 1 m), and their design might not be entirely suitable for tropical rivers. Subsequently, this research aimed to construct a low-cost axial-flow HKT acceptable for shallow rivers in the tropics and would produce 2 kWh of energy per day. Two prototypes are designed and built in this research. The first was to evaluate the concept of building an HKT solely with off-the-shelf materials while the second was to overcome the issues faced by the first. The second improved prototype, with a 0.585 m reprofiled fan rotor with swept-back blades as the turbine rotor, produced 92.29 W of power from a flow velocity of 1.26 m/s, and its estimated efficiency is 0.34. Therefore, it can generate more than 2 kWh per day and is considered sufficient for a typical rural household. Besides, the improved prototype only costs USD 750 and is a fraction of the cost of commercial HKT for shallow rivers. Nevertheless, the study also revealed the Smart Drive motor as a promising and versatile candidate to be used as a generator for small-scale HKT construction. It produces less noise and has lower cogging torque than the DC brushed motor used in the improved prototype. A basic guide is also

presented for small-scale HKT construction with the modified Smart Drive motor – with the 60 SP and 60P configuration – as an alternative generator.

Keywords: Affordable, hydrokinetic turbine, off-the-shelf materials, rural electrification, swept-back turbine rotor

Pembangunan Sistem Turbin Hidrokinetik Beraliran Paksi untuk Sungai Tropika yang Cetek

ABSTRAK

Pada masa kini, kebanyakan penduduk di dunia yang tidak mempunyai kebolehcapaian kepada tenaga elektrik adalah di kalangan negara-negara yang terletak di kawasan tropika. Walaupun Malaysia adalah di antara negara di kawasan tropika yang tersenarai untuk kebolehcapaian 100 % pada 2015, negeri Sarawak masih memiliki lebih kurang 5 % daripada penduduknya yang belum. Disebabkan oleh kos sambungan ke grid yang tidak ekonomi, kerajaan negeri telah melaksanakan sistem kuasa hidro mikro konvensional dan tenaga solar kerana memiliki sumber yang banyak. Walaupun sebagai pilihan utama, sistem kuasa hidro mikro tidak dapat diaplikasikan pada topografi yang tidak sesuai dengannya. Pada masa yang sama, masyarakat luar bandar yang di luar sambungan grid jarang memiliki kuasa membeli untuk mendapatkan peralatan mahal yang dihasilkan oleh negara-negara kaya. Tambahan pula, terdapat sangat sedikit bilangan turbin hidrokinetik yang dibangunkan khas untuk sungai yang cetek (kurang dari 1 m), dan reka bentuknya pula mungkin tidak sesuai untuk sungai di kawasan tropika. Seterusnya, kajian ini bertujuan untuk menghasilkan sebuah turbin hidrokinetik aliran paksi yang berkos rendah untuk sungai cetek di kawasan tropika serta dapat menjana tenaga 2 kWh setiap hari. Dua prototaip telah direka dan dibina di dalam kajian ini. Yang pertama bertujuan untuk penilaian pembinaan turbin hidrokinetik dengan hanya menggunakan bahan-bahan yang sedia ada di kedai manakala yang kedua adalah untuk mengatasi kelemahan yang didapati daripada yang pertama. Manakala untuk prototaip yang kedua, dengan penggunaan pemutar kipas bersaiz 0.585 m yang telah diprofil semula dan digunakan sebagai pemutar *turbin telah menghasilkan kuasa sebanyak 92.29 W dari arus sungai 1.26 m/s, dan memiliki kecekapan anggaran sebanyak 0.34. Ia mampu untuk menghasilkan tenaga elektrik lebih daripada 2 kWh setiap hari dan dianggap mencukupi untuk sebuah rumah biasa di luar bandar. Di samping itu, prototaip yang kedua hanya dibina dengan kos USD 750 dan jauh lebih rendah berbanding dengan kos turbin hidrokinetik komersil untuk sungai yang cetek. Namun begitu, kajian ini turut mendedahkan bahawa motor* Smart Drive *adalah merupakan calon yang berpotensi dan serba boleh untuk digunakan sebagai penjana untuk pembinaan turbin hidrokinetik berskala kecil. Ianya kurang hingar dan memiliki penuugalan kilas yang lebih rendah berbanding dengan motor DC berberus yang digunakan di dalam prototaip yang ditambah baik, dan satu panduan turut dibentangkan untuk pembinaan sebuah turbin hidrokinetik menggunakan motor* Smart Drive *yang diubah suai dengan konfigurasi 60SP dan 60P sebagai penjana.*

Kata kunci: *Bahan-bahan sedia ada, bekalan elektrik luar bandar, mampu milik, pemutar turbin disapu balik, turbin hidrokinetik*

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LIST OF ABBREVIATIONS

AC	Alternating Current
Back-EMF	Counter-Electromotive Force
DC	Direct Current
DPG	Diesel-Powered Generator
ER-PMSM	External Rotor Permanent Magnet Synchronous Motor
HDPE	High-Density Polyethylene
HKT	Hydrokinetic Turbine
LEA	Local Electrical Authority
MHP	Micro-Hydropower
PMDCG	Permanent Magnet DC Generator
PMDCM	Permanent Magnet DC Motor
PMSM	Permanent Magnet Synchronous Motor
RES	Renewable Energy System
RPM	Revolutions per minute
SES	Solar Energy System
Solar PV	Solar Photovoltaic
TSR	Tip-Speed Ratio
UPVC	Unplasticised Polyvinyl Chloride

CHAPTER 1

INTRODUCTION

1.1 Study Background

According to the Our World in Data in 2016, only 87% of the world's population has access to electricity (Ritchie & Roser, 2020). The majority population without access are countries in central Africa and certain countries in Southeast Asia like Myanmar and Papua New Guinea. Malaysia was among the countries listed to achieve 100% accessibility in 2015 (The World Bank, 2022).

Malaysia is a federation comprising thirteen states and three federal territories. The state of Sarawak is the biggest, with a total land area of 124,450 km^2 – approximately 37 % of the total area of Malaysia – situated on the island of Borneo. It was reported about 48 % out of the 2.8 million population in Sarawak reside in rural areas (Yap et al., 2020) and live in 6,235 widely scattered villages (Shiun, 2016).

In 2017, according to Sarawak's Ministry of Utilities, the number of rural villages without access to electricity had been reduced to 1,623, involving 36,365 households, and are characterized into three categories under the State Rural Power Supply Program as shown in Figure 1.1. However, due to their small size of communities, scattered location, ruralness, and uneconomical grid connection, 5 % of Sarawak's population remains without access to 24-hour electricity from mains or solar power (Sarawak Energy, 2019). Therefore, due to these circumstances, the Local Electrical Authority (LEA) would turn to conventional Micro-Hydropower (MHP), Solar Energy Systems (SES) and even Diesel-Powered Generators (DPG) as a short-term solution to power up rural schools, clinics, administrative offices or even small villages for several hours daily (Anyi et al., 2010; Fauzi Shahab, 2017; Saupi et al., 2018). Eventually, situations like this provide tremendous challenges to the state government as they involve huge costs to provide electricity to all the rural communities. The state government estimated RM 6.7 billion is needed to power up the entire Sarawak by 2025 (Toyat, 2018).

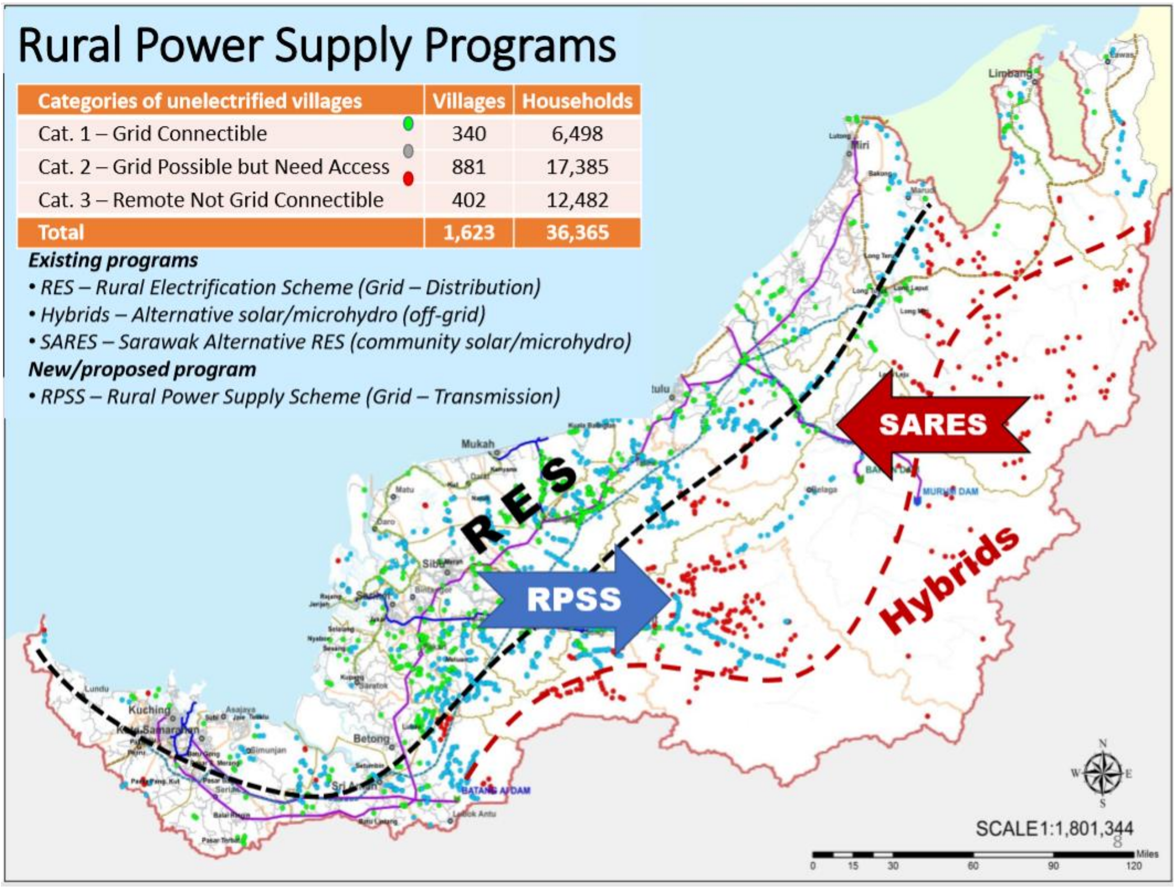

Figure 1.1: Categories of unelectrified villages (Fauzi Shahab, 2017).

Through Figure 1.1, the great concern would be category 3, which is considered remote and not grid connectible. From Figure 1.1, one can see that the majority of these villages (i.e., red dots) are scattered in the interior of Sarawak, particularly in the Rajang and Baram River basins, compared to Figure 1.2.

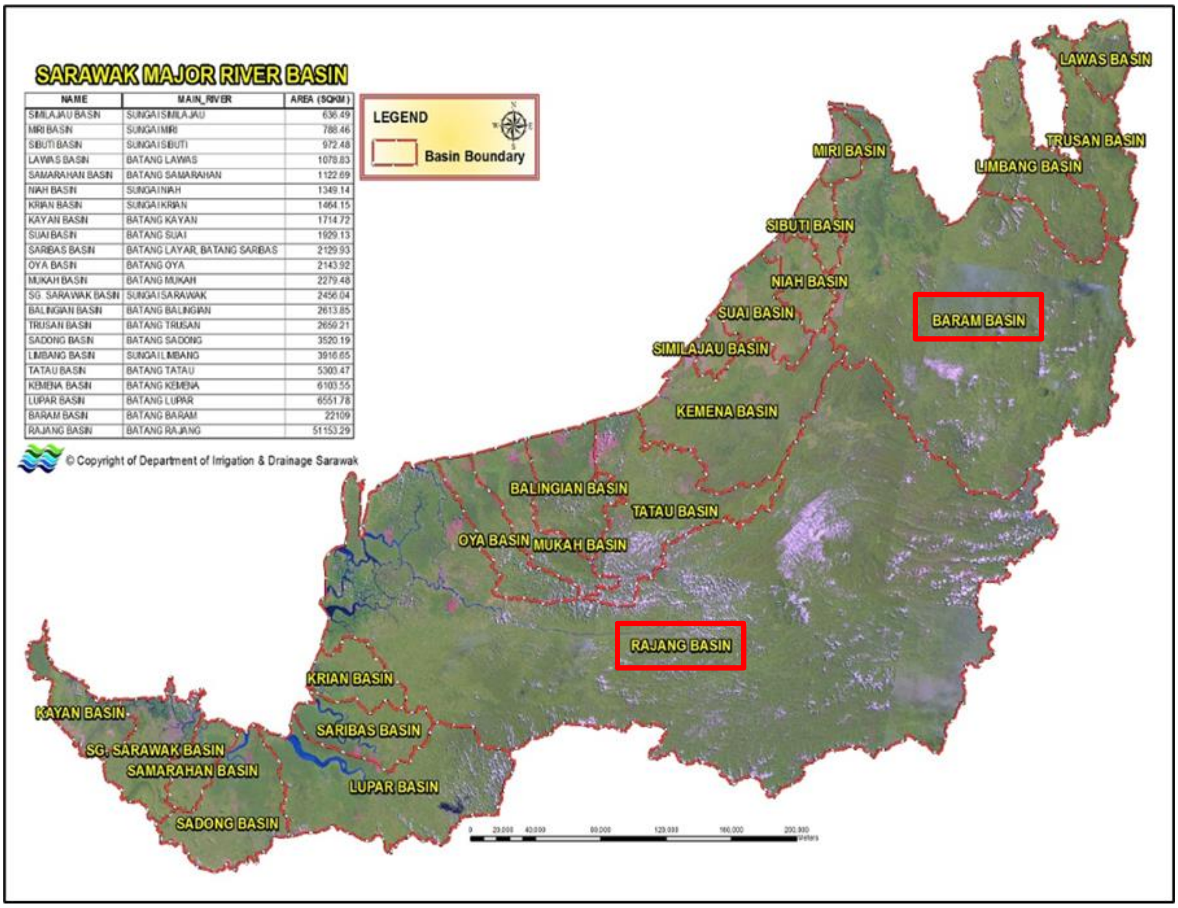

Figure 1.2: Sarawak 22 major river basins (DID of Sarawak, 2022a).

Sarawak receives an average annual rainfall of about 3850 mm, five times more than the world's average (Salleh et al., 2018). In addition, the hot and wet tropical climate has allowed a vast network of rivers to form and flow continuously throughout the year. The majority of the off-grid remote communities in Sarawak are located on the upper courses of rivers or tributaries because they rely on the river for water, food and transportation. Hence, MHPs have been considered the most suitable option for powering off-grid remote rural communities in Sarawak, where the topography is suitable (Anyi et al., 2010; Borhanazad et al., 2013; JOAS, 2015; Wan Zainal Abidin et al., 2009; Yeo et al., 2014).