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Micro-hydrokinetic turbine potential for sustainable power generation in Malaysia

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Abstract. Micro-hydrokinetic turbine (μ-HKT) technology is considered a viable option for sustainable, green and low cost power production. In recent years, there is growing number of research and development on this technology to replace conventional power production systems such as fossil fuel as well as to provide off-grid electrification to communities in remote areas. This paper provides an overview of μ-HKT system, the implementation of the technology and the potential of using μ-HKT in Malaysia. A review on the climate in Malaysia shows that its average annual rainfall is higher than the world's average annual rainfall. It contributes to the total hydropower resource of about 29,000 MW which is available all year-round. Currently, hydropower resource contributes only 7.4% of the total electrical power production in Malaysia but is expected to increase with the main contribution coming from μ-HKT. However, the μ-HKT technology has not been adopted in Malaysia due to some challenges that hinder the development of the system. This paper reviews the μ-HKT technology and its potential for application in Malaysia, particularly in remote areas.

1. Introduction

Utilization of electrical energy plays an important role in economic growth and contributes to the improvement of standard of living. Fossil fuel-based power generation is found to be the cheapest available alternative and has been the most common option for metropolitan and rural applications [1]. For example, diesel-power generator is used in many remote areas due to its simplicity, durability and requires less maintenance. However, it is observed that carbon dioxide (CO_2) equivalent emission of greenhouse gases produced by coal is 1689 g CO_2eq/kWh whereas natural gas contributes up to 930 g CO_2eq/kWh [2]. Eventually, it contributes to the climate change and global warming crisis. Due to the depletion of fossil fuel reserves, the rising of its prices put burden on electrical power usage for those who live in rural areas as most of the residents are underprevileged.

Current scenarios have encouraged the exploitation of renewable energy resources. An ideal renewable energy production technology should not only be able to sustain for future usage but must also have minimum negative impact on the environment and society [3]. Among the available renewable energy resources such as biomass, solar, wind, geothermal; hydropower energy holds the prime position in terms of contribution to the world's electricity generation under the renewable energy resource category [4]. Since water is almost 800 times denser than air, the hydropower system can extract energy of about 61.32% higher than wind turbine, even at low speed [5] [6]. In addition, it is found that small hydropower systems either at micro or nano-scale are the most reliable options to be considered particularly to power remote areas situated in close proximity to flowing water such as rivers and waterfalls [7]. This technology has capability to provide a cost-effective off-grid source of electricity less than 100kW in rural areas where populations are small and demand for power consumption is low [8].

Micro-hydrokinetic turbine (μ-HKT) system is a hydropower technology that generates electricity by harnessing kinetic energy of flowing water in a river or a stream with low elevation. The free-flowing water rotates turbine blades which turns a generator via drive shaft connection. The generator then converts the mechanical energy into electrical energy to power electrical loads. In principle, a μ-HKT system consists of five subsystems i.e. water turbine, generator, power control unit, support structure and transmission system. The water turbine of μ-HKT system can be categorized into two main groups, depending on the rotor axis with respect to the river flow, namely horizontal axis (or axial flow) turbines and vertical axis (or cross-flow) turbines [9][10]. Horizontal turbines have rotor parallel to the river flow and usually employ propeller-type rotors whereas vertical axis turbines have rotors orthogonal to the river flow. Examples of vertical axis turbines are paddle wheel, Darrieus, Gorlov and Savonius turbines [11]. Both horizontal and vertical axis turbines have their own technical advantages and disadvantages. For instance, horizontal axis turbines have self-starting capability but require high generator coupling cost due to underwater placement. Meanwhile, vertical axis turbines have lower efficiency but emit less noise due to reduced blade tip losses [9][10]. In general, the selection of the turbine type depends on the factors affecting the design and development such as hydrology and topology of a potential site, complexity, availability of technology and pertinent costs.

Unlike a conventional hydropower system, a μ-HKT does not require a construction of water reservoir or dam at strategic site to store water or canal to divert water from the main stream via penstock. Therefore, it offers minimum construction cost and minimum environmental impact which could disturb biodiversity within the potential site parameter. There are huge numbers of potential sites for the implementation of μ-HKT as it requires free-flowing stream [12].

Due to this fact, there is growing number of study on the development of μ-HKT technology recently. Researchers have done different works on various aspects which includes system design optimization, placement of turbine, augmentation application, reliability analysis, environmental monitoring and techno-economic feasibility [2]. The research on this technology is not only opted for in-land river but also extended for ocean current applications. At the same time, there are even field trial studies that have been performed all around the world to measure the practicality and feasibility of using μ-HKT system particularly for remote area application.

In this paper, several case studies on utilizing small-scale hydrokinetic turbine particularly for remote area application are discussed, respectively. The emphasis is given on the technology, system performance, reliability and problems encountered by the previous field trial studies. Based on the case study findings, the potential application of μ-HKT and its challenges in Malaysia are discussed. This paper provides an overview and potential of μ-HKT application which can be used for sustainable power production in Malaysia.

2. Case Study

Field test studies intended for remote electrification from Australia, Brazil and the United Kingdom (UK) are considered in this paper. These field tests are presented chronologically based on the publication year of the reports. Practicality aspects of small hydrokinetic turbine, technology implemented, performance, efficiency, reliability and pertinent problems are analysed and discussed for each case comprehensively.

2.1 Field trial in Australia

The evaluation of small axial flow turbines performance intended to generate electricity for Nguiu community in Apsley Strait, to replace the use of diesel fuel, was performed by Tuckey et al. [13] and

Swenson [14]. In their work, the performance of two different types of turbines was compared. In the first test, the Tyson turbine with its original high solidity rotor as shown in Figure 1(a) was utilized but the drive train was modified to fit for two car alternators. Then, in the second test, the original rotor was replaced with a lower solidity propeller turbine as shown in Figure 1(b). The second turbine was further modified to accommodate a low speed permanent magnet generator. Both turbines were mounted on pontoon which served as a structural support to keep the turbines submerged in the water. The configuration of small axial flow turbine by using Tyson turbine and low solidity turbine are summarized in Table 1.

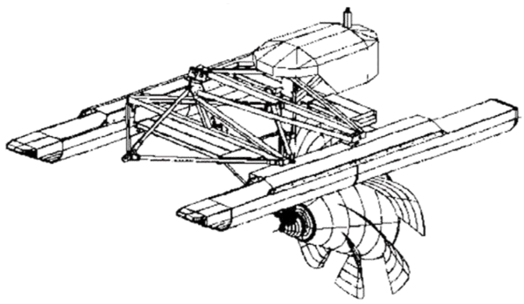
(a)

(b)


Figure 1. (a) High solidity turbine (Tyson turbine) [15] and (b) low solidity turbine [14].

Table 1. Configurations of small axial flow turbine for field study in Apsley Strait.

Type of turbine	**Configuration**
High solidity turbine (Tyson turbine)	• 2 m diameter rotor • 7 propeller blades, high solidity type • 4-stage drive train, turbine to alternator ratio of 182:1 (gear ratio) • 2 car alternators • Mounted on pontoon
Low solidity turbine	• 2 m diameter rotor • 4 propeller blades, low solidity type, 70 rpm at 2.1 m/s • 14:1 gear ratio • Low speed permanent magnet generator (rated 600 rpm) • Mounted on pontoon

A ten months of field trial showed that the maximum power coefficient C_p of the Tyson turbine was 0.17 at 1.6 m/s of river flow. The efficiency of the drive train and maximum efficiency of the alternators was estimated at 74% and 44%, respectively. Meanwhile, after a field trial of about 18 months, the maximum C_p of the second turbine was 0.32, obtained at water velocity of 1.1 m/s and 3.5 tip speed ratio. The drive train efficiency of 87.5% and generator efficiency of 89% were achieved thus resulting in the overall efficiency of 25%, higher than the first turbine with only 5.5%. However, both turbines were found to have problems with debris in which marine growth like seaweeds were found attached to the turbines. In addition, the gearbox was damaged by floating mangrove trees in the first field trial.

2.2 Field trial in Brazil

Tiago [16] demonstrated the capability of generating AC power directly using a small water turbine developed by the University of Brasilia. Some innovations were presented in the project as depicted in Figure 2 such as the use of cone-shaped grid in the turbine entrance for debris protection and a stator or guide blades fitted in front of the rotor. The purpose of the stator is to direct the water flow in the turbine in such a way to increase the angle of attack of the propeller thus optimizing the transformation of hydraulic energy. In addition, a suction tube is used at the outlet of the turbine and a cone was used at the center of the turbine to minimize turbulence in the water stream.

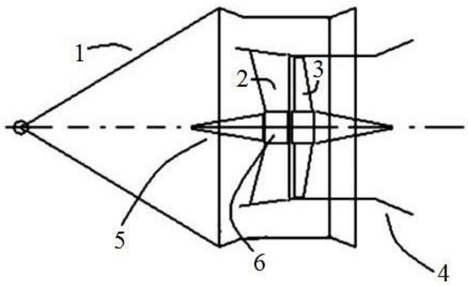


Figure 2. Turbine components: (1) cone-shape protecting grid, (2) stator or guide vanes, (3) propeller, (4) suction tube, (5) center cone and (6) transmission box [17].

The turbine was installed by simply suspending it from the river bank using a lever where the generator was mounted above the river as shown in Figure 3. This practical method allows the turbine to be adjusted according to the water level and lifted up for maintenance without sending men down into the river. Meanwhile, to counter for varying load due to varying river current, an electronic control system was designed to maintain the electrical load on the transmission grid.

Figure 3. Fully submerged turbine in the river was hold by a long lever at the river bank [17].

Both vertical flow and axial flow turbines with different configurations were tested empirically in the field. It was found that the implementation of suction tube significantly increased the overall performance of the turbine. The best results were obtained with a six-blade turbine having 30% solidity at 2 m/s river current. Overall, the turbines were able to generate electrical power of about 1kW using a 2kVA and 220 V AC generator enough to power a remote medical station in the state of Bahia, Brazil with loads including a refrigerator, a freezer and some lightbulbs.

2.3 Field trial in the UK

A turbine having similar design as previously studied by Bahaj et al. [18] in a cavitation tunnel and a towing tank at the University of Southampton was placed on a field test at Yarmouth Pier by Lowe [19]. The turbine consists of three propeller blades of low solidity with a rotor diameter of 2.75 m as shown in Figure 4, suspended from jetty. Instead of using metal shafts or gears, the kinetic energy of the turbine was transferred to a generator through mechanical power transmission by using pressurized water.

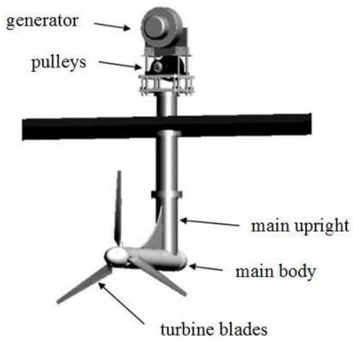


Figure 4. Design of the turbine adopted for the field trial study [18].

During field trial, the turbine was found to be able to generate about 1kW of electrical power at 1.25 m/s water velocity. The overall efficiency of the system is calculated to be about 27%. Similar to other axial flow turbines discussed earlier, the turbine was also found to encounter debris problem. It was reported that seaweed was found attached to the blades and the hub of the turbine shortly after being put in the water as shown in Figure 5. The performance of the turbine was found to be adversely affected by the debris problem. The presence of seaweed on turbine blades caused an increase in drag which slowed down the rotation of the turbine thus reducing the efficiency of the turbine. This problem has led to suggestions on avoiding or shedding debris automatically.

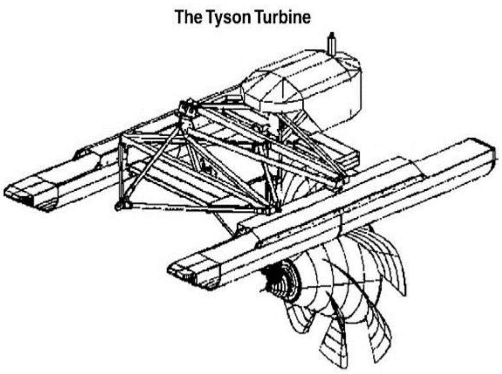


Figure 5. Seaweed on turbine [19].

3. Potential Application Of M-Hkt In Malaysia

Until December 2013, Malaysia has the maximum power generation capacity of 29, 748 MW with maximum load demand of 18, 902 MW [20]. According to the government forecast, the average annual primary energy consumption growth from the year 2004 to 2030 is 4.3%. In 2030, it is projected that the primary energy consumption will be tripled that of 2004 [21]. As the demand for energy consumption is increasing, with the increase of fossil-fuel prices as the primary energy resources, Malaysia is prioritizing renewable energy resources for electrical power production [22].

Currently, more than half of electrical power is generated from coal and natural gas which share the same percentage of 43.70%. This is followed by the renewable hydropower which contributes 8.70%, of total electrical power production, diesel (2%), fuel oil (1.2%) and other renewable resources (solar, wind and biomass) as shown in Figure 6. The percentages indicate that the electrical power production from renewable energy in total is so far less than 10%. Nevertheless, the energy generated through hydropower was found to increase year by year from 1990 to 2013 and Malaysia is targeting to increase its renewable energy production from 217 MW in 2011 to 11.5 GW by 2050 [20][23]. It is predicted that the main contribution to the increment of renewable energy resources will be from the utilization of hydropower resource specifically small hydropower system because it is most economical, simple, low operation and maintenance costs with shorter duration of construction, environmental friendly and can give direct off-grid supply of electrical power.

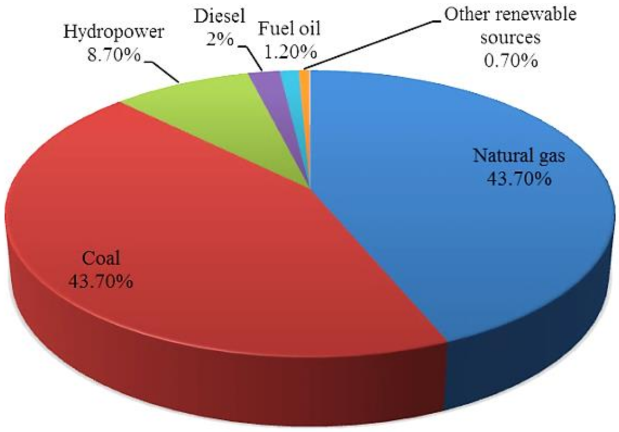


Figure 6. Electrical power production resources in Malaysia [24].

Malaysia is drained by a dense network of rivers and streams originated from highlands which act as catchment areas as shown in Figure 7. In Peninsular Malaysia, there are about 150 major river basins that flow downstream to the sea, the longest being the Pahang river (459 km) in the East Coast. Meanwhile, there are 50 major river basins in East Malaysia which mostly are larger than those in West Malaysia [25][26] while the Rajang river across the state of Sarawak being the longest river (563 km) in Malaysia and the Kinabatangan river in Sabah (560 km) being the second longest.

Due to the latitude of Malaysia that lies in the equatorial zone, the country has a tropical climate which allows reception of precipitation throughout the year. The rainfall is governed by the northeast and southwest monsoons and Malaysia receives rainfall the most during the period between these two monsoons [26]. It is estimated that the average annual rainfall in Malaysia is about 2450 mm in Peninsular Malaysia, 2630 mm in Sabah and 3850 mm in Sarawak. In fact, these values are higher than the world's average annual rainfall which is about 750 mm [8]. Unlike non-tropical countries which are prone to face drought crisis during dry season or frozen river during winter, the warm and wet tropical climate allows rivers in Malaysia to flow continuously every year.

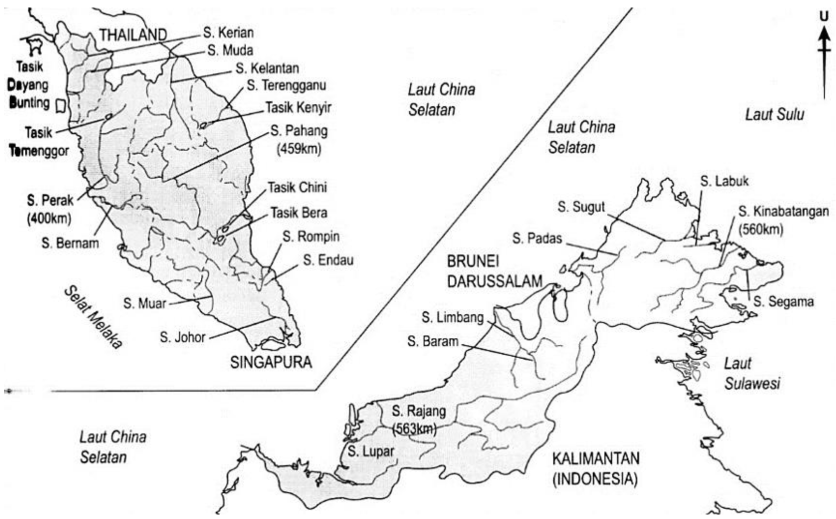


Figure 7. River networks in Malaysia [27].

Based on the vast river networks and the amount of rainfall per year, the hydropower resource is estimated to be 29,000 MW with 500 MW from small hydropower systems [8]. Therefore, Malaysia has a significant potential for the utilization of small scale hydropower especially μ-HKT where a continuous 24 hours of electrical power can be generated all year-round. Since μ-HKT generates electrical power directly from run-off-rivers, there are many potential sites available along the rivers that can opt for off-grid electrical power in remote areas where common grid power supply is less viable and non-economical due to some topological and financial challenges.

Most remote communities in rural areas live near rivers for source of water to perform their daily chores, agricultures and for drinking. These communities live under poverty with lack of access to basic needs including power supply. In Malaysia, there are roughly 8.4% of people in rural areas live below the poverty line and this is mostly found in remote areas in Sabah and Sarawak [28]. Statistical data on poverty in 2014 shows that the incidence of poverty level in Sabah is 3.9 which is the highest followed by Sarawak i.e. 0.9 [28]. The poverty level in remote areas is associated with energy poverty and lack of electricity which hinder positive economic growth and social development of the communities. In 2000, the electrical supply in rural areas in Sabah and Sarawak is found to be 67.05% and 66.91%, respectively. These values are far lower than in Peninsular Malaysia where the percentage of electrical supply in rural areas is above 90% as shown in Table 2.

Table 2. Electricity supply in urban and rural areas in Malaysia in year 2000 [25].

State	Urban	Rural	State	Urban	Rural
Johor	99.53	98.22	Perlis	99.63	99.17
Kedah	99.84	98.58	P. Pinang	99.84	99.16
Kelantan	99.52	97.50	Sabah	89.65	67.05
Melaka	99.90	99.28	Sarawak	93.96	66.91
N. Sembilan	99.61	98.60	Selangor	99.39	97.92
Pahang	99.63	93.96	Terengganu	99.65	98.24
Perak	99.64	96.11	W.P. Kuala Lumpur	99.76	-

For instance, due to the lack of grid electrical infrastructure, indigenous communities who live in thick rainforests in Kapit, Sarawak only rely on diesel generators to power their traditional longhouses [22]. The dependency on diesel-based electrical power contributes various problems to the surrounding environment. Fuel leakage can cause river pollution and reduce soil fertility which are used for agriculture whereas gas emissions from power generation increase greenhouse gases in the atmosphere. At the same time, the increase of global fossil fuel prices put huge burden to the local communities who live under poverty to get fuel supply. The situation becomes even worse as the price could be doubled due to difficulties to transport diesel supply to remote locations. Therefore, the utilization of low cost μ-HKT system is considered as a viable option to replace the conventional electrical power generation using diesel generator among remote communities.

Besides, μ-HKT has huge potential to provide off-grid electrical power at recreational sites located near the river. Some locations along the rivers in Malaysia are commonly developed to be recreational parks or camp sites due to their eco-tourism topological features such as Hutan Lipur Bukit Hijau in Baling, Kedah as shown in Figure 8. The utilization of electrical power from a low cost and environmental friendly small hydrokinetic system can minimize the operational cost of such sites thus encourage more visits from local and foreign visitors. In turn, it helps boost the growth in tourism sector as well as the socio-economics of nearby communities. Besides, the generated electricity can also be distributed to the surrounding communities where many of them still live in poverty with lack of access to the basic needs and limited power supply.

Figure 8. Hutan Lipur Bukit Hijau in Baling, Kedah [29].

4. Challenges

Although the entry of renewable μ-HKT system into the mainstream electrical power production in Malaysia is very promising, its full utilization in the rivers has yet to be realized. It is due to constraints in the current state of technology, debris threats and economical aspects which need to be addressed.

4.1 Technological aspects

Until now, the technology of μ-HKT is not well established yet where some are still under research and development phase. The μ-HKT technology is mostly adopted from the conventional large hydropower system and it does not really fit for small-scale applications. The field trial results from the case studies in the previous section showed that the maximum efficiency of the turbine was 0.27 from the theoretical maximum efficiency of 0.592 [12,18]. Various design aspects of μ-HKT still need to be investigated for optimal operation of the system.

4.2 Debris threat

Like most case studies, the utilization of μ-HKT in Malaysia has to address with the debris problem. Since Malaysian's tropical rivers flow through thick jungle, this threat can be more problematic. Sometimes huge amount of debris such as vines, leaves, logs and other jungle trash may float down the river at high speed during flash flood which can cause serious damages to μ-HKT installed in the river. This situation demand a better robust debris management strategies without reducing turbine overall efficiency and adding complexity to the systems [11].

4.3 Economical barrier

As the μ-HKT system is particularly opted to power electricity for poor communities in remote areas, cost is critical. Since the μ-HKT technology is still new, some components are not readily available in the rural areas, thus development, maintenance and replacement cost could be higher. Techno-economic analysis is required to evaluate the viability of the system design with respect to the cost without burdening the socio-economic status of the remote communities at potential sites.

5. Conclusion

A review on three case studies on the utilization of μ-HKT system has been provided. Each case study illustrated the feasibility and practicality of the system for low cost and low power demand. However, several aspects need to be investigated further for optimal and reliable operation of the system. These aspects are associated with the pertinent problems faced by the system during the field trials such as debris problems and overall efficiency enhancement. The review on the current status of μ-HKT system in Malaysia indicates a significant potential for off-grid power production in remote areas where power supply is very limited. This is strongly supported by the country's vast river networks with estimated small hydropower resource of 500 MW and Malaysia's vision in prioritizing the use of renewable energy. In order to fully utilize its potential, the challenges described here in terms of technological, potential site induced problems and economic issue need to be investigated and analyzed before implementing the μ-HKT system in Malaysia.

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