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LOW HEAD TURBINE APPLICATION IN HYDROPOWER GENERATION: A REVIEW OF POTENTIAL AND THEORETICAL FRAMEWORK DESIGN FOR OFF-GRID ELECTRIFICATION IN SARAWAK

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Abstract: This paper presents the overview study of small hydropower potential sites in Sarawak with additional review on existing project development. Sarawak is gifted with hilly areas and vast water resources which promise to give high potential in hydropower development. However, Sarawak was recorded as the lowest electrification coverage with 78.74% compares to Sabah and Peninsular Malaysia with 99.62% and 82.51%, respectively. In this research, reviews on the previous research works emphasized on low-head turbine application in Sarawak are presented. On the other hand, the potential of low-head turbine application is discussed as the pattern of remote population in Sarawak shows that most of the rural communities are located along the riverbank without elevation, thus implying the great potential for low-head turbine application to generate electricity. Moreover, most of the river in Sarawak are classified as low-pressure head with less than 10 meters and the average velocity of 1 to 2 m/s. Archimedes turbine is known as nearly zero-head turbine application, hence suitable to be installed in Sarawak particularly for remotes areas as Archimedes turbine used in low head and high flow rate application. Archimedes turbine is able to operate in less than 5 meters of water head with efficiency range in between of 60% and 80% and remains high even as available head approaches zero. The challenges and future perspectives of hydropower development in Sarawak are also discussed in this paper. Overall, this paper summarizes previous research works on hydro development in Sarawak and hence identifies the potential of low head turbine application mainly for off-grid electrification in Sarawak based on the geographical conditions as well as the topographic studies results.

***Keywords*:** Sarawak, hydropower, Archimedes, topographic, low-head turbine

1. INTRODUCTION

Rural electrification in Malaysia has always been a central concern as Malaysia is looking forward as one of the development countries. Rural communities commonly experience minimal access to the power supply due to the inconvenient conditions which result in the failure to provide electricity consistently in the rural areas. Moreover, expanding the grid to rural areas requires high cost of maintenance and installation due to the topography of land in Sarawak.

Malaysia is popular with the combination of huge river networks and hilly areas. For that reason, Malaysia promises to give high potential for hydropower constructions. Currently, Malaysia is having 150 river systems situated in West Malaysia and additional 50 rivers in East Malaysia. In Sarawak generally, there are 22 major river basins which located all over Sarawak region. Moreover, with the geographical position in equator, Malaysia received 2000 mm, estimated average annual rainfall which is 1250 mm higher than the world's average annual rainfall, 750 mm [1].

Malaysia had initiated small hydropower development back in 1905 and was constructed at Sungai Gombak, Selangor with 700kW generating capacity. Meanwhile in 1927, small hydropower was installed at Sempam River near Raub, Pahang with 1.2MW generating capacity [2]. Specifically, renewable energy sources in Malaysia contributes 22.5% national installed capacity mix at end of 2018. Sarawak has become the largest contributor with its large hydropower capability [2]. The main hydropower sources in Sarawak namely as Batang Ai, Bakun and Murum dam. However, despite being clean energy production and progressively cost-effective, Sarawak still continues to rely on non-renewable energy sources for most of the energy consumptions recorded in 2020. The total of 86.1% of energy consumption are from non-renewable resources such as gas, diesel and coal with 60.2%, 13.8% and 12.1% respectively. Meanwhile, only 13.1% of energy is from hydropower [3]

2. OVERVIEW OF HYDROPOWER POTENTIAL IN SARAWAK

Sarawak is the largest state in Malaysia, which has 124 450 km2 of land areas [4], [5]. Being known as the largest state in Malaysia, Sarawak also has the longest river in Malaysia with 760 km known as Rajang River [4]. Figure 1 shows the location of Sarawak in the Malaysia map.

Figure 1. Location of Sarawak in Malaysia Map [4]

As depicted in Figure 1, Sarawak encompasses about 40% of Malaysia's total land areas. In particular, Sarawak is identified as tropical rainforest climate which characterised by uniform temperature, high humidity and copious rainfall throughout the year. Specifically, Sarawak was recorded for having 3300 mm to 4400 mm of annual rainfall [5] [6]. However, despite being gifted with hilly areas and vast water resources which promise to give high potential in hydropower, Sarawak has the lowest electrification coverage with 78.74% compares to Sabah and Peninsular Malaysia with 99.62% and 82.51%, respectively according to electrification status in Malaysia in 2010 [7]. Sarawak Energy Berhad (SEB), wholly owned by Sarawak State Government is responsible for Sarawak's electricity infrastructure. In recent years, as State Government aims to provide full electrification in Sarawak by 2025, SEB considered various renewable energy resources to cater for the energy demands, especially in rural areas. Positively, the electricity coverage was massively increasing with 96.9% of domestic and rural electrifications in Sarawak by 2019 [8].

As a result of abundant annual rainfall and suitable topography, hydropower has been identified as the main driver for Sarawak Corridor of Renewable Energy (SCORE). Currently, Sarawak has three main hydropower plants; Batang Ai Hydropower (108 MW), Bakun Hydropower (2, 400 MW) and Murum Hydropower (944 MW) [9]. Table 1 shows the current hydropower at Sarawak.

Table 1: Current Hydropower at Sarawak [8], [10]

Hydropower	Total Capacity Installed (MW)
Bakun	2400
Baleh	1300
Baram	1200
Batang Ai	108
Belaga	260
Belepeh	114
Lawas	87
Limbang	245
Linau	297
Murum	944
Pelagus	410

Referring to Table 1, Sarawak has three major hydropower which shows that hydropower has a great potential as the main renewable energy resource in Sarawak. In fact, Baleh Hydropower which is expected to contribute 1,285 MW total capacity and to be completed by 2025 verified that hydropower development is recommended in Sarawak.

Batang Ai is the first hydropower in Sarawak with a total installed capacity of 108 MW. Batang Ai consists of four Francis turbine units each of 27 MW [9]. Murum hydroelectric is the second dam to be built after Batang Ai hydroelectric. The first generator was commissioned in December 2014 even though the dam was started in 2008 [11]

Bakun Hydro project was successfully commissioning in 2011 with the construction of 2400 MW hydroelectric dam. This indirectly marked Bakun Hydro as the largest hydroelectric project in the Southeast Asia region outside of China. Initially, during the completion of Bakun Hydro project, Sarawak Energy Berhad (SEB) and TNB would form a partner regarding to the power transmission project. However, due to the called off of the submarine cable issues, the collaboration between TNB and SEB was also unsuccessfully [11]. And currently, the whole electricity supply from Bakun Hydro project is channeled to SEB and supplied within Sarawak only as a result of the issues. Murum is another large hydropower in Sarawak with 944 total installed capacity. Murum hydropower is equipped with four Francis turbine units with 236 MW each. Murum hydropower regulates about 20% of Bakun catchment by discharging water through Murum powerhouse [9].

Other than being known for having larger hydropower in Malaysia, Sarawak also has various small hydropower development. To keep ahead with the goals to provide 100% of electrification towards Sarawak's people by 2025, various small renewable energy are being considered as energy resources for rural areas. In fact, 42% of Sarawak's people live in rural areas which in need of continuous electricity in assisting their daily chores [12]. Fortunately, Sarawak is blessed with abundant resources enabling it to meet the energy demand by harnessing various renewable energy resources with international best practices. Specifically, 64.6% of energy in Sarawak are from hydropower as recorded in 2020. Meanwhile the remaining of 34.5% are from non-renewable resources which are coal and gas resources with 20.7% and 13.8% respectively [3].

Particularly, currently Sarawak has two major Micro Hydropower and Solar Energy systems specifically for rural electrifications. Generally, other than being installed as a stand-alone micro hydropower, some of the micro hydropower is installed mix with Solar Photovoltaic system and diesel. Various method has been taken in order to offer continuous electricity towards Sarawak rural communities. Table 2 depicts the existed micro hydropower in Sarawak.

Table 2: Existed Micro Hydropower in Sarawak [12]

Division	Village	Total Capacity Installed (kW)
Kuching	Kpg Parang	10
	Kpg Sapit	6
	Rh Laroh*	5
Sri Aman	Kpg Keranggas*	Not Available
	Kpg Sri Stamang 2	18.3
	Rh Jawang Janting	-
	Rh Michael Jantan	-
Sarikei	Rh Jugom Jegging	120
	Rh Nyaiyang	-
	Rh Suin Tebru	-
	Rh Kedit Chundang	-
	Rh Unyat Chupong	8
Kapit	Rh Suing Ensan	8
	Kpg Mudung Abun	20
	Long Lawen	10
	Pa Ramapoh	20
Miri	Kpg Bario Asal	40
	Long Kerangan	10

	Long Lamai	15
	Long Banga**	320
Lawas	Long Semadoh Nasib	20
Limbang	Buduk Nur	7.5
	Buduk Aru	10
	Buduk Nur	30
	Buduk Bui	12.5
	Long Langai	15
	Long Rusu	35
	Total	740.3

*Micro Hydropower with PV Hybrid
**Micro Hydropower with Diesel

Referring to Table 2, most of the existed micro hydropower in Sarawak are installed as stand-alone, while some of the micro hydropower is installed in hybrid with solar photovoltaic and diesel generator. Generally, installed hydropower in Sarawak were funded by Government Sector, NGOs, private sector as well as community-based.

Through the Local Authority Survey, Sarawak is identified to have 50 sites of hydropower with a total installed capacity of 20 GW. Meanwhile, based on the conducted survey by Local Authority Survey, micro hydropower has a great potential in Sarawak with an estimated total capacity installed at about 10.2 MW through 104 sites in eight divisions. In fact, 27 sites of installed micro hydropower with the total generated power of 740.3 kW has been existed in Sarawak as shown in Table 2.

Particularly, only 2% of Sarawak land are identified and having potential as hydroelectric project [3]. According to SEB, hydropower development in Sarawak is developed by adhering to International Commission on Large Dams (ICOLD) standards and guidelines in order to ensure all hydropower in the land of Sarawak are built and operated safely, efficiently, economically and are environmentally and socially equitable. As referring to ICOLD, a ‘large dam’ defines as minimum of 15 meters high, measured from the bottom to the peak of a dam, and store at least 3 million cubic meters of waters [13], [14]. In Sarawak, Bakun dam meets all the criteria as large dam as Balui river characterized with 37 km upstream from Belaga Power and designated to generate 2400MW of electricity [13]. Figure 2 illustrated the identified and potential of hydropower in Sarawak.

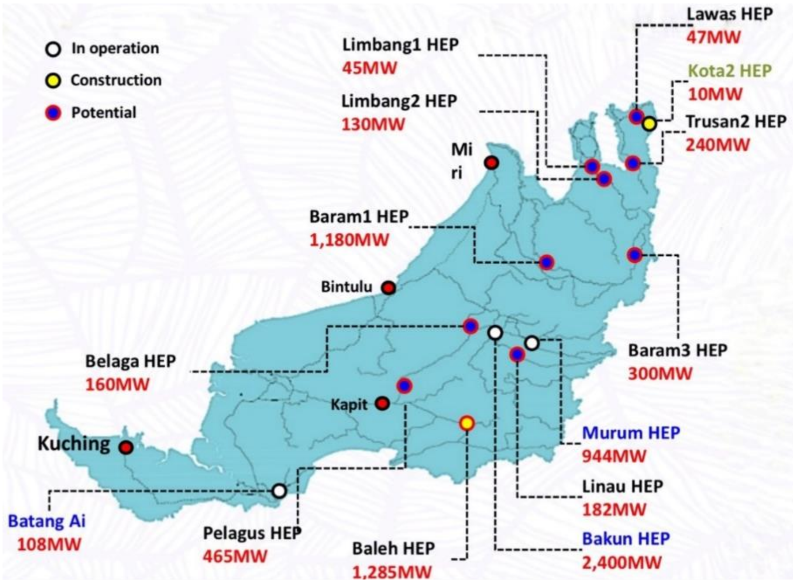

Figure 2. Identified and Potential of Hydropower in Sarawak [3]

Referring to Figure 2, nine sites are identified as having great potential for hydropower development. Meanwhile, 3 sites are identified as having a major hydropower project which are, Batang Ai, Bakun and Murun hydropower electric. Additionally, the Sarawak Alternative Rural Electrification Scheme (SARES) has been implemented which focused on mini/micro hydro and solar generation system development to ensure the rural communities are provided by continuous electrification by year 2025. Specifically, the remaining 1, 600 villages and 36, 000 households are yet to be electrified as recorded in 2017 [3].

3. THEORETICAL FRAMEWORK DESIGN CONSIDERATION

Hydropower generates energy by the potential energy of falling water or flowing water of rivers or selected streams. In hydropower installation, the viewpoints of electromechanical equipment, civil structures and energy distribution systems must be taken into account as they influence the effectiveness of the built-in system. The electromechanical equipment in hydropower mainly consists of turbine and generator. Selection of turbine is crucial part in hydropower installation which based on the characteristic of the site location. Generally, powerhouse is to protect the electromechanical equipment that convert the potential energy of water into electricity. Meanwhile, civil structure components are to regulate and control the water flowing to the turbine. The gravitational force from the water potential energy over height differences between the upper elevation and downstream of water level is converted to rotational mechanical energy. In small hydropower, main civil structure components are weirs, channels, intakes, forebays, regulating gates, powerhouse, penstocks and spillways.

The output power in hydropower is categorized into two parts; theoretical available power, Pin and practical output power, Pout. The theoretical power available is to identify the expected generated power in order to measure the potential of a particular site location [15]. The general equation for a hydropower system is;

$$P_{in} = \rho g Q H \tag{2.1}$$

$$P_{out} = \eta \rho g H Q \tag{2.2}$$

As in equation (2.1), the theoretical hydropower output, Pin (Watt) is influenced by the head, H (m) and flow rate of the water, Q (m^3/s) as well as the gravitational constant value, g (m/s^2) and water specific density, ρ (kg/m^3). In hydropower system, head defines as the differences between the upper and downstream water levels[16], [17]. As the density of water (1000 kg/m^3) and gravitational constant value (9.81 m/s^2) also affect the general operation of hydropower system, the constant value of both gravitational and specific water density must be considered as in equation (2.1). On the other hand, practical output power, Pout (Watt) known as mechanical power, define when the overall efficiency, η (%) of turbine is being taken into consideration along with the characteristic of environmental effect as in equation (2.2).

As turbine is the one of the main parts of electromechanical equipment in hydropower installation, the efficiency of turbine must be considered as the energy losses typically occurred at any electromechanical equipment and indirectly affects the output power of the system. General equation for hydropower efficiency is;

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \tag{2.3}$$

Numerous research study has been conducted which stated that maximum hydraulic effectiveness is in the range of 80-90%. Meanwhile, micro-hydropower demonstrated the effectiveness of 60-80% [18]– [20].

Occasionally, different physical site conditions result in various types of turbine selection and turbine designs. Turbines can be broadly categorized into two types; impulse turbine and reaction turbine. Nowadays, advanced turbine technology design with numerous modifications is also available in the marketplace in order to cater for the progressively higher demand for water turbine as well as to improve the quality of hydro-generated power. Turbine specific speed, Ns is defined as;

$$N_s = \frac{RPM\sqrt{P}}{H^{1.25}} \tag{2.4}$$

Referring to equation (2.4), RPM is known as the turbine rotation in RPM, while P is power output (Watt) and H is the water head (m) [20]. Each turbine type is specified as radial, mixed flow and full axial turbine depending on the flow direction and path across the turbine wheel. Table 3 Shows the speed turbine specification.

Table 3: Speed Turbine Specification[20]

Specified Speed	Type of Flow	Type of Turbine
15-65	Radial Flow	Turgo Turbine, Pelton Turbine
60-400	Mixed Flow	Cross Flow, Francis
300-800	Axial Flow	Kaplan, Propeller

Referring to Table 3, the specific speed between 100 and 600 which classified as mixed flow and axial flow is specifically for low head system [20]. Particularly, high head site generally uses impulse turbine and low head site uses reaction type turbine.

Unlike large-scale hydropower system, small-scale hydropower system has minimal environmental effect as small scale hydropower system mainly consists of run-off river with no dam's installation. For small hydropower system, no dams were installed. The intake structure will be installed instead in order to gather the water before it flows inside the pipeline. The pipeline is also buried underground which minimizes the environmental effect in the area.

3.1 Archimedes Screw Turbine Application

Archimedes Screw Turbine used in low head and high flow rate application. The turbine uses hydrostatic pressure difference across the blades which applied the Archimedes Principle [21]. Basic principle of Archimedes screw turbine and Gravity water turbine is almost similar as both of the turbines utilized the water weight to create pressure on the turbine's blades [22]. Figure 3 shows the Screw type turbine design.

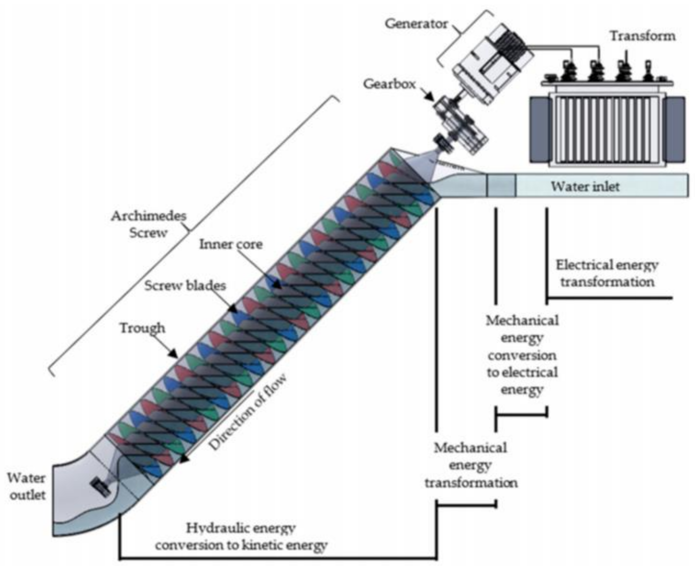

Figure 3: Screw Type Turbine Design [23]

As shown in Figure 3, the turbine works based on the hydrostatic pressure of the water weight as the screw is rotating when the water falls through it. The differences in the head will also affect the rotation velocity as it depends on the water depth over the blades. In the screw type turbine, the rotation of the screw will rotate the gear box hence generating the electricity [24]. Energy conversion in the turbine is converted from the potential energy of water to kinetic energy by the rotating screw then create electrical energy by the generator [23]. Compare to other turbine principles, screw turbine design is mainly driven by the hydrostatic pressure difference that develops across the screw surface. The difference weight of water volume with different water levels within the incline screw will result in a difference hydrostatic pressure.

Screw type turbine and gravity water wheels are generally partially immersed in water with 0.5 meters to 0.6 meters head applications. Typically, Archimedes screw rotates around an axis inclined of 22° to 35° on the horizontal [22]. Numerous research study has been conducted which stated that higher inclination angle for Archimedes Screw Turbine can achieve 80% efficiency in run-of-river real scale application [23].

Various theoretical studies have been conducted to identify the ideal geometric factors for a good performance of Archimedes turbine. In fact, numerous experimental laboratory-scale has been done to acquire the synchronous results between the numerical data as well as the empirical results for a good performance of the turbine. Overall, the three-bladed screws turbine has been proved to be an ideal number for Archimedes turbine performance compared to double-bladed, four and five-bladed screws turbine. However, for the single-bladed and double-bladed screws turbine comparisons, the double-bladed turbine gives a good performance with higher power output for the system compares to single-bladed screw turbine [25].

3.2 Research study on Archimedes Turbine using CFD Modelling

Computational Fluid Dynamics (CFD) is widely used in industrial and non-industrial applications areas. CFD involved the analysis of fluid flow, heat transfer and any related phenomena such as chemical reaction by means of computer-based simulation [26]. Numerous numbers of research study on turbine design were conducted using CFD modelling analysis in order to improve the turbine efficiency performance. Previously, research works on impulse and reaction-type turbines were commonly conducted by researchers using CFD modelling analysis. Several research works using CFD modelling analysis were conducted to improve the efficiencies of the turbine and minimize power losses in systems. CFD modelling data of Archimedes turbine have been widely introduced with a similar goal. Even though no current perfect theory for optimal hydraulic design, but almost all Archimedes turbine lab-scale testing models using CFD modelling analysis claimed that the turbine achieved an average of 80% efficiency with the low pitch inclination angle application [23].

Archimedes turbine consists of helical screw blades which fix to a centre core of the blades. The helical screw is also known as screw blades. The screw blades freely rotate on its centre axis with constant screw pitch. The number of blades influences the performance of the turbine. Past research studies found that three-bladed screw blades are sufficient as it results in good performance as well as easy to manufacture [23]. The output power of three-bladed Archimedes turbine is based on the rotation of the screw [27]. Three-bladed screw Archimedes turbine with geometrical shapes with ratio radius of 0.54 and pitch of 2.4Ro achieved up to 89% of turbine efficiency [27]. Numerical analysis of two-bladed screws also shows a good performance of Archimedes turbine with an appropriate condition of water flow. In the recent experimental study for double-bladed Archimedes screw turbine, the turbine was tested for micro-hydro application in Aceh region with three varies water flow conditions. The results show that the highest turbine rotations and turbine power occurred at 0.025 m^3/s compared to flow rates at 0.0125 m^3/s and 0.0044 m^3/s, respectively. The maximum turbine performance obtained is 295 rpm with 116.10 Watt, while the maximum turbine efficiency is 55% at 0.0125 m^3/s [28]. The researchers conclude that the highest value of water flow rate resulting in maximum torque and output power even though its efficiency did not reach its maximum value with the highest value of water flow rate [28].

The comparison study of three-bladed, four-bladed and five-bladed have been found as the investigation of the turbine performance is studied based on the number of screws installed. For this particular research study, the three-bladed screw was found to have the highest efficiency with the lower inclination angles, meanwhile, five-bladed screw generates the highest power [29]. The research study was conducted with the CFD simulations of three, four and five-bladed Archimedes turbines design.

Various theoretical studies have been conducted to identify the ideal geometric factors for a good performance of Archimedes turbine. In fact, numerous experimental laboratory-scale has been done to acquire the synchronous results between the numerical data as well as the empirical results for a good performance of the turbine. Overall, the three-bladed screws turbine has been proved to be an ideal number for Archimedes turbine performance compared to double-bladed, four and five-bladed screw turbines. However, for the single-bladed and double-bladed screw turbines comparison, the double-bladed turbine gives a good performance with higher power output for the system compared to single-bladed screw turbine [25], [30], [31].

The relation of inclination of angle and the output power for Archimedes turbine has been studied theoretically using numerical method of CFD simulation and lab experimental works. Recent research works using CFD simulation show that the mechanical torque and efficiency of turbine change with the value of volume of flow rate and inclination angle [32]. The research works show that the geodetic head decreases with the inclination angle and cause the efficiency to be increased.

3.3 Low Head Turbine Selection for Off-Grid Electrification in Sarawak

Turbine is one of the main components in hydropower system that convert the potential energy of falling water to mechanical rotation energy before its transform to electrical energy by the generator. Nowadays, advanced turbine technology design with numerous modifications also available in marketplace in order to cater for the progressively higher demand for water turbine as well as to improve quality of the hydro generated power. Archimedes turbine do not categorize as impulse or reaction turbine mechanism as Archimedes turbine practically generate energy due to pressure differences across the blades which created by the weight of the water [33]. Archimedes turbine is considered as quasi-static pressure machines as the turbine driven by the weight of water which would also involve water wheels applications. Figure 4 depicts the range of typical commercial types turbines with respect to site head and flow rate.

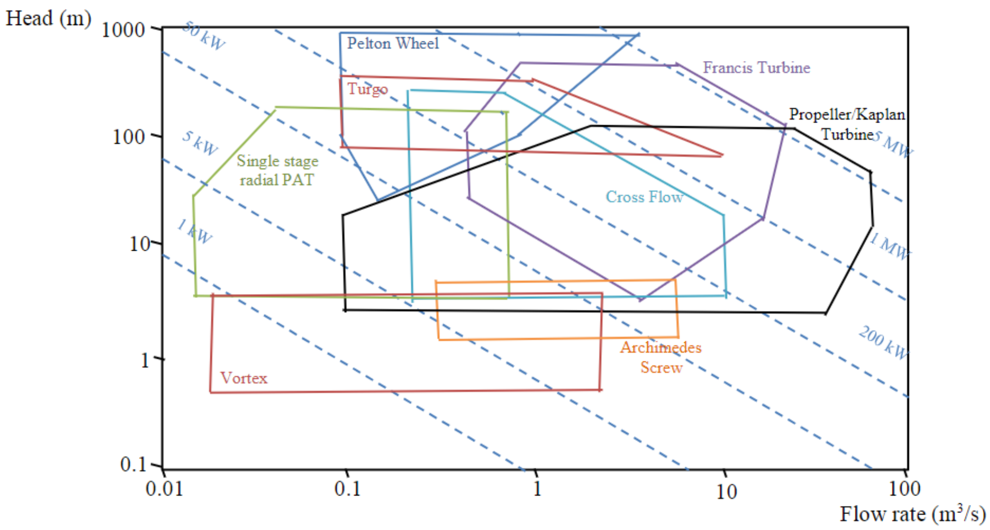

Figure 4: Range of Typical Commercial Types Turbines [18], [20], [33]

Figure 4 shows the range of typical types commercial types turbines such as Pelton Wheel, Turgo, Francis, Cross-flow and Kaplan as well as Vortex and Archimedes turbine. Generally, in order to conduct the turbine selection and to design the ideal turbine, site assessment must be conducted in order to identify the available head and the flow rate of the water flow. Table 4 shows comparison of commercial types of impulse, reaction and quasi-static pressure turbine respectively.

Table 4: Comparison of Commercial Types of Impulse, Reaction and Quasi-Static Pressure Turbine

<table>
<tr><th>Types</th><th>Turbine</th><th>Head (m)</th><th>Flow Rate (m3/s)</th><th>Specification</th></tr>
<tr><td rowspan="3">Impulse

Suitable for high head and low water flow application</td><td>Pelton</td><td>50-1000 [33]</td><td><50 [33]</td><td>i. Designed with symmetrical bucket shaped blade attached to the wheel
ii. Water pressure will hit directly to the blade bucket shape and rotates the wheel</td></tr>
<tr><td>Turgo</td><td rowspan="2">50-250 [33]</td><td rowspan="2"><10[33]</td><td rowspan="2">i. Modification of Pelton
ii. Incoming jet is directed at an angle of 20° to the buckets [33]</td></tr>
<tr><td>Cross-Flow</td></tr>
</table>

Reaction For low head measurements which below than 50 meters with wide flow rate volumes	Francis	40-600 [33]	0.2-1000[33]	i. Positioned in spiral voute as water enter in radial direction guided with adjustable guides vanes [20] ii. Main components' spiral casing, guide vanes, runner blades and draft tubes iii. Complexity of blade profile and vanes applications. Hence, its more expensive and less popular in micro hydropower application. iv. Guide vanes tend to trap the debris and requires frequent maintenance
	Kaplan	<50 [33]	0.5-1000[33]	i. Common turbine in markeplace and uses propeller ii. Simple installation and require minimal civil works iii. Lower effeciency with 50% typical range [20]
Quasi-static Pressure Practically applied in combined low head and low flow rate	Water wheel/ Vortex	<10 [33]	<5 [33]	i. The turbines utilized the kinetic energy to rotate the turbine instead of using the potential energy as the turbine ii. The well-constructed of the turbine recorded the efficiency in the range of 50%-70% [33]
	Archimedes		<10 [33]	i. Smaller impacts on fish and other fauna ii. Efficiency range between 60% and 80% and remains high even as available head aprroaches zero.[33] iii. Cost-effective, lower installation and operating costs.

Referring to Table 4, innumerable types of low head turbine application in hydropower generations such as Archimedes turbine applications are immensely beneficial compare to other turbine application for low water flow sites and low head conditions. In Sarawak, most of the river are classified as low-pressure head with less than 10 meters and the average velocity of 1 to 2 m/s that give the greatest potential for low-head turbine application [34]. Therefore, Archimedes turbine is suitable to be installed in Sarawak particularly for sustainable development as Archimedes turbine offered positive social and economic impacts as well as environmental advantages with smaller impact on fish and other fauna. However, research works related to Archimedes turbine applications in Sarawak are limited and eventually, the prototype of Archimedes turbine would be useful for off-grid electrification in Sarawak.

4. CHALLENGES AND FUTURE PERSPECTIVE OF LOW HEAD TURBINE APPLICATION

Malaysia has launched five corridors of devolvement in 2008 including SCORE which stress on hydropower development. Unlike Peninsular Malaysia, Sarawak is known for vast networks of rivers, suitable topographic features and adequate annual rainfall which enhance its hydropower potential. Particularly, up to 2018, 67.9% of Sarawak's electricity supply was sourced from hydropower [11]. However, in spite of the greater potential for hydropower development, Sarawak still relied on the conventional power resources for most energy consumptions. Some issues that encountered the hydropower development in Sarawak are identified. Followings are the common challenges that can be observed in Sarawak in the development of hydropower:

4.1 Limited Field Studies for Small Hydropower

Various theoretical studies have been conducted to identify the ideal geometric factors for a good performance of Archimedes turbine. In fact, numerous experimental laboratory-scale has been done to acquire the synchronous results between the numerical data as well as the empirical results for a good performance of the turbine. However, the small hydropower is limited to lab experiments and simulation results such as CFD in order to determine the best design turbine which applicable in available conditions [19].

In term of laboratory scale works, Archimedes turbine has been shown good potential to be used at low-head small hydropower installations. Archimedes turbine is capable to generate electricity at ultra-low head as well as fish-friendly. The experimental lab works has been done with the outside diameter of the turbine of 142mm and with the head of 0.25 m, the Archimedes turbine is able to generates 1.4-Watt maximum power with 49% of efficiency with 22° angle of inclination [35]. Other literature studies claimed that almost all lab-scale testing models for Archimedes Screw Turbine resulted in 80% efficiency with low pitch angles in the system [23]. In the run-of-river hydro application, the Archimedes Screw turbine with the highest possible inclination angle up to 45° was able to achieve 80% efficiency. However, with the inclination angle of 45°, more turbulent flow throughout the system. In fact, in real hydro application, high inclination angle is considered less efficient due to energy loss as well as leakage loss in the system. In Archimedes turbine, friction losses closely relate to the inclination angle. The higher inclination angle will increase the friction losses in a system. However, by identify an ideal inclination angle in Archimedes turbine, it would create an optimal balance between the friction losses and leakage losses in a system. As Sarawak is blessed with vast water resources and demonstrated numerous locations that have high potential for small hydropower both theoretically and practically, the development of small hydropower in Sarawak is still at the infancy stage that does not fully exploit the available resources. Therefore, this research works aims to fill the gap as the simulation and laboratory scale works are being considered as the main future research works by identify the optimum design of Archimedes turbine specifically for low-pressure head river in Sarawak.

4.2 Local Expertise

Limited local expertise is still the main issue in developing hydropower in Malaysia which made China became the most significant foreign partner in Sarawak's hydropower development. Even though Japan was involved in the first dam construction in Sarawak which is Batang Ai, Dam, however, China is involved in three dam construction; Bakun Dam, Murum Dam and upcoming Baleh dam [11]. In Bakun hydropower scenario, the project was initiated by Australia however led to their withdrawal due to the massive wave of criticism from the local communities. Additionally, other than opposition of the longhouse communities, the massive cost overruns led to their withdrawal. Then, Chinese took over the project by joint-venture between Sinohydro and Sime Engineering Berhad which is part of Sime Darby. The Sinohydro holds 30% of the joint venture while Sime Engineering holds 70% [11]On the other hand, like Murum dam, Baleh dam is also having China's involvement as the main civil works contract has been awarded to a joint venture formed by China Gezhouba Group Company Ltd and local firm Untang Jaya Sdn Bhd [11][36]–[38]

Regardless to the outsider involvement towards the mega hydropower project in Sarawak shows that local expertise in hydropower development become one of the main challenges in hydropower development. In order to become a host economy through the powering hydropower development in Sarawak, continuous improvement in the governance dam-building and enhancement of local expertise should be considered. Therefore, sufficient education, training and quality insurance focused on hydropower development to cater for lack of local hydropower expertise.

4.3 Financial barrier

Financial barrier is a common issue in constructing the hydro projects. In the case of small hydropower in Sarawak, mini or pico hydropower only contributed very low power consumption compared to conventional power resources which resulted in less significant to the eyes of society. Additionally, the efficiency of small hydropower is decreased to 20%-30% during the draught session due to the decrease of rainfall capacity in certain months throughout the year [18]. Therefore, because of the uncertainty in some technologies required as well as the generated power capacity, high financing costs are also required to cover up research, development and deployment of the project. Table 5 shows the estimated cost of dam in Sarawak under SCORE.

Table 5: Estimated Cost of Dam in Sarawak under SCORE [10]

Dam	Status	Output (MW)	Date of Operational	Estimated Cost (Mill USD)
Bakun	Built	2400	2011	4644
Baleh	Planned	1300	-	2424
Baram	Planned	1200	-	1515
Batang Ai	Built	108	1985	387
Belaga	Planned	260	-	242
Belepeh	Planned	114	-	49
Lawas	Planned	87	-	95
Limbang	Planned	245	-	439
Linau	Planned	297	-	264
Murum	Under Construction	944	-	1061
Pelagus	Planned	410	-	424

Table 5 shows the estimated cost of dam in Sarawak under SCORE project. Much uncertainty exists over the cost of dam in Sarawak which cause financial barrier become the main concern in hydropower development [10]. Researchers also found out that three dams of every four dams are suffer from cost overruns. While, one of every two dams costs exceed the benefits [10].

Specifically, many small hydropower projects have been implemented by different non-govermental agencies. Universiti Malaysia Sarawak (UNIMAS), PACOS and Green Empowerment are the active agencies in small hydropower installations particularly in rural settlement in Sarawak. The finding of local reconnaissance studies found that several sites in existing settlements in Sarawak have a high potential for low head large flow small hydro run of river schemes. In addition, according to surveys done by SEB, small hydropower in Sarawak are expected to generate over of 4400kW power [10]. However, because of insufficient specific incentives and renewable energy policies, access to finance for small hydropower is limited and difficult. Promotions and related courses on renewable energy in detail should be proposed in educational institutions as well as financial institutions to raise awareness on the importance of renewable energy among people.

5. CONCLUSIONS

As a conclusion, literature studies on small hydropower in Sarawak are still scarce even though Sarawak has great potential for small hydropower due to its geographical conditions. Extensive literature studies show that varies types of turbines are applicable for small hydropower even though low head application in Sarawak is scarce as the research works mainly focused on the successful numbers of high head hydropower applications. Archimedes screw turbine is used in low head and high flow rate applications which shows great considerable potential for small hydropower. However, only the simulation research works were found instead of field studies testing. Future research works on field studies of Archimedes screw turbine application is requires further attention as Sarawak shows great potential for small hydropower development.

In fact, comprehensive literature studies show that small hydropower is applicable for rural areas communities to cater for the daily basis necessity. Therefore, in order to ensure small hydropower development in Sarawak, the effort should not be limited to government sectors only, but also towards private sectors as well as individual awareness. The identified challenges also show that small hydropower in Sarawak has not been fully exploited yet despite being a preferable choice and having considerable potential for energy generation in Sarawak. On top of that, Sarawak aims to provide 100% of electrification towards Sarawak's people by 2025. Therefore, further attention towards small hydropower is essential to fulfill the Sarawak goals by 2025 especially to provide electricity in rural areas.

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