Low Head Micro Hydro Systems for Rural Electrification

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Abstract. Off-grid micro hydro is an economical and practical approach to generate electric power to fulfil energy demand in rural areas. Large numbers of successful high head micro hydro project have been reported however the application of low head micro hydro system is scarce. Low head micro hydro system commonly recognized using complex profile blades, larger civil structure and electromechanical components to extract energy. This leads to a more complex system and higher cost with respect to similar power rating. On the other hand, the potential to exploit low head micro hydro system is enormous because there is where population is concentrated. The aim of this paper is to present the main issues and technologies encircled the application of low head micro hydro power for rural electrifications. Reviews on relevant issues on micro hydro surrounding available turbines for low head sites, civil structures and electric motor are also presented. This is followed by accentuating the importance of information dissemination using the internet to potential users. The information can be used by researchers, plant managers, individual or rural communities to understand the potential of available technologies.

1. Introduction
Out of the total population of 630 million of ASEAN (The Association of Southeast Asian Nations) countries, 107 million are without access to electricity in 2015, and most of those affected live in remote areas and are far from electricity grids [1]. Myanmar and Cambodia were reported to be countries having the lowest percentage of electrification rate in 2017 with electrification percentage of 59.0% and 60.0% respectively [2]. Current statistics indicated an exponential increase in energy supply since 2005 with the implementation of new policies, strategies and experiences among ASEAN countries [2, 3]. One of the approaches is the use of appropriate technology solution to suit local condition, environment and resources. With that in mind, the main philosophy of rural electrification has been to provide cost effective and technical support, appropriate for remote isolated places.

The traditional way to generate electricity for rural areas is by extending existing national grid through distance and hilly terrain and this is prohibitively expensive. On the other hand, decentralized electric generation by building an off grid power generation system using diesel generators, solar power, wind power, biomass, hydropower or a hybrid system is increasingly being recognized and accepted. Considerable numbers of off-grid projects have been reported and highlighting the benefit and challenges faced by any types of power generation sources [4-7]. In many cases, it has become clear that micro hydro is a favourable source of energy if there is a potential site. With careful design and implementation, the capacity factor of a micro hydro system can reach up to 50%, beyond other types of renewable energy [8].
Currently, common commercially available micro hydro in rural areas utilizes high head impulse type turbine such as Pelton Turbine and Crossflow Turbine. These impulse type turbines are widely used for high head micro hydro systems because they are cheaper and smaller than reaction turbines since pressurized water from head is used to generate power instead of flow rate. However, low head micro hydro is applicable to flat sites where the resident population is denser. Low head micro hydro systems typically require larger equipment and professional technical input to enable implementation and this is expensive. Consequently, applications of low head micro hydro in rural areas are rare and there is limited information available for potential users.

2. Hydropower formula

Power output from a hydropower is directly proportional to head and flow rate at the proposed site. For large hydropower, the hydraulic efficiencies are usually in the range of 80 -90 per cent however small hydropower systems are in the range of 60 -80 per cent [9]. The potential installed power from the selected site can be calculated using equation

\[ P = \eta \rho g Q h \]  

where \( P \) (Watt) is the net power generated at the generator terminal, \( \eta \) (%) is the overall efficiency of the systems, \( \rho \) (kg/m\(^3\)) is the density of water, \( g \) (m/s\(^2\)) is the gravitational acceleration, \( Q \) (m\(^3\)/s) is the stream flow rate and \( h \) (meter) is the net head at the turbine inlet.

The selection of proper turbine to suit a potential site is dictated by the power generated by the turbine shaft, head, and flow rate at the turbine inlet. Specific speed as a dimensionless unit is used to characterize the type of flow and predict the turbine characteristic. Turbine specific speed, \( N_s \) is defined as

\[ N_s = \frac{RPM \sqrt{P}}{H^{1.25}} \]  

where \( RPM \) is the turbine rotation rate in RPM, \( P \) is power output (kW) and \( H \) is the water head (meter). Depending on the flow direction and path across the turbine wheel, each turbine type is specified as a radial, partial axial (mixed flow), or full axial turbine. Turbines with lower specific speed are often called impulse turbines and have a relatively higher head with lower flow rate.

For a low head system, the type of flow is categorized as mixed flow and axial flow and the specific speed is between 100 and 600 (mm/mm). In overall, high head site uses impulse type turbine and low head site uses reaction type turbines shown in table 1.

| Specific speed | Type of Flow     | Types of turbine          |
|---------------|------------------|---------------------------|
| 15-65         | Radial Flow      | Turgo Turbine, Pelton Turbine |
| 60-400        | Mixed Flow       | Cross flow, Francis       |
| 300-800       | Axial Flow       | Kaplan, Propeller         |

Impulse type turbine converts all the kinetic energy from high speed water jet exiting from the nozzle. The water jet makes contact with the turbine blade at atmospheric pressure, changing the momentum of the water and spins the turbine. Common impulse type turbines for micro hydro application are Turgo turbine, Pelton turbine and cross flow turbine. On the other hand, reaction type turbine uses the combination of kinetic and potential energy from the flowing water. The turbine is fully submerged in an enclosed casing, changing water pressure across the turbine. Draft tube is used to extend the tail water head and increase the pressure difference across the turbine. The range of typical commercial type turbines with respect to site head and flow rate is shown in Figure 1.
3. Micro hydro Turbines

Micro hydro refers to hydropower systems that produce power up to 100 kW; however this article will only be focusing on presenting a review for systems below 20 kW which is self-manageable by any individual or rural communities with adequate training. Very few commercial turbines are designed for the application of low head micro hydro in rural areas but low head micro hydro system is not a new technology. Several varieties of low head turbines may be found, including crossflow turbine, pumps as turbine, open flume turbine, bulb turbine, Archimedian screw, Kaplan turbine and the new turbine technology which is the Gravitational Water Vortex Hydropower Plant (G WVHP). The common commercial type turbines are shown in figure 2. The selection of turbines mainly depends on the pressure and flow available at the site.

![Flow rate vs Head Diagram](image)

**Figure 1.** General micro hydro turbine with respect to operation range.
Adapted from [20, 23]

3.1. Francis Turbine

Francis turbine is used for medium and high head site. The turbine is positioned in a spiral volute. Water enters in a radial direction guided with adjustable guide vanes, tangential to the turbine. Pressurized water is converted into kinetic energy by spinning the turbine which is connected to the shaft. Nautilus LLC has manufactured Francis turbine that can operate between 1.2 meter and 12.2 meter generating power from 300 W to 6.4 kW. The main components of Francis turbine consists of spiral casing, guide vanes, runner blades and draft tube. Due to the complexity of the blade profile and application of guide vanes, this turbine is more expensive and less popular for micro hydro application in rural areas. Furthermore, with regard to the control mechanism for Francis turbine; guide vanes tend to trap debris from the flowing water and it mandates frequent maintenance.

![Types of Turbine](image)

**Figure 2.** Commercial micro hydro turbines.
3.2. Open Flumes-Kaplan Turbine

Pico-scale open flumes turbine, with a range between 200 W up to 3 kW is the most common turbine in the marketplace for application with heads between 1 and 3 meter [10-13]. This system uses a propeller type turbine and an AC or DC generator generating up to 1.5kW to charge a bank of batteries to supply electricity for a typical remote home [14]. Large numbers of these units are installed in over 60 countries [13]. These turbines are suitable for operation in rural areas due to their light weight, portability, simple installation and they also require minimal civil work. Due to their simple design, they have lower efficiency compared to spiral casing installation. Typical turbine efficiency is 50%.

3.3. Archimedean Screw

Archimedean screw offers fish friendly, with variable speed low head turbine generator. The system uses a special enclosed turbine casing to create tangential momentum to produce rotational movement. It uses non-regulated blade fixed with a permanent magnet variable speed generator and offers a good turbine performance over a large head range. The maximum single variable speed low head turbine generator can work for heads up to 8 meter with a flow rate ranging between 100 l/s up to 12000 l/s [15, 16]. This system requires considerable civil work to accommodate a large turbine which contributes to the high cost. Additionally, the Archimedean screw rotates at low speed, so a gearbox is used to increase the rotational speed to match the standard generators. For this reason, the Archimedes turbine is less popular for rural electrification.

3.4. Pump as Turbine

A pump as turbine (PAT) is a low cost option for generating electricity in terms of price and simplicity. An end suction centrifugal pump operating in turbine behaves similar to Francis turbine without guide vanes and the axial type pump behaves similar like axial type turbine. Mass production pump covers a wide range of medium-low head sites [17]. A standard induction pump with an induction motor can be used as an independent power generator in isolated micro hydro sites to avoid the use of belt or gear mechanism [18-20]. The application of PAT in Lao PDR for remote communities to substitute crossflow turbine to reduce electromechanical cost offers technical and economical alternative [18]. Turbine performance prediction can be presented by mathematical models; however it has been reported to give fairly inaccurate results. Typically, the performance of a standard PAT is best estimated from test results which are rarely available and not readily accessible [21]. This is a challenge to match the turbine characteristics to a particular micro hydro site.

3.5. Gravitational Water Vortex Hydropower Plant (GWVHP)

Gravitational water vortex power plant is one of the most recent turbine technology for low head micro hydro sites which was developed by Franz Zotlöterer in 2006. The system generates electricity by introducing a flow of water tangentially into a circular basin that creates a free vortex when the water drains from the bottom of the basin. A turbine thereof withdraws rotational energy from the gravitational vortex, which is converted into electric power in a generator [22]. The key difference of GWVHP arrangement compare to the classic Kaplan or Francis turbine arrangement is the fact that the chamber is ‘open channel’. The fluid is subjected to atmospheric conditions with no large pressure differences built up in the system. Thus, the free surface develops a classic hyperbolic depression and air core, which results in a reduction of cross-sectional area at the orifice for water to pass, therefore resulting significant reduction of the relative flow rate and significant increase in both tangential and axial velocity of the vortex [23].

The turbine does not function based on pressure differential, but on the dynamic force of the water vortex. It uses both kinetic (run-of-river) and static potential energy (head) principles to generate electricity, and also aerates the water in a gentle way with minimum interference with the river and aquatic life. The plant can be installed with a water drop as little as 0.7 meters with relatively small and simple structure [22]. This technology is considered still in its infancy with limited literatures available for the technology to proceed beyond prototyping stage. The maximum efficiency obtained by
researchers are approximately 30% while the commercial companies claimed about 50% of efficiency with 500 W to 20 kW of power generated. This is lower compare to conventional low-head turbines such as the Archimedean screw turbine. However, due to its ability to sustain relatively high efficiencies at low heads and small to medium flow rates, this technology addresses a gap in the current turbine application chart and demonstrates potential to be developed and optimized in both performance and hydraulic and mechanical efficiency [23, 24].

4. Electric Generator

Induction generator is desirable as electric generator generating continuous alternating current (AC) at rated frequency and voltage. A bank of capacitor supplies the reactive energy to build its own magnetism. With the advent of electric controller, induction generator controller (IGC) may be used to maintain good power quality at generator terminals. The most popular IGC for micro hydro application is Electric Load Controller (ELC). This type of IGC uses solid state electronic controller regulating the output power of a micro hydropower system, maintaining constant applied load at generator terminal by dummy load. The function of ELC is to eliminate hydraulic control mechanism and let the turbine and generator run at their optimum operating speed [20, 23]. Nowadays, three phase induction generators are widely used for most stand-alone micro hydro projects because of their availability and price. Direct current (DC) generated from dynamo or from rectifier should be avoided if the site has the potential to generate continuous reliable energy. Moreover, there are many losses related to energy storage and power conversion between AC to DC.

Figure 3. Schematic diagram of three phase induction motor [20, 23]

5. Civil Structure

Civil structure for any micro-hydro system is site specific and unique to the site itself. However, the main civil structure components are similar which comprise of diversion weir, channel, intake, forebay, regulating gates, powerhouse, penstock, spillways and penstock. The function of civil structure for a small scale hydropower is to regulate and control the water flowing from the intake to the turbine. Careful design and planning, exploiting locally available materials can reduce the civil structure components in micro hydro scheme.

For many cases, run-off river scheme is the most favourable system for micro hydro applications compared to gravity dam. A diversion weir is used to divert part of the flowing water of the river into a channel or penstock. The water is then transported to the silt basin to remove unwanted debris and suspended solids before being channelled to the forebay. The water flows downhill using the gravitational force to build up pressure. The pressurized water is used to rotate the turbine which is coupled with electric generator to generate electricity. The water is then returned to the river, so minimum water storage is required thus reducing the impact to the environment. With the absence of a dam, the ecosystem and natural habitats of the river is maintained and preserved. Furthermore, it is easier to control water flow to the turbine by using spillways. This will reduce the risk of damaging the powerhouse if flooding occurs. On top of that, the use of run-off river permits optimum power design for the electromechanical based on diverted flow from the river.
The micro hydro penstock is commonly the third in terms of the overall micro hydro cost. The selection criteria of a penstock should include pipe joints, valves, labour work, logistic and penstock anchoring. Therefore, the use of local available domestic pipe such as uPVC, MDPE and HDPE pipe is highly recommended to reduce the overall cost [25]. The selection of penstock and other building materials for isolated micro hydro sites is strongly influenced by the logistic.

6. Knowledge Dissemination

In order to make a low head micro hydro scheme relevant for rural electrifications, know how knowledge must be accessible and reachable by potential users. Most micro hydro information is available in books, magazines and web sites. With the advent of the Internet, online searches on micro hydro have become popular and widespread [26]. Generally, information with micro hydro in web portals is published by individuals, DIYers, renewable energy suppliers, non-governmental organization and research institutes. The first discussion web portal associated with micro hydro is microhydropower.net [27] which began when internet communities started sharing information related to micro hydro power technology in 1998. It was intended to be a dedicated information source for micro hydro enthusiast. The website was incorporated into Yahoo! Groups later on and provides information concerning micro hydro power updates such as events, news, database, downloadable files, literature overview, Internet links and case studies.

A non-government organization, Practical Action [28], a registered charity in the UK, provides information on innovative and practical solutions for poor communities to improve their quality of life and access technical options and knowledge by allowing anyone to access records and documents. Implementation guides on renewable energy are made available and free to download as an open source including micro hydro. Using best-practices cases for demonstration, technical standards for small isolated schemes are shared promoting technology and know-how transfer.

Pico-hydro is a web portal sharing hydropower for sizes below 5 kW [29]. It was pioneered by Arthur Williams, the director of a course taught in Nottingham University. This website shares information on ways to design, manufacture and install parts of pico hydro projects for low and high head sites. Case studies are presented, including technical and nontechnical information such as costing, manufacturing guidelines, electric distribution systems design, safety and financing support by academic research. Despite the fact that each hydropower site is unique, the author suggests the use of standardized parts and low cost approaches to make it relevant for the Third World countries. For low head turbines, this website focuses on the development of micro hydro turbine for site that have a head of 2.5m and a flow rate of 230 l/s which can produce 5kW.

Micro hydro suppliers [10-13, 30] have published a substantial amount of technical information, guides and manuals on their web site; covering installation of mechanical and electrical systems and include feasibility studies of the proposed sites. A web-based micro hydro power forum designed by a German authorized micro hydro power supplier combines most popular micro hydro power manufacturers’ information concerning micro hydro topics including low and high head scheme. Currently, more than 3,000 active registered members discuss a broad range of issues on hydropower. Discussed topics are related to commercially available micro hydro power packs with strict discussion on listed hydropower products.

It is clear that by providing technical information through web portal, the potential users in flat areas who possess hydro sites may exploit low head micro hydro technology. Efforts to disseminate technology through the internet are valuable for rural electrification. The information should incorporate academic research and technical support to demonstrate reliable energy production. Based on the review on previously presented works, it is important to provide a sound web based information that uses internet as knowledge dissemination medium to help potential users exploit the potential of low head sites to generate electricity.

7. Conclusion

The potential of generating electricity from flowing water for rural remote communities should be considered as the focal power options where there is available suitable site. The study presented in this paper highlights the main issues relevant to low head micro hydro in rural areas. The main objective is
to promote the application of available technologies and exploit the opportunity of generating electric power from low head sites. Current technologies allow micro hydro users to decide on applicable schemes, optimizing cost and efficiency. The dissemination know-how knowledge work should be prominence with the advent of internet.

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