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Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review

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ABSTRACT

Electrical power is essential in commercial, economic and social investments especially in emergent countries. Hydropower energy has become one of the most suitable and efficient sources of renewable energy, though it has taken more than a century of experience to actually generate efficient electricity for supply. Nowadays, most rural areas in developed and developing countries use cheap and effective micro-hydropower plants for producing electricity. To achieve more efficiency, researchers are looking forward to using simple turbines for achieving good performance with minimum initial and running cost, for utilization especially in poor countries. This paper presents a review of low head micro-hydropower turbines; focusing on categories, performance, operation and cost.

Contents

1. Introduction

Water is a clean, cheap and environment friendly source of energy generation which is of significant value for sustainable future [1]. Hydropower has been utilized for more than a hundred

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years, and undeniably being the most efficient and confident source of renewable energy [2]. Hydropower contributes to 19% of total global output of electricity by the end of 1999, which produced 2650 Terawatt hour (TWh) [3]; later producing almost 3100 TWh in the beginning of 2009 and is expected to reach 3606 TWh in 2020 [4]. According to United Nations Development Program (UNDP), 1.4 billion people still remain without access to electricity [5], notably in poor areas in developing countries [6]. Generally, a large dam with high capital cost is required to produce sufficient power supply. Low head micro-hydropower stations present an attractive and efficient way for electricity generation in rural, remote and hilly areas because of the increment in the level of greenhouse gas emissions and fuel prices in these sites and they have become increasingly popular for application at small rivers [7–10]. Micro-hydropower schemes can be used to generate enough electrical power for home, farm, and plantation or for small village [11]. They can also be used in mechanical end-uses like agro-processing, textiles fabrication, ice cream production, cooling, and drying [12]. The main advantages of low head micro-power system are that it is predictable if enough water supply is available [13] and possesses positive environmental impacts [14]. Therefore, the system has become the main interest for future hydro-developments in Europe, where large-scale stations have indeed been utilized but in return giving negative effects to the environment [10,14]. Most low head micro-hydropower plants generate power less than 100 kW [15–18], but there are also other categories with classification below 500 kW [10] and <10 m head [19]. The general formula for any hydropower system output is [16]

$$P = \eta \rho g Q H \qquad (1)$$

where P is the mechanical power produced at the turbine shaft (watts), η is the hydraulic efficiency of the turbine, ρ is the density of water volume (kg/m^3), g is the acceleration due to gravity (m/s^2), Q is the flow rate passing through the turbine (m^3/s) and H is the effective pressure head of water across the turbine (m).

Recent publications raise the importance of using simple turbines to achieve minimum cost to produce power [8]. Installation of large and mini hydropower plants with dams, huge reservoirs, large turbines, electrical equipments and controllers have been proven very expensive, uneconomical and negative environmental impact. Though intended as clean and cheap source of energy generation, many developing countries that are in need of rural electrification are instead exposed to economic problem when installing this costly hydro-equipment [20]. Using micro-hydropower with new design and arrangement of these equipments leading to, especially the turbines, can be the perfect solution to overcome the economical and operational problems and reduction of the total cost of hydropower plants. Hence, this study is aimed to review different types of hydropower turbines which can be used in micro-scale. This paper also presents several recommendations and solutions in terms of operation, performance and cost effective points of views. Micro-hydro-turbines have gained a rapid growth in the power generation field, especially in rural areas, as their power is needed to feed both base load and peak demand requirements of grid supply [21]. Micro-hydropower generation efficiency is generally in the range of 60–80% [10]. Micro-turbines generate very reliable power though with very simple designs and fabrications [22]. Nevertheless, the selection of micro-hydropower turbines for achieving the most efficient and best result is rather difficult, as most turbines are designed for higher systems; they may be modified applicable for low head micro-systems, but the operational principle often does not change [19].

2. Performance characteristics of turbines used for low head micro-hydropower

Hydropower turbines are categorized into two types, which are impulse and reaction turbines, each suitable for different types of water flows and heads. Fig. 1 shows the classifications of both types of hydropower turbines.

2.1. Impulse turbines

Impulse turbines have simple design and are inexpensive [18]. There are various types of impulse turbines, namely Turgo, Pelton and cross flow turbines. These types are commonly used as high and medium heads [19]. Recently, they have been applied for lower head micro-sites, and their proven effectiveness has made them becoming an accepted alternative practice in many countries [23].

Energy Systems & Design Ltd. [24] has produced a **Turgo turbine** which can be used for heads between 3 m and 150 m. In the previous researches, Williamson et al. [25,26] optimized Turgo turbine models in micro- and pico-projects, altering the location of low heads from 3.5 m down to 1 m to improve the turbine performance. Generally, the efficiency of the Turgo turbine depends on many factors, such as nozzle or jet inclination, cup design and speed ratio. The Turgo turbine efficiency for micro-hydro is very sensitive to jet position and jet inclined angle [25–27]. References [26,27] defined that the optimum jet inclination angle to achieve the peak efficiency of Turgo turbine for low head micro is approximately 20°. Koukouvinis et al. [28] performed a parametric study on Turgo turbine, related to the turbine inlet angle, by using smoothed particle hydrodynamics. Inappropriate nozzle angle may cause severe effects on the performance of Turgo turbines, as well as increasing the rate of erosion in the presence of silt particles [29]. Williamson et al. [25] presented new configurations of cups and jet inclination to improve Turgo turbine

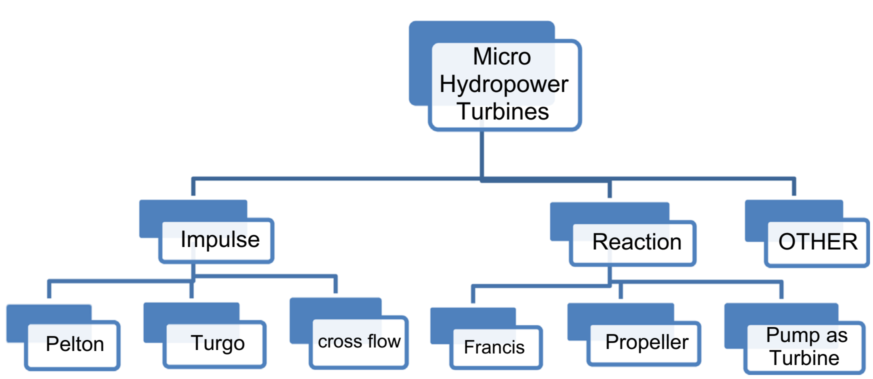

Fig. 1. Micro-hydropower turbines classification.