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Hydrokinetic energy conversion systems: A technology status review

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ABSTRACT

Hydrokinetic energy conversion systems are the electromechanical devices that convert kinetic energy of river streams, tidal currents, man-made water channels or waves into electricity without using a special head and impoundment. This new technology became popular especially in the last two decades and needs to be well investigated. In this study, the hydrokinetic energy conversion systems were reviewed broadly. They have been categorized into two main groups as current and wave energy conversion devices. Their technology, working principles, environmental impacts, source potential, advantages, drawbacks and related issues were detailed.

Contents

1. Introduction

Increasing energy demand, harmful environmental effects of conventional energy production technologies, increasing cost and running out reserves of fossil fuels, climate change, spreading health problems and social pressure have led scientists and engineers to find alternative non-consuming, harmless, cheaper and sustainable energy production methods. Renewable energy technologies offer many environmental benefits over conventional energy sources [1].

The hydropower is the world's largest and cheapest [2] source of renewable energy. It is also the most efficient way to produce electricity [3]. Approximately 18% of world's electricity is supplied from hydropower [4]. Predictability, regularity and having world-wide spreading sources make hydropower one of the most attractive choices of energy production.

There are mainly two approaches to harness energy from water, namely, hydrostatic and hydrokinetic methods. Hydrostatic approach is the conventional way of producing electricity by

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storing water in reservoirs to create a pressure head and extracting the potential energy of water through suitable turbo-machinery [5]. In hydrokinetic approach, the kinetic energy inside the flowing water is directly converted into electricity by relatively small scale turbines without impoundment and with almost no head [2]. Hydrokinetic turbines are also called free flow turbines, ultra-low or zero head hydro turbines [5]. Hydrokinetic technologies are designed to be installed in natural streams like rivers, tidal estuaries, ocean currents, waves, man-made waterways [6] and other flowing water facilities with an optimum velocity.

Hydrokinetic energy technologies have some advantages over the conventional hydropower production methods. Hydrokinetic systems require minimum amount of civil work [5]. There is no extra cost to construct a dam or a reservoir to accumulate the water. The kinetic energy is harnessed based on water motion in the form of current and waves. Although the hydrokinetic turbines have relatively small scale power production, they can be installed as multi-unit arrays like wind farms to increase energy extraction [6]. The hydrokinetic systems provide more valuable and predictable energy than wind and solar devices [7]. Especially river streams and tidal currents are highly predictable.

In developed countries the suitable sites for large scale hydropower plants have been mostly exploited. Furthermore, across some river valleys dam construction may be either technically or economical infeasible, due to the topography, geology of the site, non-availability of construction materials, seismic hazards, right of way cost, etc. Hydrokinetic energy conversion systems provide a good choice for electrification of such sites. On the other hand, employing hydrokinetic turbines can be the most suitable and cheap way of supplying electricity to remote and off-grid areas where transmission lines do not exist [8]. According to United Nations Development Programme (UNDP), in 2008, there were globally about 1.5 billion people who lived without electricity especially in least developed countries and in sub-Saharan Africa [9]. Reliable energy can be supplied with hydrokinetic systems to remote areas having rich water resources such as South Africa [10].

Additionally, hydrokinetic systems have minimal environmental impacts compare to dams [5]. Large scale hydroelectric power plants have some unfavorable effects on the environment such as; people relocation, inundation of agricultural, historical and habitat areas, sedimentation of fertile lands, methane (CH_4) gas emission, altering the river regime, etc. Contrarily, the natural tissue of the energy production site is not seriously affected by hydrokinetic systems.

Hydrokinetic technology has several drawbacks compare to the other energy production methods. These systems have relatively small scale power production with lower power coefficients. The maximum efficiency that an in stream hydrokinetic turbine can reach is 59.3% which is also known as Betz limit. Only high quality professional systems can reach 50% efficiency. On the other hand, cavitation is one of the biggest constraints of hydrokinetic turbines. It is defined as the formation of water bubbles or voids when the local pressure falls below the vapor pressure. Cavitation can significantly damage the turbine. Especially high speed moving parts can be subjected to cavitation [11,12]. Harsh marine environment is another disadvantage of hydrokinetic systems. Especially wave energy conversion devices should be strongly designed to withstand high and irregular water loads. On the other hand hydrokinetic systems can have small scale environmental risks. Installation of hydrokinetic systems can block the navigation and fishing. The turbine parts, chemical agents, noise and vibration can badly affect the water habitat. Bad environmental influences of hydrokinetic systems are still investigated by scientist.

There have been limited studies on hydrodynamic characteristics of hydrokinetic turbines. These systems are still in their infancy and need to be well investigated. The scientific background behind in-stream energy conversion systems is very similar to that of wind energy conversion technologies. The main principles such as utilization of blade sections, BEM theory, Betz limit, etc. are learned from aerodynamic and hydrodynamic applications, wind turbine and ship propeller methodologies apart from a number of fundamental differences [13]. The design of hydrokinetic systems requires interdisciplinary study of environmental, hydraulic, hydrologic, electric and mechanical branches.

Considerable amount of power can be obtained from an in-stream hydrokinetic turbine comparing with the equally sized wind turbine [5]. A hydrokinetic turbine operating with a rated speed of 2–3 m/s can produce four times energy of similarly rated wind turbine [14]. The approximate fluid densities are 1000 kg/m^3 and 1.223 kg/m^3 for water and wind, respectively. Wind turbines are usually designed to operate at rated wind speed of 11–13 m/s [15]. In contrast, the rated velocity for hydrokinetic turbines is between 1.5 and 3 m/s. The comparison of power densities for water and wind turbines are given Fig. 1. The power density of a hydrokinetic turbine operating with 2 m/s free stream velocity is same as that of wind turbine running with approximately 16 m/s flow speed.

Several hydrodynamic models have been developed in order to model tidal, river and wind driven circulations (Mecca, MIKE, etc.) [16]. Many analytical and numerical modeling efforts have been made to calculate the amount of extractable power from river, marine and tidal resources [17]. One dimensional (1-D) analytical models are used for the effects on water level and velocity, whereas, advanced 2-D and 3-D are implemented to calculate the source potential [18]. Yang et al. [17] gives an updated list of models that employed to determine the tidal stream resources. Majority of developed models are based on tidal power. A riverine kinetic energy model was discussed recently by Khan et al. [5,18].

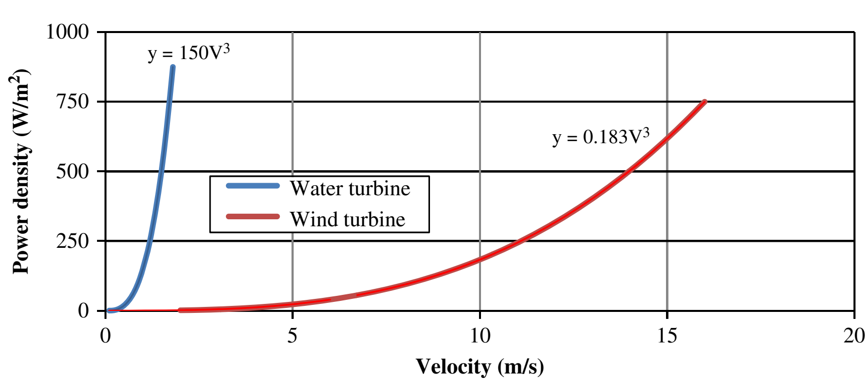

Fig. 1. Comparison of power density for in-stream water and wind turbines.