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A review on the technology, performance, design optimization, reliability, techno-economics and environmental impacts of hydrokinetic energy conversion systems

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ABSTRACT

The hydrokinetic energy conversion system has capabilities to supply inevitable and secured power which is obtained from free stream like ocean, river, and man-made channel etc. So far, researchers have done different work on resource availability, design parameter, electricity generation cost, reactivity of plant, its impact on environmental separately. In this paper an attempt is made to review the technology, performance, design optimization, reliability, techno-economic analysis and environmental impact of the hydrokinetic energy conversion systems altogether to establish the relationship between the above said aspects towards the viability of power project. After conducting these reviews it has become clear that in order to avoid cavitation, coefficient of pressure should be less than cavitation coefficient especially at leading edge of hydrokinetic turbine blade. Moreover, to avoid stall and separation, angle of attack should be kept as less as possible. By implementing hydrofoil blade profile, performance of the hydrokinetic turbine can be improved. Sometimes, implementation of double blade hydrofoil may be beneficial and increase the coefficient of lift more than that of the single blade hydrofoil. Apart from the above considerations it is to be noted that deployment of turbine near bed level should be avoided as it brings down available power, increase hydrodynamic loading, turbulence level, and fouling by sediments. Moreover to increase the performance arm and end plate can be incorporated in hydrokinetic turbine design. It is also observed that hybrid conversion system is also viable in order to reduce power generation cost. This paper will help researchers to identify areas of design parameter of hydrokinetic turbine that need to improve and encourage the project developer, funding and financial institution, policy maker or government officials, and local community, to provide knowledge about hydrokinetic energy conversion system for executing the project and compete with the existing market.

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1. Introduction

Diminishing fossil fuels leads engineers towards using renewable energy. Renewable source of energy viz. hydro, biomass, solar and geothermal energy tenders reliable and clean energy by reducing green house gas emission. It is observed that CO_2 equivalent emissions of greenhouse gases produced by coal are maximum i.e.1689 g CO_2eq/kWh, whereas the same for ocean energy and natural gas are 23 and 930 g CO_2eq/kWh. Among different renewable energy technologies, hydro-power generation holds prime position in terms of contribution to the world's electricity generation. Moreover, complexity in land acquisition, environmental clearance etc., particularly in Indian context, if considered, it is found that small hydro such as zero head turbine or hydrokinetic turbine (HKT) is often acceptable particularly for a remote location [1,2]. Hydrokinetic turbine, as per US Department of Energy (DOE) reported in 1981, can be defined as a low-pressure, ultra low head (≤ 0.2 m), run-off river turbine. These turbines came into reality in 2003 when world’s first HKT (rated capacity 300 kW) was installed by Marine Current Turbine Ltd. and I-T Power Company. Hydrokinetic energy is captured from ocean, flow of water in rivers, channel and constructed waterways etc. Specially, in ocean, osmotic pressure differences, wave energy caused by ocean thermal energy conversion, tidal barrages and marine current energy are the feasible form of energy development. Among them, marine current and wave energy are the most promising form of energy sources, where kinetic energy can be converted to power, without using of conventional hydroelectric facilities based on dams, penstocks etc. On the other hand, tidal barrages are like conventional hydroelectric dam and converts potential energy due to difference of water level to power. Ocean thermal energy conversion system uses water temperature differences for power production [3]. These small-scale generating systems are more beneficial for off-grid power to underserved communities. The technology is becoming more popular among other renewable energy sources due to its high energy density, good predictability and minimal environmental impact. Basically, working principle of HKT is analogous to wind rotor. However, maximum power extraction of HKT is about 61.32% higher than wind turbine as the fluid is heavier [4,5].

Installation of HKTs may have a significant and complex effect on flow patterns, sedimentary and biological processes. Several issues in terms of techno-economic feasibility, design optimization, reliability, placement of turbine in channel, application of duct augmentation, anchoring and environmental monitoring are still needed to be considered before widespread adoption of the technology [3]. However it produces negligible amount of greenhouse gases compared to others, therefore it can be considered as environment friendly [6,7].

Researchers have done different work on the various aspects of techno-economic feasibility, design optimization, reliability, placement of turbine, application of augmentation, anchoring and environmental monitoring separately. There is a scope of exploring how all above mentioned aspects influence the design of Hydrokinetic Energy Conversion system (HKEC) and viability of power project. Moreover, detailed investigation may be performed to find out the influences of different parameters on the performances of HKT. Generally, Hydrokinetic Energy Conversion system can be employed in oceans, natural streams and constructed waterways etc. to convert water energy. Since, design principal of HKEC is same for all, in this paper; emphasis is given on tidal energy, marine current power and wave energy as the part of ocean energy in details. Therefore, in this paper, main objective of this article is set to investigate the relationship and their behaviour between technology in terms of performance, design optimization, reliability, techno-economics and environmental impacts of HKEC systems that may lead to feasible hydrokinetic energy future scenario.

2. Technology

Currently there are several hydrokinetic technologies under development, especially for ocean power application which are discussed as follows [1,3]. The HKEC system consists of five subsystems: HKT, generator, support structure, control system and transmission system which are shown in Fig. 1.

For harnessing ocean-energy, HKEC devices can be arranged into arrays. Thus, energy can be extracted from marine currents similar to a wind farm. Presently, there are several HKEC device technologies under evolution for marine current power harness. Fig. 2 shows the number of systems under development with ducts. Among these HKEC systems Cross-Flow, vertical-axis, and horizontal-axis turbines, Venturi and Gravitational-Vortex systems belong to turbine category; whereas, Oscillating-Hydrofoil, Fan-Belt, Piezoelectric, Flutter-Vane, and Paddle-Wheel systems come under the non-turbine category.

While designing the HKEC devices, particularly HKT, both axial and vertical axis turbine along with duct usage aspects have got higher preference considering the facts of extracting maximum power with an economic, reliable and environment friendly product [3]. The propeller type turbine is horizontal axial flow turbine, whereas Darrieus and Savonius type is vertical axis turbine in which the flow passes through the turbine is perpendicular to axis