Journal of Environmental Management 228 (2018) 416–428

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Recent innovations and trends in in-conduit hydropower technologies and their applications in water distribution systems

Mutiara Ayu Sari[a,*], Mohammad Badruzzaman[a], Carla Cherchi[a], Matthew Swindle[b], Newsha Ajami[c], Joseph G. Jacangelo[a,d]

[a] Stantec Consulting Services Inc., 300 N. Lake Avenue, Pasadena, CA, 91101, USA
[b] NLine Energy, Inc., 5170 Golden Foothill Parkway, El Dorado Hills, CA, 95762, USA
[c] Stanford University, 450 Serra Mall, Stanford, CA, 94305, USA
[d] The Johns Hopkins University- Bloomberg School of Public Health, 615 N. Wolfe Street, Baltimore, MD, 21205, USA

ARTICLE INFO

Keywords:
In-conduit hydropower
Small hydropower
Hydro-turbine
Energy recovery
Water distribution systems
Man-made water conduits

ABSTRACT

Water conduits have a large untapped potential to recapture energy for small hydroelectric generation, which can substantially reduce grid electricity consumption and/or provide renewable energy to water agencies. Over the past decade, there has been a recent technological renaissance in off-the-shelf "water-to-wire" turbine technologies including reaction, impulse, and hydrokinetic turbines that target the sub 1-MW in-conduit hydroelectric market. However, adoption of small hydropower technologies remain limited in water and wastewater utility sector, possibly due to the lack of market penetration and exposure. Moreover, information about newly developed small hydropower technologies in the last 5–10 years for in-conduit applications are highly dispersed in the literature. As such, this paper is a comprehensive review on recent technological innovations and trends in hydropower generation from water conduits. Sixteen turbine technologies (eight conventional turbines and eight emerging turbines) are assessed and compared based on their potential benefits and challenges, technology readiness levels, as well as potential sites for installations in diversion structures, potable and irrigation water distribution systems, and wastewater outfalls. Although conventional turbines are considered to be more robust, the modular design of the newer turbines potentially offers a more cost effective solution and better scaling-up capability. Selected case studies on the application of conventional and new turbines for pipelines are also are also reviewed and discussed.

1. Introduction

Increasing population growth coupled with rising energy demand and climate change have shifted our energy focus from traditional fossil fuel to renewable energy sources. One of the renewable energy sources of interest currently in the United States (U.S.) is hydropower (Doig, 2009). The current U.S. hydropower fleet consists of 2198 active plants with a total capacity of 80 gigawatts (GW), accounting for approximately 7% of all U.S. generating capacity (Uría-Martínez et al., 2015). In recent years, development of large hydropower (> 30 MW) installations has declined due to concerns associated with regulatory and permitting challenges, land acquisition costs, and environmental impacts (Lisk et al., 2012). Nonetheless, according to the U.S. Department of Energy (DOE), hydropower growth is still expected to occur from the following projects: (i) upgrades at existing hydropower plants; (ii) powering of non-powered dams; (iii) new stream-reach developments (NSDs); (iv) new pumped-storage hydropower; and (v) powering existing canals and conduits (DOE, 2016). Through its Hydropower Vision initiative, the DOE predicted that hydropower in the U.S. will grow to nearly 150 GW by 2050 due to the implementation of these projects (DOE, 2016).

Within the above hydropower project portfolio, small hydropower systems are increasingly being considered as an important source of renewable energy in the U.S. and other parts of the world. Small hydropower is a unit process capable of generating capacity up to 10 megawatts (MW) (FERC, 2017a), typically installed in existing dams/weirs, canals, ditches, aqueducts, and pipelines. According to Paish (2002), small-hydro systems can also be further classified as mini-hydro (< 2 MW), micro-hydro (< 500 kW), and pico-hydro (< 10 kW). The two key advantages of using small hydropower are: (i) its higher efficiency compared to wind and solar (70–90% efficiency) and (ii) its less output power variation (Uhunmwangho and Okedu, 2009). There are

* Corresponding author.
E-mail addresses: ayu.sari@stantec.com, mutiara.ayu@gmail.com (M.A. Sari).

https://doi.org/10.1016/j.jenvman.2018.08.078
Received 8 May 2018; Received in revised form 26 July 2018; Accepted 20 August 2018

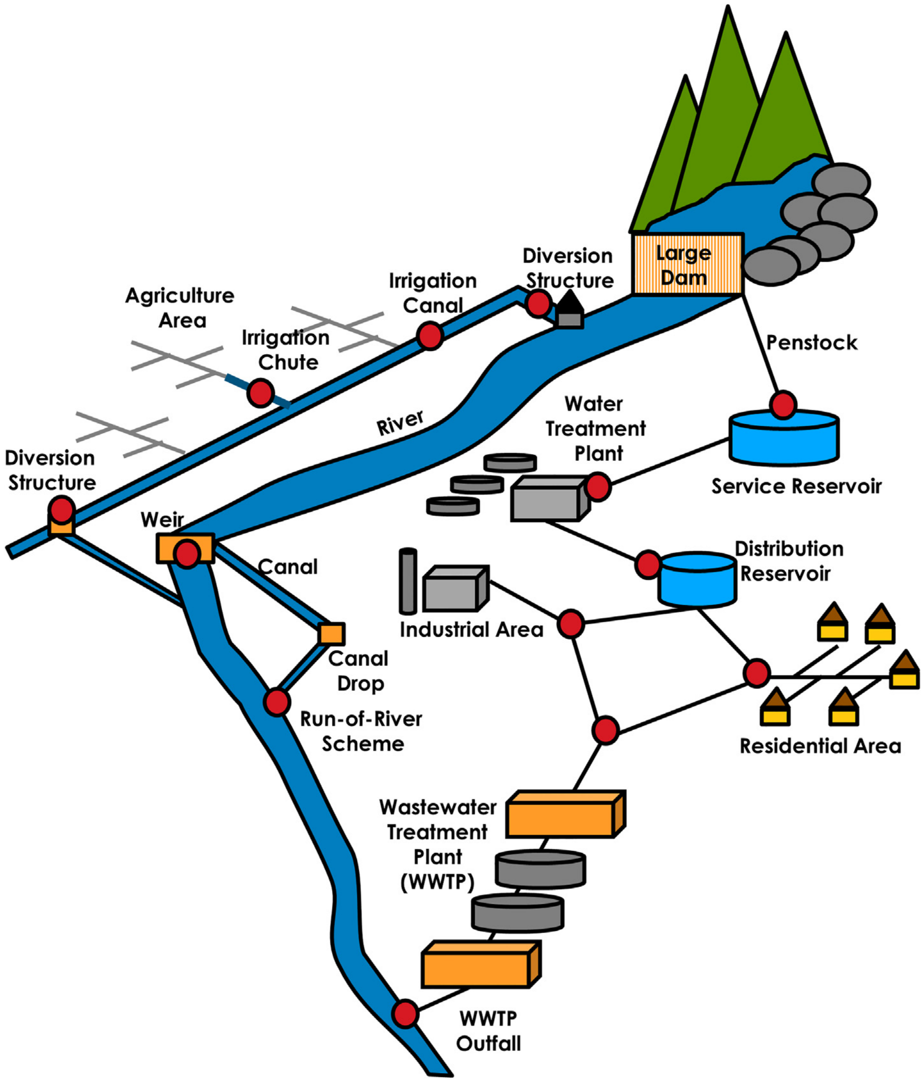

Fig. 1. Potential locations for implementation of small hydropower in water conveyance system (marked by red circles). Adapted from (Loots et al., 2015).

currently 1640 small hydropower plants with a combined generating capacity of approximately 3670 MW in the U.S (Johnson and Hadjerioua, 2015). However, there is a tremendous untapped potential of small hydropower installations. For instance, in the state of California alone, there is 2467 MW undeveloped small hydropower potential (Park, 2006). Although the greatest potential lies in natural water courses (2189 MW), the same study also estimated substantial hydropower potential in man-made water conduits (255–278 MW).

Water and energy are inextricably linked in engineered water conduits. Water pumping in these conduits can be an energy intensive process. In turn, the embedded potential and kinetic energy can be also a source of recoverable renewable energy. Currently, much of this energy is being wasted in energy dissipating devices such as pressure reducing valves (PRV) and canal drops. These energy dissipating points can alternatively serve as energy harvesting spots to make the overall water conveyance system more energy-efficient by off-setting electricity usage and, in some cases, providing additional electric power to surrounding communities. As in-conduit hydropower can be installed at multiple locations of water delivery systems (e.g., Fig. 1), the potential benefits can be significant.

Presently, one of the most salient drivers for development of in-conduit hydropower projects is a simplified regulatory framework (Johnson and Hadjerioua, 2015). As an add-on to existing infrastructure, in-conduit hydropower is often considered to have minimal environmental impact. As a consequence, most of the conduit hydropower facilities (≤ 40 MW) are eligible for conduit exemption from licensing by Federal Energy Regulatory Commission (FERC) (FERC, 2017b). FERC also requires no license or exemption from qualifying facilities that (i) use man-made conveyance not primarily used for electricity generation; (ii) generates electricity only from non-federally owned conduit; (iii) has installed capacity of ≤ 5 MW; and (iv) are not licensed or exempted prior to August 9, 2013 (FERC, 2017c). These qualifying facilities can simply file a Notice of Intent (NOI) with FERC without going through a costly and time-consuming exemption process.

In addition to regulatory incentives, significant technological developments in the past decade have lowered the cost of ownership of small hydropower installations. Recent studies, for example, have indicated that the levelized cost of electricity (LCOE) of small hydropower projects ($20/MWh - $270/MWh) is now comparable with larger projects ($20/MWh - $190/MWh), especially when constructed in existing water structures (IEA-ETSAP and IRENA, 2015). A new generation of small hydropower technologies has also appeared as major competitors to century-old conventional turbines, especially for in-conduit applications. Many of the newer turbine technologies targeting the sub 1-MW in-conduit hydroelectric market are now typically manufactured as compact, modular, and ready-to-deploy “water-to-wire” packages, which can potentially lower construction and installation costs to water and wastewater utilities.