Applied Energy 188 (2017) 378–391

Contents lists available at ScienceDirect

Applied Energy

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

Sustainable and economical small-scale and low-head hydropower generation: A promising alternative potential solution for energy generation at local and regional scale

Khaled S. Balkhair [a,b,*], Khalil Ur Rahman [a]

[a] Department of Hydrology and Water Resources Management, King Abdulaziz University, P.O. Box 80208, Jeddah 21589, Saudi Arabia
[b] Center of Excellence in Desalination Technology, King Abdulaziz University, P.O. Box 80200, Jeddah 21589, Saudi Arabia

HIGHLIGHTS

- Studied hydro-sites provided considerable production of renewable and stable energy.
- Small-scale hydropower is a potential solution to increasing electricity demand.
- Combination of site-area-power can be viewed as an optimization/management issue.
- Proposed hydropower system minimizes energy shortfall significantly.
- Spatial power distribution scenarios lead to a cost-effective energy generation.

ARTICLE INFO

Article history:
Received 20 April 2016
Received in revised form 28 November 2016
Accepted 4 December 2016

Keywords:
Small-scale hydropower
Energy shortfall
Cost-effective
Canal hydrograph
Spatial distribution

ABSTRACT

Accounting for more than 16% of the world's net electricity production, hydropower is one of the most commonly used renewable sources of energy. Small-scale hydropower (SSH) systems are becoming increasingly successful options for hydropower generation, particularly in small localities and remote areas. Regardless of its low capacity, small-scale hydropower produces cheap, clean, and reliable electricity. The objective of this study is to provide a sustainable and economical solution for the increasing demand of electricity through small-scale hydropower generation in Pakistan. River flow and low head potential were investigated at twenty sites along the Upper Swat Canal and Swat River for hydropower generation. The sites were selected based on large differential head, velocity, ease of access, close proximity to dense population, and structural support. Hydropower capacity was calculated for each site based on the collected flow and hydraulic data. The cost per kW h of energy generated has been estimated by dividing the average annual recurring cost with annual generation over the lifetime of the project. Cost analysis indicated that purchasing one unit at 0.04 US$ is suitable for both the consumer and the government. Results revealed that each site is qualified to provide stable energy to more than 1500 houses based on the maximum consumption per home. The cost of the proposed power system was identified as the incentive factor in this study. In addition to the minimal variation in the seasonal production, the studied sites produced as much as 21% of the total Swat River production. The proposed spatial power distribution scenarios have contributed a potentially flexible alternative and cost-effective solution to the proposed SSH system.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Hydropower is one of the most commonly used renewable sources of electricity, accounting for more than 16% of the world's net electricity production and more than 65% of the global power generation capacity [1]. As compared to other renewable energy sources, hydropower is reliable, economical, high efficient, low maintenance cost and large storage capacity [2,3]. In addition to large hydropower projects, two terms are used simultaneously: Small Scale Hydropower (SSH) and Low Head Hydropower (LHH). SSH in most cases represents "Run-of-River" projects which generally store little or no water and purely serve the function of regulating water to the hydro-plant. Yet SSH is a promising source for

* Corresponding author at: Department of Hydrology and Water Resources Management, King Abdulaziz University, P.O. Box 80208, Jeddah 21589, Saudi Arabia.

E-mail address: kbalkhair@kau.edu.sa (K.S. Balkhair).

http://dx.doi.org/10.1016/j.apenergy.2016.12.012
0306-2619/© 2016 Elsevier Ltd. All rights reserved.

producing sustainable, inexpensive energy in rural or developing areas. SSH is related to the magnitude of the generated power which varies from country to country. There is no internationally agreed upon definition for SSH capacity; however, production mostly varies from 2.5 MW to 25 MW. According to European Commission, SSH production is less than 10 MW. Mini-Hydropower refers to production below 2 MW; Micro-Hydro refers to production below 500 kW, and Pico-Hydro refers to production below 10 kW [4]. Williams and Simpson [5] studied the Pico-Hydro scheme, and determined that Pico-Hydro was a cost-effective option for off-grid areas. The authors presented that Pico-Hydro scheme's generation cost is lower than small petrol or diesel generators, wind turbines, or photovoltaic (PV) system. On the other hand, LHH refers to heads of water which are less than 5 m. It generates energy less than 100 kW, but there are more classes producing power below 500 kW [4,6]. The many advantages of low head canal include no hydrological risk, close proximity to load center, easily accessible, and assured water availability [7].

Small scale hydropower has been used for a long time; however, due to economic feasibility, the use of large scale hydropower has increased steadily over the last few decades [8]. According to International Hydropower Association (IHA), hydropower is utilized in more than 160 countries. At the end of 2008, the globally installed hydropower capacity was 874 GW: derived from 11,000 stations equipped with 27,000 generating units [9]. Refs. [10,11] estimated the global potential of exploited hydropower to be approximately 16 petawatt hours per year or about 35% of the theoretical power generated from total annual surface runoff . In Europe, there are more than 70% fully developed theoretically available hydropower capabilities [12]. China plans to produce 270 GW by 2020. In 2002 Asia's hydropower capacity was approximately 225,000 MW which produced approximately 754,000 GW h/yr. Currently, nearly 84,400 MW of hydropower is under construction, with a major portion being in China. Turkey's hydropower potential is 433 TW h, which is 1.1% of the world's total hydropower potential. In 2014, an additional 37.4 GW of newly installed capacity has been added, thus bringing the global total to 1036 GW. It has been projected that the world annual renewable energy generation may reach 5.8 trillion kW h by 2020, out of which 4.4 trillion kW h (76%) generated by hydropower [13]. Another projection by (US-EIA, 2013) indicated that the world electricity demand is growing with a rapid pace of 93% in next 30 years, increasing from 20.2 trillion kW-h in 2010 to 39 trillion kW-h in 2040. The end-use energy for all-purpose in U.S. are met by variety of sources, however, it has been projected that hydroelectric power use would exceed the combined use of geothermal, wave, and tidal power by the year 2050 [14]. Several studies have analyzed the feasibility of hydropower as an energy system. Of these studies, all agree that hydropower is clean, stable, and cost-effective; hence, it is an efficient back-up technology to other renewable energy resources [15–17].

Advantages of SSH, especially in Run-of-River (RoR), include the requirement for small construction facilities, hence avoiding the migration of people out of the area; flooding small areas relative to their output; less ecological migration; less risk of sedimentation; and cost-effective technology [18,19]. SSH also causes reduction in greenhouse gasses, no significant environmental impacts, and no land acquisition or significant operating costs, hence providing quicker benefits and energy security to developing economies[20,21]. Most of SSH are economically viable and their viability depends on many factors like site, conditions and size of the project [22].

The most important parameter in SSH is the site selection, which determines the amount of electricity production as well as the cost. The hilly areas require more civil work but in turn can yield maximum power due to high slope and high velocity. Suitable sites can be selected either by field visits or by the analysis of topographic maps and the use of Digital Terrain Model (DTM) in Geographical Information System (GIS) applications. The GIS is a powerful tool for selecting appropriate SSH plant sites by considering engineering, economic, environmental, and social issues [23–25].

There are numerous studies in literature focused on mathematical modeling of hydropower generation, these studies were developed based on large scale power generation case studies including but not limited to dynamic and control of hydro turbines [26–30], self-optimization simulation model of cascaded hydropower system [31], optimization of maintenance of hydro power components [32], linear and nonlinear optimization model for power and energy of river cascade falls [33], algorithms for optimization of multiple turbines under specific hydraulic conditions [34], and empirical techniques that maximize economic benefit of investment for computing physical characteristics of commercial turbine [35]. Recently, Yang [36], applied a mathematical model for hydropower units on a case study of Swedish hydro power plant (HPP) and three Chinese plants under different operating conditions. Their model consists of eight turbine equations, one generator equation, and one governor equation, which are solved for ten unknown variables.

On the other hand, small-scale hydropower generation mathematical models are few in literature. The reason could be due to their simple and few number of set up components, known parameters, and low production rate. Relevant studies in this regard include Boustani [37], who described the basic requirements for a low head hydropower projects. He envisaged that a minimum of two units are necessary to cater discharge during low and high flow periods. It was concluded that the efficiency of the turbine is not constant at all flow period. Montanari [38] has developed a procedure to achieve the best operation of hydraulic energy in low head sites. Shakir and Maqbool [39] emphasized on the installation of low head hydropower generation on canal falls due to increased discharges after re-modeling. Singal and Saini [40] computed economic viability of low head hydro plants on canals. They concluded that the major part of the total cost is due to electromechanical equipment's that vary with the head. Bockman et al. [41] developed a technique for the assessment of low head hydropower schemes. They introduced an electricity price threshold beyond which investment is unadvisable.

The project's cost is a vital factor which should be considered before and after the installation of SSH. The aim at this perspective is to minimize the production cost and maximize community benefits. Singhal and Kumar [42] explained the estimation of cost for various civil structures. They established the cost curve which can be used to estimate the cost of civil work on the bases of site parameters. Singal et al. [7] also determined the cost of different components of low head hydropower scheme based on the available head and capacity. Their estimation of cost led to an error of only ±12%. Andaroodi et al. [43] discussed the standardization of civil works to obtain the standard design chart which includes geometric and volumetric functions. The chart helps the designer to evaluate the different alternatives (production, transmission, cost, etc.) of the project according to the location, discharge, and head. The cost of SSH station is divided into four categories: civil work comprises 40% of the total cost, turbine and generator comprise 30% of the total cost, control equipment comprises 22% of the total cost, and management comprises 8% of the total cost [44].

Pakistan is currently facing an acute power shortage which causes people to suffer from privation and the desperate economic conditions as they buy their own systems for electricity generation. The Upper Swat Canal (USC), which is the largest canal in Khyber Pakhtunkhwa (KP), covers most of the areas in the KP province. If utilized for its full potential, USC could minimize the energy shortfall in the village and town bases.

Download English Version:

https://daneshyari.com/en/article/4911141

Download Persian Version:

https://daneshyari.com/article/4911141

Daneshyari.com