Energy 81 (2015) 511–518

Contents lists available at ScienceDirect

Energy

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

Custom design of a hanging cooling water power generating system applied to a sensitive cooling water discharge weir in a seaside power plant: A challenging energy scheme

Chuan Min Tian [a], Mohd Narzam Jaffar [b], Harunal Rejan Ramji [a], Mohammad Omar Abdullah [a,*]

[a] *Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), 94300 Kota Samarahan, Sarawak, Malaysia*
[b] *Sejingkat Power Corporation Sdn. Bhd. (SPC), Kampung Goebilt, Off Jalan Bako, 93010 Kuching, Sarawak, Malaysia*

A R T I C L E I N F O

Article history:
Received 11 April 2014
Received in revised form
22 December 2014
Accepted 24 December 2014
Available online 24 January 2015

Keywords:
Critical energy scheme
Exhaust cooling water
Hanging energy recovery system
System efficiency
Techno-economic

A B S T R A C T

In this study, an innovative design of hydro-electricity system was applied to an unconventional site in an attempt to generate electricity from the exhaust cooling water of a coal-fired power plant. Inspired by the idea of micro hydro, present study can be considered new in three aspects: design, resource and site. This system was hung at a cooling water discharge weir, where all sorts of civil work were prohibited and sea water was used as the cooling water. It was designed and fabricated in the university's mechanical workshop and transported to the site for installation. The system was then put into proof run for a three-month period and achieved some success. Due to safety reasons, on-site testing was prohibited by the power plant authority. Hence, most data was acquired from the proof run. The driving system efficiency was tested in the range of 25% and 45% experimentally while modeling results came close to experimental results. Payback period for the system is estimated to be about 4.23 years. Result obtained validates the feasibility of the overall design under the sensitive site application.

1. Introduction

It is true that there is a lack of grid-based electricity supply to remote areas in developing countries and as a consequence, renewable energy technologies such as hydro, solar and wind are to be developed and implemented [1–5]. Broader application of renewable energy technologies contributes substantially towards sustainable economic growth and prominent environmental conservation, though it is common that the intermittent nature of renewable energies has made them comparatively less efficient and economic when operate independently in providing reliable and consistent electricity to consumers [6]. More often than not, a combination of both renewable energy and conventional fuel are found to be the most feasible and practical solution to off-grid electricity, with the conventional fuel complementing the renewable energy [1–3,7]. Most often, there will be many issues associated with different energy schemes and requirements [2,3]. Evidently, there are rooms for improvements and innovations for renewable energy technologies.

Among various types of renewable energy technologies, micro hydro is deemed as one of the most reliable [4–6,8–10]. Typical micro hydro directly utilizes moving water from stream or river to generate electricity, and in many cases these natural water resources are rather consistent and predictable [6,11]. Considering its consistency and availability which are relatively better than other renewable energies, micro hydro has been widely accepted as the most established and reliable. Its other advantages include zero emission, low maintenance, high durability as well as can be efficiently run by just a few of average local folks. In fact, it has been proven as an effective yet economic solution for off-grid electrification in rural areas [8,9,11,12].

So far it is known that perhaps only drought and winter will affect the water supply, and these factors are relatively gradual and discernible. In the case of these unsteady, torrential rivers having different runoff regimes there is a need to optimize the plant and find the suitable system parameters thus optimized efficiency with shorter investment payback time [13]. Using a mixed-integer nonlinear programming approach, Catalao et al. [14] introduced

* Corresponding author. Tel.: +60 82 583280; fax: +60 82 583409.
E-mail addresses: amomar13@gmail.com, amomar@feng.unimas.my (M.O. Abdullah).

http://dx.doi.org/10.1016/j.energy.2014.12.064
0360-5442/

optimal hydro scheduling scheme in which the short-term time horizon parameters such as the effect of head on power production, start-up costs related to the units, multiple regions of operation, and constraints on discharge variation were modeled. Also, market uncertainty was introduced in their model via price scenarios and risk management analysis. The present paper, however, is dealing with consistent head and flow rate flow system.

The fact that micro hydro stands out as one of the most established renewable energy technologies since Industrial Revolution has seen a recent trend in adapting and applying it to unconventional areas of interests. For example, McNabola et al. [15] performed a review of energy use and CO_2 emissions in the water industry as well as the opportunities and challenges for micro hydro energy recovery. Results of the review indicate that significant potential exists for energy recovery in the water-related industry. However many investigations have not considered variations in flows or turbine efficiency. In a subsequent study, their investigation also showed that in certain circumstances significant energy, environmental and economic savings were available with modest investment [16].

Inspired with its efficacies, present study aimed to adapt this concept but on a very different site – a cooling water discharge weir in SPC (Sejingkat Power Corporation Sdn. Bhd.), which is a local seaside power plant. SPC is a base load power plant located near estuary connecting to South China Sea. It pumps water from the estuary to cool its coal-fired power generators due to two distinctive reasons: (1) the water is abundantly available for the plant-wide heat rejection applications, and (2) it is very consistent all year round – an average drought will have no adverse effect on the water supply. The exhaust cooling water is then discharged back to the estuary. However, at the discharge weirs, the cooling water is observed to have an abrupt drop, forming an artificial waterfall. The waterfall has the potential for energy recovery. Thus, present study attempts to recover the energy by design, develop and install a cooling water power generating system, which is in some ways similar yet very different from other existing micro hydro. The surrounding variables and the marine environment are among the challenges that have made this project a unique case.

It is worthy of note that utilizing artificial sites to generate electricity has become one of the newer trends in the renewable energy technologies. One of the recent efforts has been done by Stevanovic et al., who carried out a feasibility study on the potential of hydro-electricity at a thermal power plant which utilizes river water as the cooling water [17]. Due to seasonal variations, the head changes with time depending on the river water level, while the flow rate remains constant most of the time. The study and proposed design of a conventional micro hydro done by Stevanovic et al. seemed promising in harnessing the hydro potential of the site. Present study, however, dealt with sea water of consistent head and flow rate at an artificial pond site which prohibits any civil work.

As to modeling works, Barelli et al. [13] presented the mean and median AFDC (annual flow duration curves) model which utilizes recorded data, allows the optimization of the hydro plant under unsteady, torrential rivers having different runoff regimes, with optimized efficiency and shorter investment payback time. A payback period range of 0.9–9.7 years has been estimated via the model for the five rivers investigated.

Using a mixed-integer nonlinear programming approach, Catalao et al. [14] considered optimal hydro scheduling and offering strategies considering price uncertainty and risk management. Market uncertainty was introduced in the model via price scenarios; while risk management was included using CVaR (Conditional Value-at-Risk) to limit profit volatility.

By combining a production cost simulation model (PLEXOS) to represent the operations of the electric system with a hydropower modeling tool (RiverWare), Ibanez et al. [18] presented a methodology which allows for the combined optimization of both systems.

Unlike the complex variable flow schemes, the present study only requires the development of an uncomplicated mathematical model.

2. Physical and mathematical model

2.1. Performance analysis

In the present study, it was observed that the cooling water at the discharge weir undergoes a drop of h = 2.4 m, as shown in Fig. 1. The energy input coming from the waterfall inside the discharge weir is constant. This is supplied by 2 pumps with a capacity of 2.9 m^3/s. Therefore the energy input, E_{in} of the system can be expressed in Eq. (1). An expression of potential energy from a flowing water;

$$E_{in} = mgh \tag{1}$$

Meanwhile the energy output, E_{out} from the turbine is expressed in terms of mechanical energy in the form of work shaft, W_{sh} as described in Eq. (2);

$$E_{out} = W_{sh} = Fs \tag{2}$$

Energy transmission comes from the shaft can be expressed in terms of the rotation, n that is produced form a resulting Torque, T applied. A force, F acting on the wheel generates T as shown in Fig. 2. This can be written in Eq. (3). Therefore, substituting Eq. (3) into Eq. (2), Eq. (4) was obtained. Hence, the overall W_{sh}, can be expressed as Eq. (5);

$$T = Fr \tag{3}$$

$$W_{sh} = \left(\frac{T}{r}\right)(2\pi r\dot{n}) \tag{4}$$

$$W_{sh} = 2\pi nT \tag{5}$$

The turbine efficiency, η can be written as mechanical energy produced, E_{out} over the potential energy from the waterfall, E_{in} as expressed in Eq. (6). It is a common practice in micro hydro design to assume the efficiency to be 50% [11].

$$\eta = \frac{E_{out}}{E_{in}} \times 100\% \tag{6}$$

Considering the provided parameters obtained from the site are given in volume flow rate, V. The approximate mass flow rate, m

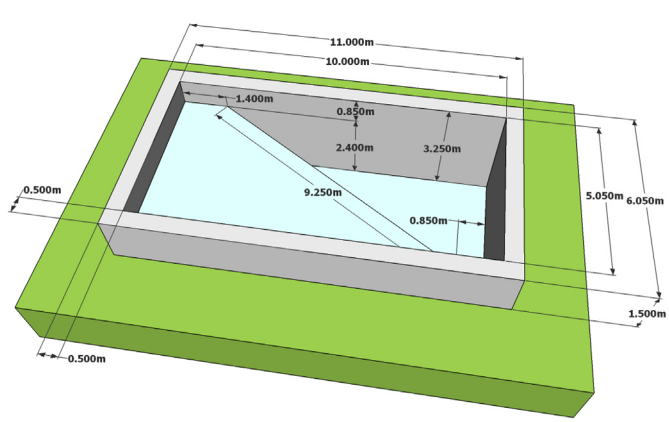

Fig. 1. Measurements of the chosen site.