Renewable Energy 122 (2018) 265–274

Contents lists available at ScienceDirect

Renewable Energy

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

Techno-economic optimization for two SHPPs that form a combined system

Vladan M. Karamarković [a], Miloš V. Nikolić [a], Rade M. Karamarković [a,*], Miodrag V. Karamarković [b], Miljan R. Marašević [a]

[a] Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Serbia
[b] Siemens AG Austria, Power and Gas, Vienna, Austria

ARTICLE INFO

Article history:
Received 20 September 2017
Received in revised form
19 December 2017
Accepted 21 January 2018
Available online 1 February 2018

Keywords:
Energy efficiency
Small hydropower plant
Turbine
Optimization
Technical solution
Net present value

ABSTRACT

More pronounced climate changes and strict environmental requirements change the criteria used for the determination of the installation capacity and the turbine type for a small hydropower plant (SHPP). This paper proposes a technical solution that determines the optimal configuration for two existing SHPPs that operate in a combined system with the aim to increase the production of electricity during the flow rates lower than the minimum flow for which the supplier guarantees the turbine efficiency. When these two SHPPs with the installed capacities 1.220 MW and 1.327 MW and a common weir water intake, work as a combined system, a techno-economic optimization shows that the addition of a turbine in the downstream plant for flows smaller than 17% of the installation flow improves the electricity production. This nonlinear optimization problem is solved in the Matlab environment with constraints defined by applying the Active-Set algorithm. Based on the criterion of the maximum net present value (NPV), the techno-economic analysis shows that a less efficient but cheaper mechanical plant that comprises a less efficient turbine gives the highest NPV during the period of feed-in tariffs.

1. Introduction

The Republic of Serbia was among 63 countries that globally had enacted feed-in policies as a support mechanism for electricity production from renewable energy in 2009 [1]. The milestone for the implementation of this kind of energy policy was the signing of the Treaty establishing the Energy Community [2]. By signing the Treaty, the Republic of Serbia accepted the binding obligation to increase the share of renewable energy in the final energy mix by 2020.

The establishment of legal framework [3–8], which is reviewed in detail in Refs. [9,10], and the implementation of feed-in tariffs resulted in the construction of 76 SHPPs with the gross installed capacity of 49.892 MW by the June 2017 [11]. The owners of all these SHPPs have acquired the status of privileged power producers for the period of 12 years.

The existence of inadequate cadaster of SHPPs, lack of experience of municipalities and designers in the field are difficulties that cause insufficient use of hydro potential. Hydrological studies, which are used for the determination of the installed capacity and the equipment selection for a SHPP, do not take into account the climate change and the occurrence of long draught periods. These difficulties are indirectly addressed in a specific problem that is being solved in the paper.

Fig. 1 schematically presents the existing state of the combined (coupled) system of small hydropower plants SHPP1 and SHPP2. Water from the weir intake is led by the penstock A to the first hydropower plant SHPP1, where, at the exit from the turbine, it directly flows into the penstock B and is led to the second hydropower plant SHPP2.

The maximal flow of both hydropower plants is 5.65 m^3/s. The gross head for SHPP1 is 34.50 m, and for SHPP2 37.76 m. The SHPP1 was put into operation in January 2014. At that time, the location for SHPP2 was not in the cadaster. The location was registered subsequently and SHPP2 started electricity production in 2016 when SHPP1 had already been used the status of privileged power producer for two years.

Each SHPP is equipped with one *Crossflow* turbine, and these two turbines, T1 and T2, have the same power of 1475 kW. The

* Corresponding author. Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Serbia.
E-mail address: karamarkovic.r@mfkv.kg.ac.rs (R.M. Karamarković).

https://doi.org/10.1016/j.renene.2018.01.081

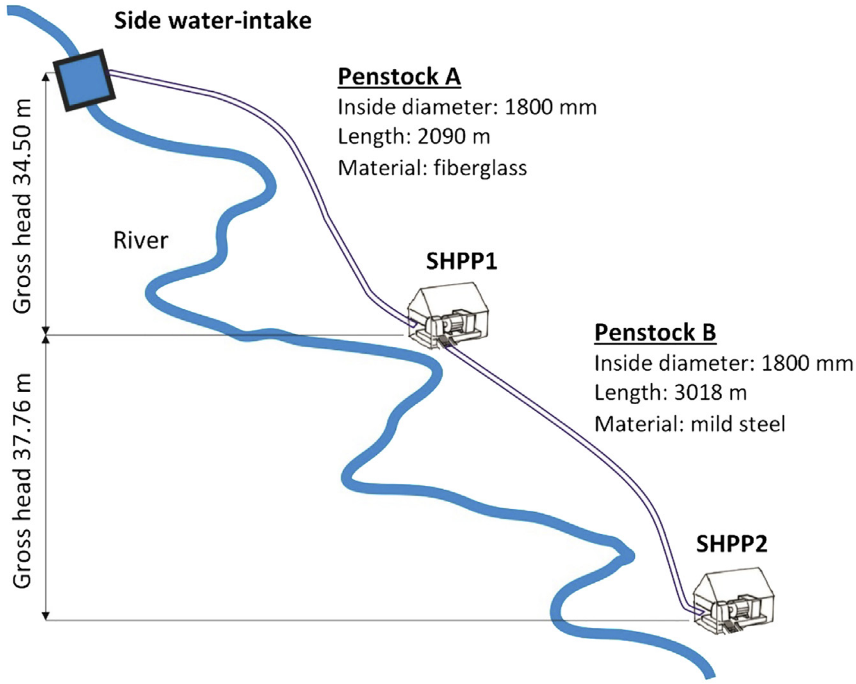

Fig. 1. Existing state.

experimental results obtained in exploitation conditions have shown a low degree of efficiency of the existing turbines at the flows smaller than 960 l/s (see Fig. 2). The limit noticed at 960 l/s represents 17% of the installation flow of the hydro power plant and the minimum flow for which the supplier of equipment guarantees the degree of efficiency of the turbine of 78%. During last couple of years, flow rates smaller than 960 l/s have been frequent during summer months.

This paper proposes a technical solution for two existing SHPPs that operate in a combined system with the aim to increase the production of electricity during the flow rates lower than the minimum flow for which the supplier guarantees the turbine efficiency. Three technical solutions are proposed for solving the problem. Each of the solution requires the installation of additional turbines, which would work independently or in parallel with the existing turbines at water flows smaller than 960 l/s. Fig. 2 shows also the efficiency of the additional turbine depending on the flow. The possibility to install the turbine parallel with the existing one was considered, and analyzed in Ref. [12], based on the techno-economic analysis, for the purpose of increasing energy efficiency. The difference in relation to [12] is that this paper considers the possibility of parallel and individual operation of two turbines, depending on the available water capacity.

To justify the investment into the reconstruction of the combined system, for each of the proposed solution, the optimal technical variant is chosen by a techno-economic analysis. The applied method of techno-economic optimization of turbine power is analogous to the optimization of capacity of wind turbines

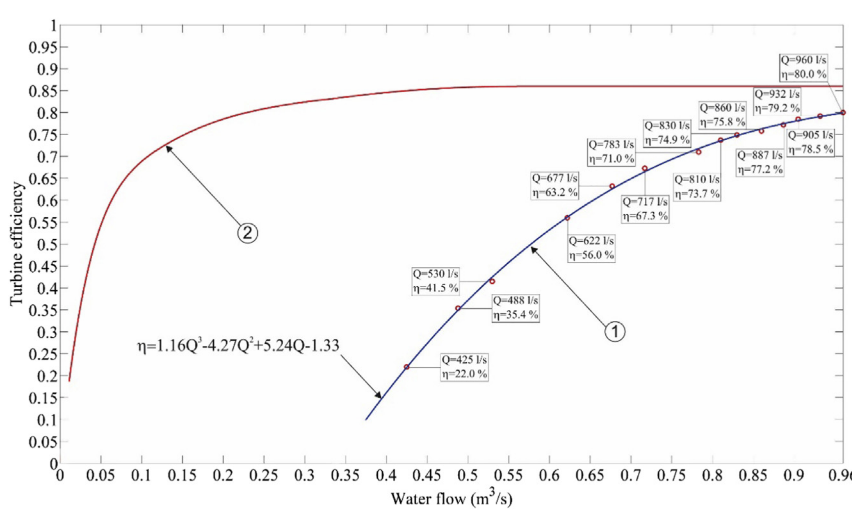

Fig. 2. The turbine efficiency depending on the water flow. 1 - is the approximation function obtained by the experimental data collected during the exploitation of the Crossflow turbine SHPP1 T1 at low flow rates. 2 - for the Crossflow turbine with the maximal installation flow of 960 l/s.