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Coupled Hydraulic And Electronic Regulation For Banki Turbines

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Abstract

The potential benefit of coupling hydraulic and electronic regulation to maximize the energy production of a Bank turbine in hydraulic plants is analyzed and computed with reference to a specific case. Design criteria of the Banki turbine inside hydraulic plants are first summarized, along with the use of hydraulic regulation in the case of constant water head and variable discharge at the end of aqueducts feeding water distribution systems. Optimal turbine impeller rotational speed is derived and traditional, as well as innovative systems for electricity production according to controlled rotational speed of the generator are presented. The study case at the purification plant named Risalaimi, in Italy, is analyzed, and the potential production of energy along the year is computed according to the known monthly average demand and two possible choices: the choice of hydraulic regulation only, called CFT1, and the choice of coupled hydraulic and electric regulations, called CFT2. The Return time of Capital Investment (RCI) is then computed for both the CFT1 and CFT2 cases. The result is that the CFT2 choice provides an increment of the total produced energy, along with an increment of about 30% of the corresponding RCI.

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Keywords: Cross-Flow turbines; Banki-Michell; CFD analysis; distributed generation units; electrical drives

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1. Introduction

The biggest expenses for many water management companies are, after personnel, the pumping energy costs. On the other hand, the potential energy of rainwater at its impact on the soil is much larger than the energy needed for pumping and the energy cost in the company balance sheet could easily change in sign by recovering only part of that energy [1]. At the present time the potential gravitational energy of rain (or snow) water most of the times is totally dissipated in transportation from the catchment location (wells, natural or artificial basins, rivers) to the reservoirs located at the top of the pipe distribution networks. Losses can be split into three parts: continuous dissipations along the conduit, proportional to the pipe length according to a constant J called piezometric gradient; local energy losses Λ' due to abrupt geometry changes along the pipe; and local energy losses Λ due to valves placed at the end of the conduit in order to regulate discharge from zero to the maximum possible value (corresponding to fully opened valve and zero Λ). A recently popular idea has been to replace the regulation valves with micro-turbines and to convert into electrical energy the dissipation Λ required to limit the discharge carried by the conduit. This also add sits energy value to the domestic and agricultural value of the water, and makes the water distribution business more advantageous.

Assuming atmospheric pressure at the turbine outlet, the piezometric gradient J and the power P_T produced by the turbine are linked to the discharge q by the following relationships:

$$J = K_p \frac{q^2}{D^5} \tag{1a}$$

$$P_T = \eta \cdot \gamma \cdot q \cdot \left(\Delta H - JL - \Lambda'\right) \tag{1b}$$

where K_p is a parameter depending on the pipe material and its aging conditions, D is the pipe diameter, and ΔH is the total topographic jump between the aqueduct inlet and the turbine axis. Observe that coupling the Eqs. (1a) and (1b) we get a third order polynomial in the q variable, which is zero for both the zero and the maximum discharge values; the latter corresponds to the maximum discharge allowed by the conduit (without turbine or regulation valve) and to the condition $\Delta H = JL+\Lambda'$. The economic benefit of micro-turbines to be installed depends on two main parameters: 1) the small cost per unit power, 2) the possibility to maintain high efficiency values η in Eq. (1b) with different discharge and net head values, where the net head H_n is the hydraulic head at the turbine inlet, given by:

$$H_n = \Delta H - JL - \Lambda' \tag{2}$$

Observe that a turbine with a single characteristic curve, placed at the end of an aqueduct, cannot always provide the power given by the r.h.s. of Eq. (1b) for different discharges, because a one-to-one relationship exists between discharge q and net head H_n and this relationship is usually different from Eq. (2). In this case, for example if PATs (Pumps As Turbines) are installed, when the discharge changes from its design value part of the potential energy must be anyway dissipated by a valve placed immediately before the turbine or part of the discharge must be bypassed by means of a parallel pipe [2]. A possible alternative strategy is to provide the turbine with a regulation system, with the effect of changing the characteristic curve according to the net head measured at the turbine inlet. Many regulator systems are available to change the turbine characteristic curve according to the variation of the hydraulic working conditions. Recent power electronic devices make it possible to regulate the electrical voltage and frequency in order to vary also the generator speed [3]. In the following sections, after a short review of the Banki turbine (hereafter called CF as Cross-Flow) design and of its hydraulic regulation system, we shall show that the best global efficiency is obtained by coupling the hydraulic regulation with the electric regulation of the turbine impeller rotational velocity, but that electric regulation is only worthwhile if the net head variability exceeds a minimum value depending on the specific cost/benefit ratio. A study case is analyzed in order to validate the theoretical study.