Water level control system for a low-head run-of-river variable speed small hydropower plant

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1. Interest of the work

Due to its ability to quickly respond to short-term changes in the electricity demand, hydropower plants associated to reservoirs with enough storage capacity are usually operated to provide power during periods of peak demand, thus providing the electric grid with operational flexibility and avoiding to some extent the power level variations in thermal plants. This operation scheme, referred to in the technical literature as *hydropeaking*, *hydroshifting* or simply *load-following*, can lead to fluctuating hydrologic patterns in the downstream river reach; furthermore, one should take into account that, next to high water releases during peak demand periods, the releases decrease sharply in order to refill the reservoir and regain head during off-peak periods. The rapid fluctuations in water levels associated to peaking operation can cause considerable ecological damage to downstream river ecosystems.

Run-of-river operation allows following the natural flow pattern and hence it is becoming every day more and more frequent, to the extent that in several industrialized countries the corresponding regulatory authorities are reviewing or re-licensing hydropower projects and forcing them to change from peaking operation to run-of-river operation [1].

Run-of-river small hydro plants do not contribute to load-frequency control of the electrical system; hence, instead of a conventional power-frequency control loop, a water level control loop is used in these cases [2] in order to adapt the water discharged through the turbines to the natural river flow. This requires monitoring the water level at the reservoir, or head pond, where the water intake is located, and adjusting the flow through the turbines in such a way that the level stays within certain pre-specified limits. In this regard it is worth noting that, to authors' knowledge, only few references are concerned with water level control in hydro plants [3].

Conventional hydro generating units either operate at the synchronous speed (synchronous generators) or deviate only slightly from the synchronous speed (induction generators). Therefore, in most cases the water level in the head pond is controlled by modifying the wicket gates opening. Kaplan turbines provide a very broad range of operating flows with considerably high efficiencies [4], thus being very suitable for low-head run-of-river hydro plants. However, there exists an increasing concern in many industrialised countries about the oil leakages due to the runner blades and wicket gates regulation mechanisms, to the extent that there have been several cases where double-regulated Kaplan turbines have been converted into single-regulated ones by welding the runner blades to the hub in a fixed position.

On the one hand, it is clear that single-regulated propeller turbines are more environmentally respectful than Kaplan turbines but, on the other hand, they present a narrower range of operating flows out of which the efficiency decreases rapidly [5].

Variable speed operation (VSO) allows the turbine speed to change in accordance with hydraulic conditions thus enlarging the turbine operating range. It could therefore represent an alternative to the adjustable blades of Kaplan runners. VSO in small hydro plants has been recently tested in several European projects [6-8] where its technical feasibility was demonstrated. With regard to its economic feasibility, it must be properly assessed in each specific case since it depends on several different factors such as the power plant capacity or how changing the site hydrologic conditions are, among others, and hence it is outside the scope of this paper.

In this paper, some of the activities carried out within the framework of a research project entitled *Application of variable speed and intelligent control technologies to hydropower generation* will be presented and discussed.

Keywords: Small hydropower, Run-of-river plants, Variable speed operation, Water level control.

2. Objectives and activities

One of the main objectives pursued by this project was *to design a water level control system for a low-head run-of-river variable speed small hydropower plant.* For this purpose, several activities have been carried out by the authors during the last three years, some of which are listed below.

i. An axial-flow propeller turbine with four adjustable guide vanes, directly coupled by a connecting shaft to an asynchronous generator, was placed on a test bench where several measurements were carried out in order to evaluate the turbine performance under different operating conditions, namely: flow, net head, guide vanes position and running speed.
ii. The turbine generating unit was moved to a laboratory plant, the complete system being composed of: cylindrical water tank (playing the role of the head pond); head-race conduit; surge tank; penstock; turbine generating unit; and draft tube. The generator is connected to the AC grid through a regenerative frequency converter by means of which the turbine speed is conveniently modified. The guide vanes are connected to a shift ring, which is in turn coupled by a connecting rod to a circular bronze plate, driven by a servomotor. The water inflow to the tank is controlled by means of a variable-speed water pump, thus allowing the plant to operate under different river flow conditions.
iii. From measurements taken on the test bench two artificial neural networks have been trained in order to simulate the turbine behaviour and estimate the turbine efficiency [9].
iv. From the above-mentioned measurements, it was observed that the regulation capability provided by the variation of turbine speed was rather greater than that provided by the guide vanes position. Therefore, the former has been selected as control variable to keep a constant water level in the head pond.
v. A control algorithm composed of two differentiated control loops has been simulated [9]. In the primary control loop, a conventional PI regulator tuned adequately provides the regenerative frequency converter with the speed signal to keep a constant water level in the head pond [10]. Once the water level has been stabilized, a maximum efficiency tracking algorithm chooses (in the secondary control loop) from a look-up table the guide vanes position that generates the largest turbine efficiency for the actual river flow, thus providing the servomotor with the corresponding position signal. In order to fill in the look-up table, several simulations of the primary control loop were carried out, sweeping different combinations of river flow and guide vanes position. During each simulation, the river flow is varied whereas guide vanes position and water level reference remain constant. The results of the simulations demonstrated that it is possible to improve the turbine efficiency by adequately modifying the guide vanes position without losing head pond stability.
vi. The primary control loop has been already implemented in the laboratory plant and manages successfully to control the water level in the head pond.
vii. Several experimental tests of the primary control loop, sweeping different combinations of river flow and guide vanes position were carried out in order to fill in the actual look-up table.

3. Main contributions

The main contributions of this research project in regard to the above-mentioned objective can be summarized as follows:

a. An experimental low-head run-of-river variable speed small hydropower laboratory plant has been constructed and commissioned successfully.
b. A water level control system has been designed and implemented at this laboratory plant. This system controls the water level in the head pond by means of a conventional PI regulator that provides a regenerative frequency converter with the necessary turbine speed signal.
c. A simulation model of the water level control system has been developed in Matlab-Simulink®, the results of which have been verified from experimental results.

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