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Optimal control of hydrokinetic-powered pumpback system for a hydropower plant in dry season: A case study

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Abstract

Low hydropower generation in dry season due to low water levels in hydropower dams is a common problem, particularly in drought-prone regions such as Southern Africa. In this paper, an optimal hydrokinetic-powered pumpback retrofit for recycling a part of the dam's downstream discharge to optimise the performance of the dam is proposed. The optimisation problem is formulated as a multi-objective problem to minimise grid pumping energy, maximise the use of hydrokinetic energy for pumping operation and maximise restoration of the dam volume through the pumpback operation. Simulation results of the proposed model using a practical case study show the potential of the model to increase the energy yield of the plant by 39 to 41.48% in the dry season.

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Keywords: Hydrokinetic; Hydropower ; Pumpback operation; Hydraulic head; Optimal control.

1. Introduction

Hydropower is the most matured renewable energy technology with a huge potential to substitute the depleting fossil fuel sources. However, its main limitation is vulnerability to climate change factors [1], a problem that has been experienced in recent years in vulnerable regions such as Southern Africa with Tanzania, Zimbabwe and Zambia worst affected. The anticipated decrease in precipitation in Southern Africa implies that the problem is bound to become more pronounced [1]. This problem underscores the need to re-model the existing hydropower dams to optimise the economic value of the available water. One of the strategies used to optimise hydropower generation in dry seasons is pumpback operation [2,3,4]. In these references, pumpback operation is used to recycle a part of the downstream discharge back to the main dam during the off-peak period to maintain a high water level in the dam for peak generation. However, the use of grid power for pumping operation is uneconomical for high head applications due to high head and pressure losses [5]. To minimise reliance on grid imported power for pumpback operation, this paper proposes the use of hydrokinetic energy conversion (HEC) system to power the pumpback system. Optimal control of the pumpback system has the potential to minimise the overall pumping energy demand over the control horizon as demonstrated in [6].

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2. **Mathematics model formulation**

Figure 1 shows the schematic layout of the proposed optimal control model. It comprises the conventional hydropower system, the hydrokinetic energy conversion (HEC) system and the pumpback system. In Figure 1, $P_1(j)$, $P_2(j)$, $P_4(j)$, $P_5(j)$ and $P_6(j)$ are respectively, the power output of the hydro-turbine generator, the power output of the HEC system, the pumping power demand supplied through a control switch u(j), the excess hydrokinetic power exported to the grid and the grid power imported to offset pumping power deficit in cases of low HK power generation. The fraction of HK power supplied to meet the pumping power demand is denoted by $P_3(j)$ while $H_o(j)$ and $h_u(j)$ are respectively, the net head and the depth of the dam. The quantities, $Q_o(j)$, $Q_k(j)$ and $Q_i(j)$ are respectively, the turbine discharge for hydropower generation, the flow rate of pump K and the in-stream discharge expressed in m^3/s.

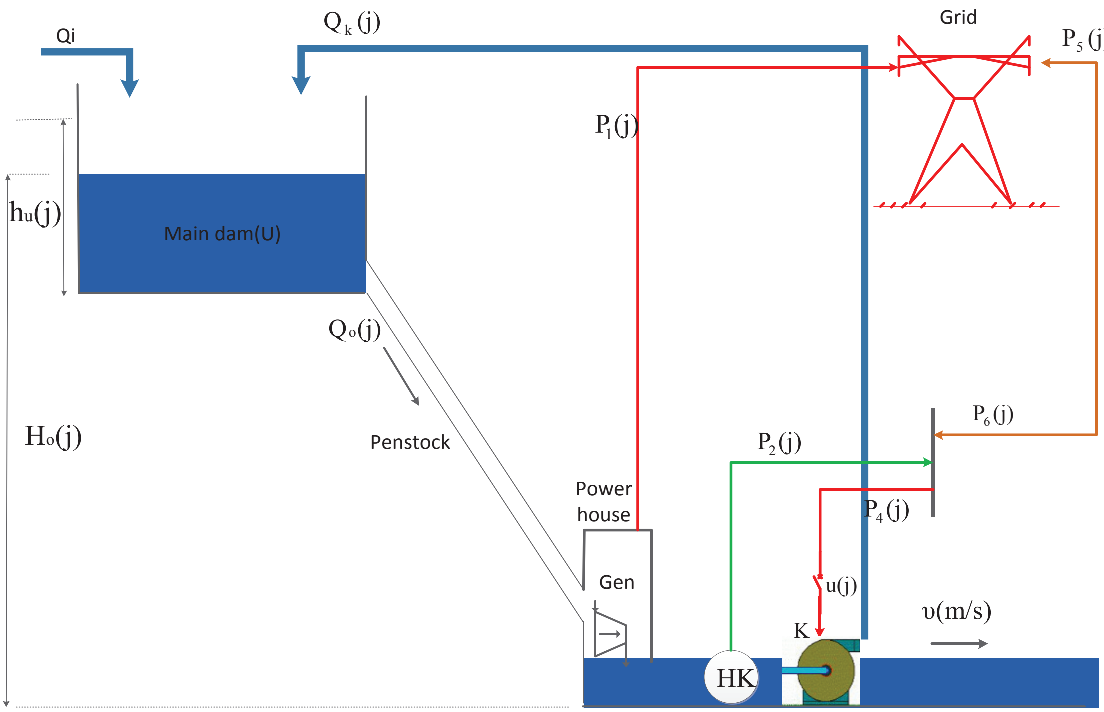

Fig 1: A hydroelectric power scheme with a cascaded HK-powered pumpback system

2.1. Conventional hydropower model

The theoretical power output of a hydro-turbine generator, $P_1(j)(MW$, is a non-linear function of the turbine discharge, $Q_o(j)$, and the head of the water fall, $H_o(j)$, expressed as follows [2]:

$$P_1(j) = \rho g \eta_e H_o(j) Q_o(j) \times 10^{-6}, \quad Q_o^{min} \le Q_o(j) \le A_c \sqrt{2gH_o^{max}}, \tag{1}$$