Upstream influence on the Francis turbine full-load surge Part II: The role of penstock dynamics

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Abstract. Full-load surge (FLS) is a self-excited pulsation occurring in some hydropower plants with Francis-type turbines or pump-turbines in case of high discharge. Using a one-dimensional (1D) transient model, previous studies showed that the variation of swirl at the runner exit can produce instability, both with and without contribution from runner blade cavitation, and that instability can occur in absence of any suitable natural frequency of the upstream water conduit. However, information from many other sources proves that penstock resonances do play a role for the appearance of FLS. The present study deals with two examples of FLS reported in literature. Unlike Part I, the influence load is examined instead of variable cavitation number, but this also results in a variation of cavitation compliance, surge frequency, and stability. One example refers to laboratory tests with the reduced-scale model from Part I, the other one deals with a slow load ramp performed in a power plant, exhibiting two different modes of oscillation. In the laboratory case, the relative surge frequency was clearly dictated by the model's operating condition. Runner speed and the test rig's natural frequencies had but little influence; this resembles the results of Part I with different penstock inertia. In the prototype example, the 1D simulation reproduces a sequence of distinct surge phenomena with frequencies related to different wave patterns in the penstock. This illustrates a rule established by Héraud (2018) concerning the likely frequencies of self-excited pulsations in plants with long penstocks. The results are compared with an earlier publication (Alligné 2022) which was based on a different theoretical concept. It is shown that FLS at successive modes do not require additional pressure nodes in the draft tube cavitation zone, and that considerable differences are possible between the results with alternative 1D models.

1. Introduction

Full-load surge (FLS) is a self-excited pulsation which affects the entire water-conducting system connected to a Francis turbine or pump-turbine as well as the output power. It is caused by feedback between high-load flow conditions with sufficient counter-swirl in the draft tube and the resulting cavitation volume of the draft tube vortex. Numerous studies have been undertaken in order to describe the phenomena involved by means of 1D models because researchers assume that such models can predict, or at least explain, instability at high load. Part I of the present article [10] deals with one particular turbine model which has been used for many investigations before. It confirmed that FLS may be produced by at least 3 different effects: (1) pressure recovery (diffuser effect) at low frequencies, (2) swirl variation due to pulsation of turbine discharge and/or runner speed, and (3) swirl variation due to pulsation of runner exit cavitation and flow angle [1][7]. Part I may be referred