Building a structural digital twin for the transient behaviour of a hydraulic turbine using modal analysis

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Abstract. The present work deals with the construction of a simulation-based simplified model to provide stress of a hydraulic turbine during transient operation by leveraging two well-known concepts: hydraulic similarity and linear load combination. This strategy is applied to a 200 MW medium head Francis turbine which underwent an experimental campaign to acquire steady and transient stress signature. A modal analysis is first required to extract mode shapes, characteristics and corresponding stress tensors. Then a coarse CFD database is generated to populate the operating space. Modal forces are obtained through FEA for the gravitational, centrifugal and pressure loads. Modes are then combined using either quasistatic or dynamic assumptions. The model can provide in real-time most of the transient trends and has a very good correspondence in operation.

1. Introduction

Hydraulic turbines are expected to fulfil an important role in decarbonizing the global economy due to their inherent flexibility. While standard design practices relying on fluid and structural computations are nowadays essential to obtain insights on structural stresses, transient simulations are still unfortunately time-consuming and limited in scope. The development of a digital twin able to incorporate inputs from various sources to track the observed behaviour of a unit in real time and quickly forecast the impact of an operational change on life expectancy is therefore key to stay in control of the turbine operation, maintenance and degradation. From a utility perspective, the objective is to incur minimum operating costs while preventing unexpected outages.

Some attempts to describe the full transient behavior of a hydraulic turbine have already been made using complex physical modelling, including moving mesh, variable runner speed and multiphase flow [1]. The downside of this approach is that it is very time and resource-intensive and therefore not applicable to lengthy events or real-time monitoring. Data-driven models are another possibility for describing transient behaviour. However, their performance is strongly linked to their training dataset and they are generally poor at explaining their performance making them hard to improve. Instead of relying on black box models, this paper shows how the modes contribution can be combined to infer stresses and displacements. This makes it possible to understand the model's response with the desired level of details and fine-tune it to meet operator needs. It also provides insight in regions where there is no experimental data.