Dynamic Mode Decomposition of Rotating Vortex Rope Instability

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Abstract.

The current work presents an in-depth study of the physical aspects of the Rotating Vortex Rope (RVR). Such studies are essential for later mitigating and controlling the instability. The Dynamic Mode Decomposition (DMD) method is adopted to understand and explain the phenomenon. DMD is a mathematical method to extract and represent the coherent structures and features in a complex dynamical system, including fluid flows. DMD decomposes a signal into dominant eigenmodes having distinct frequencies associated with physical phenomena. Here, the Timosoara Swirl Generator is selected as the test case which is designed to mimic the RVR phenomenon inside the draft tube of Francis turbines at part load conditions. The CFD simulations are performed using OpenFOAM while the DMD computations are carried out as a post-processing step through an in-house code. The eigenfrequency and eigenmodes of the flow field are extracted and explained. The DMD results are then used to reconstruct the flow field and it is shown that the main features of the flow field can be recovered with only a few DMD modes.

1. Introduction

The ever-increasing production of electrical energy from intermittent energy sources, such as solar, wind, tidal, and wave, requires an increased regulation of the electrical grid. The flexibility, reliability, and fast responsiveness of hydraulic turbines have made them a beneficial alternative to grid regulation [1]. However, that requires the turbines to frequently work at off-design conditions. It has been shown repeatedly that such conditions could generate complex flow structures and instabilities that lead to flow-induced vibrations and mechanical stress which are harmful to the lifetime of the turbines [2].

One such well-known instability is the Rotating Vortex Rope (RVR) that is formed in the draft tube of hydraulic turbines at part load conditions. The RVR is a crucially important phenomenon to understand and control, as it can have significant impacts on the performance, reliability, and lifetime of the turbines. In spite of extensive studies on the RVR phenomena, some aspects of it are still not well-understood, such as formation, propagation, and attenuation of the pulsation of the vortex rope [2].

In the past few decades, advancements in data-driven and machine-learning methods have led to the development of different algorithms for identifying coherent structures in fluid flows. Dynamic Mode Decomposition (DMD) [3] has received a great deal of attention in the past few