Numerical Investigation of the Hydrodynamic Instabilities of Pump-Turbines Operating at No-Load Conditions

Thesis Supervision

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Context

The integration of renewable energy sources such as wind and solar onto the electrical grid constitutes a significant engineering challenge. The intermittent nature of these energy sources represents a potential mismatch between the generation and consumption of electricity, a mismatch that covers a wide range of time scales. On one extreme of the spectrum, flexible energy sources are needed that can quickly compensate for power generation fluctuations on the grid, for instance when a wind farm stops generating due to the sudden lack of wind. On the other extreme of the spectrum, energy storage solutions are required to compensate the seasonal mismatch driven by the drop in solar production during winter.

Pumped-storage plants (PSPs) feature an upstream and a downstream reservoir, as well as hydraulic machines that can operate both in pump and turbine modes. By operating in pump mode during periods where there is overgeneration of electricity in the grid, PSPs represent a massive energy storage solution for both short- and long-term use cases. This energy can be restored when needed by operating in turbine mode, making PSPs a fast-response dispatchable renewable energy source.

In order to boost the flexibility of PSPs, pump-turbines are commonly operated at conditions where complex hydraulic phenomena develop. These phenomena may potentially cause instabilities that complicate the operation of the machine. The accurate prediction of these potential instabilities is therefore fundamental in the development of PSPs.

Detailed Description and Objectives

This research project focuses on the hydrodynamic instabilities that arise in turbine mode close to the no-load condition, an operating regime that occurs when a pump-turbine is about to be synchronized with the grid. If present, flow instabilities result in rotational speed fluctuations that can make the synchronization with the grid very challenging unless specific mitigation techniques are used.

The complex flow behavior close to the no-load condition is the consequence of a delicate balance between two driving effects: On the one hand, the centrifugal force the flow is subject to when rotating with the runner; on the other hand, the radial momentum of the flow downstream of the guide vanes. Whereas under normal operating conditions the radial momentum dominates, at the low discharge characteristic of this operating regime the radial momentum is not sufficient to overcome the centrifugation effect consistently. This results in partial pumping: An oscillating coexistence of positive and negative radial velocity regions. This highly complex flow field results in an almost complete dissipation of the hydraulic specific energy, resulting in a negligible torque on the runner, hence the "no-load" condition.

The objective of this study is to better understand the hydrodynamic instabilities that appear at no-load conditions, with the aim of identifying the main driving geometric parameters involved. Computational fluid dynamics (CFD) will be used to simulate the flow field for several operating conditions close to no-load on several pump-turbines. These results will be validated with measurements taken on reduced-scale models on GE Vernova's Grenoble test rigs; these data will be available at the start of the study.

Two CFD approaches will be used to achieve the objectives of this investigation:

1) Full-machine simulations with a hybrid RANS-LES turbulence model on relatively fine meshes using the commercial tool Ansys CFX. The computational cost of this approach is compatible with industrial practice, so it is possible to run several operating points on several turbines in order to build a basis for understanding the hydrodynamic instabilities and the driving geometric parameters. However, it might not be accurate enough since the turbulence model can become a precision bottleneck for a flow field that is dominated by the interactions among many small flow structures.
2) High-fidelity wall-modeled LES simulations using the research code YALES2[1]. Since LES explicitly solves for the dynamics of most of the flow structures, it can in principle improve the prediction accuracy on complex unsteady flows. Given the very high computational cost, a careful choice of computational domain, operating points and turbines will be done based on the results of the RANS-LES simulations.

An important aspect of this research project is comparing the results of the RANS-LES and LES simulations to understand the accuracy limitations of the former. This comparison will be made in terms of flow structure identification, energy loss spatial distribution characterization, and energy loss mechanism quantifications.

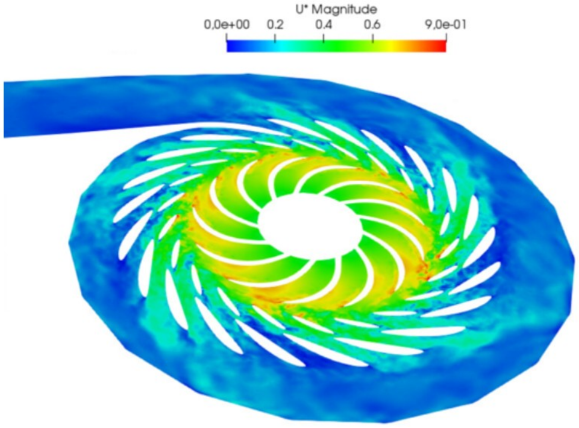

Figure 1 – Example of LES simulation on a pump-turbine[2].

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[1] YALES2 public page - www.coria-cfd.fr

[2] Etude numérique des instabilités hydrodynamiques dans le distributeur et l'avant-distributeur de turbines-pompes, Elliot Alloin (2024).

Application

The candidate must hold an engineering degree and/or a master's degree in fluid mechanics.

The key competences that are required are:

- Deep knowledge and application experience in computational fluid dynamics
- Good knowledge of hydraulic machines
- Experience in scientific programming and numerical analysis
- English: Fluent in written and oral communication

Applications must include the following:

- A one-page cover/motivation letter
- A detailed CV
- At least two references (likely to be contacted)
- A one-page summary of the master's internship/final project
- Engineering school transcripts, including grades

Applications shall be addressed to guillaume.balarac@legi.grenoble-inp.fr