Analytical approach for Francis turbine part load resonance risk assessment

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Abstract. Francis turbines operating at part load conditions experience cavitating vortex rope in the draft tube resulting from the swirling flow at the runner outlet. This cavitating vortex rope induces convective and synchronous pressure fluctuations at the rope precession frequency. The pressure fluctuating synchronous component, comprised between 0.2 and 0.4 times the turbine rotational speed, can be addressed as a draft tube pressure source forced excitation of the entire hydraulic system including the turbine itself. The synchronous component propagates through the entire hydraulic circuit and may lead to hydroacoustic resonance if the part load excitation frequency matches with one of the hydraulic system natural frequencies or even the natural frequencies of the synchronous generator. The paper presents a simplified analytical method to assess the resonance risk of the hydraulic system at early stage of a project. This method is based on a first estimation of the hydraulic system natural frequencies which is achieved from hydroacoustic properties of the hydraulic system such as pipe length, cross section area and wave speed. The cavitating draft tube is modelled with equivalent wave speed representative of the cavitation compliance and with a hydraulic inductance representative to the draft tube water inertia. The accuracy of this method is evaluated by comparison with a detailed 1D SIMSEN software frequency analysis, enabling to determine the eigen frequencies and eigen mode shapes of the hydraulic system, considering 3 different Francis turbine hydraulic layouts in terms of tailrace tunnel's length and diameter. The simplified methodology provides reasonably good results to identify potential risk of resonance at early stage of the project. The proposed analytical method for the assessment of the Francis turbine part load resonance risk is nowadays included as ANNEXE E.3 of the technical specification of the new IEC Technical Specification 62882 ED1 entitled "Hydraulic machines – Francis turbine pressure fluctuation transposition" which was issued in 2020-09.

1. Introduction

Unless extreme submergence applies, Francis turbines operating at part load conditions experiences cavitating vortex rope in the draft tube resulting from the swirling flow at the runner outlet, [4], [5], [7]. This cavitating vortex rope induces convective and synchronous pressure fluctuations at the rope precession frequency, [3]. The pressure fluctuating synchronous component, comprised between 0.2 and 0.4 times the turbine rotational speed, can be addressed as a draft tube pressure source forced excitation of the entire hydraulic system including the turbine itself, [4], [18]. The synchronous component propagates through the entire hydraulic circuit and may lead to hydroacoustic resonance if the part load excitation frequency matches with one of the hydraulic system natural frequencies or even the natural frequency of the synchronous generator, [14]. At early stage of a project, it is useful to evaluate if such vortex rope resonance may occur on the prototype, in order to anticipate the installation of possible