Realizable velocity profiles downstream Francis runner for reduction of part load pressure pulsations

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Abstract. The range of stable operation of a Francis turbine is restricted by unsteady phenomena, observed in the draft tube at high load and part load operating conditions. In part load the pressure pulsations are caused by the rotation of the helical vortex rope in the draft tube. The aim of the present paper is to develop the methodology for minimization of the part load pressure pulsations through optimization of runner shape. The main problem here is associated with high computational cost of unsteady CFD analysis needed to evaluate the amplitude of pressure pulsations. In case the runner shape is described by 20 free parameters, several thousand runner variations should be evaluated to find the optimal solution using evolutionary algorithms. This fact makes unsteady CFD analysis prohibitive for direct evaluation of pressure pulsations within optimization. In order to overcome this problem it is suggested to perform CFD analysis in steady state and estimate pulsation characteristics indirectly, based on the computed velocity profile downstream the runner. This approach raises the second problem, namely how to find a correlation between velocity profile and corresponding amplitude of draft tube pressure pulsations. In order to avoid trivial but unacceptable solutions like “the less swirl the smaller the pulsations”, we need to focus only on those velocity profiles, that can be realized in part load by high efficiency runners, meeting power and efficiency requirements in the other operating points (BEP, full load, etc.). In order to generate such a set of admissible part load velocity profiles it is suggested to solve an auxiliary multi-point optimization problem. Once the set of admissible profiles is found the desired correlation can be found using unsteady CFD analysis for several dozens of selected geometry variants. The paper discusses the pitfalls, solutions and preliminary results obtained in course of practical implementation of the above approach.

1. Introduction

In Francis turbines moving away from best efficiency point (BEP) both to full load and part load zones leads to appearing of residual swirl downstream the runner. The resulting vortex structures in the draft tube (DT) produce severe pressure pulsations in the flow [1]. The amplitude of these pulsations determines the boundaries of the permitted zone of turbine operation, figure 1.

In part load, when turbine discharge is about $0.4Q_{BEP} – 0.8Q_{BEP}$, where Q_{BEP} is the discharge in best efficiency operating point (BEP), the flow exiting the runner has a significant tangential velocity component and reduced axial velocity near the runner hub [1]. As the result, the flow in the draft tube loses its axial symmetry, forming a helical vortex rope with vapor core, precessing at frequency 0.2-0.4 f_n, where f_n is the runner rotation frequency. Rotation of the helical vortex, its frequency and