Influence of Guide Vane on Winter-Kennedy method: A Numerical study

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Long Abstract

Introduction

Most of the hydropower plants in the industrialized nations are under refurbishments or modernizations, as there were developed a few decades ago. The main drivers for the refurbishments are to increase plant efficiency, production, wide operating ranges, relicensing and safety issues, among others. Whatever are the drivers, the benefits in the upgrading of the plant are usually verified by the efficiency tests before and after refurbishment projects. The procedure to measure efficiency at a site is mentioned in the IEC41 field testing code [1], and practically used as:

$$\text{Efficiency, } \eta = \frac{Electrical\ power\ output\ (P_e)}{Hydraulic\ power\ input\ to\ turbine\ (P_h)}$$

The Hydraulic power is given by, $P_h = \rho g h Q$, where ρ, g, h, and Q are water density, gravity, head, and discharge respectively. The discharge is difficult parameter to assess. There are several fundamental methods for measuring discharge, as mentioned in the IEC41 standard, which is applicable for the high head plants. But there are no specific guidelines for the low head plants, i.e. below 50 m head. The shorter intake with the continuously varying cross sections in the low heads complicates the challenges in discharge measurement.

As a comparatively cheaper and easier alternative, the Winter-Kennedy (WK) method is widely used in the relative discharge measurement and thus efficiency step-up in the low head plants. The WK is an index testing method is based on the differential pressure measurement at the suitably located taps on the spiral casing (SC) of a turbine. In this method, the discharge Q is linked to the square root of the differential pressure (ΔP) through a constant K which is usually termed as WK coefficient, i.e. $Q = K\Delta P^n$. Theoretically, the value of n equals to 0.5, but for a better fitting during calibration, the IEC41 code allows adjusting the value between 0.48 – 0.52. The coefficient K is determined by model testing or calibrating against some absolute method.

The WK method usually produces reliable results, but the results can sometimes be dubious. Kercan et al. [2] concluded the method is unacceptable for guaranteed efficiency measurement because the inlet flow conditions strongly disturb differential pressure measurements so that the WK results are unstable and unreliable. The numerical simulations performed by Nicolle and Proulx [3] showed the WK method is sensitive to the inlet as well as guide vane opening. Further, in the experimental work performed by Lövgren et al. [4], 2% error was found in the discharge when the coefficient of the old runner was used in the flow estimation of the new runner. It signifies that if the flow condition is changed after refurbishment, the WK coefficient is no more constant. Moreover, it may not be reliable to verify the efficiency upgrades. When an old runner is replaced by the new and efficient runner during refurbishments, there might be a change in guide vane angle and flow rate in its operating points.

Therefore, this numerical study focuses on how the change in guide vane opening can affect the WK results. Furthermore, the paper also addresses how the flow condition is changed during the change in guide vane profile with different openings and its influence on the WK coefficients.

1. Methods

The 1:11 scale turbine model of Hölleforsen hydropower plant located in Sweden is used in this numerical study. The model has 0.522 m^3/s discharge and the head of 4.5 m at the Best Efficiency Point (BEP). The computational domain was built in two blocks: penstock and distributor, which were connected with the help of general grid interface (GGI). The distributor consists of 24 guide vanes and 10 stay vanes. The total mesh count was 7.5 million. The runner and draft were not modeled in the present work and results are independent of the effect of these components. The computational model and the grid are shown in Fig. 1.

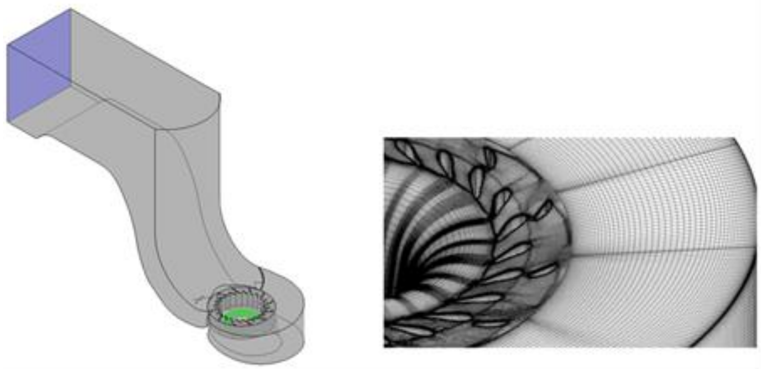

Figure 1. Computational domain (left) and mesh in the distributor and semi-spiral case (right). The inlet is shaded with light blue color and the outlet with the light green color in the left figure.

The commercial solver ANSYS CFX v16.0 was used for the CFD analysis of the model turbine. The numerical results were validated against the previously conducted WK results and Laser Doppler Anemometry (LDA) results, taken from [4] and [5] respectively. The boundary conditions and solution parameters used in the study is tabulated in Table 1.

Table 1: Boundary condition and solution parameters used in the study

Parameters	Description
Analysis type	steady and unsteady
Fluid	Water properties
Boundary conditions	Inlet: 1) mass flow and 2) total pressure, Outlet: static pressure
Discretization	Advection scheme: high resolution
and solution controls	Turbulence numeric: 1st order
	Turbulence models: *k-ε* with scalable wall function
	k-ω SST with automatic wall treatment
Convergence control	RMS set below 1e-6, with stable variable values

In the full paper, we will present how the change in guide vane and different openings will influence the WK results. Different WK configurations are taken into consideration to study the most stable and unstable points for measurement.

References

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