HydroFlex Peer-Reviewed Publicationsand Conference Proceedings

HydroFlex

Increasing the value of hydropower through increased flexibility

Deliverable 6.21 Peer review publications and proceedings from conferences 4

Work package	WP6 Communication, dissemination and exploitation
Task	Task 6.4 Publications and presentations
Lead beneficiary	Multiconsult
Authors	Shreejana Poudyal and Bjarne Børresen
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1 Introduction

Peer-reviewed scientific publication in journals and conference proceedings is a core part of disseminating the results of the HydroFlex project. The project has stated the quantitative target of more than 32 peer-reviewed publications. This deliverable lists the peer-reviewed HydroFlex publications and a list of articles which have been submitted for publication over the project period. Open access to all publications willbe ensured.

2 List of peer-reviewed journal publications and conferenceproceedings

Burman, A, Andersson, A & Hellström, G (2019): Inherent damping in a partially dry river. In: *Proceedings of the 38th IAHR World Congress* / [ed] Lucas Calvo, p. 5091-5100.

Abstract: As intermittent power sources such as solar power and wind power gains traction in Scandinavia it is likelythat the electricity production will become increasinglydependent on hydro power as a buffer in times ofpower deficit from intermittent power sources due to weather conditions. Rapid changes in hydro powerdemand can rapidly change the flow conditions in proximity to the power plant. This paper aims to model thetransient behavior and quantify the inherent damping in a dry reach in proximity tothe largest hydro powerplant in Sweden, with respect to production. A two-dimensional model solving the Navier-Stokes equationswith shallow water approximations was set up using the open-source solver Delft3D. The Manning numbers inthe reach was calibrated with measured steady state water surface elevation data. The simulation data wasthen validated with transient water level measurements. The results show that it's possible to calibrate theManning numbers using steady state water level measurements. The model also shows that it's possible tocapture the inherent damping and more transient behavior using Delft3D. The results can be used to bettermodel rivers withoutthe need for resolving the upstream reach. The results can also be used forecohydraulical applications where the transient behavior is important.

Felicetti, R, Abrahamsson C& Lundin, U (2019): Experimentally validated model of a fast switchedsalient pole rotor winding. *Proceedings of the IEEE WEMDCD 19. Greece.*

Abstract: The article proposes a model of a salient pole synchronous machine field winding based on a single transmission line model. An experimental method to derivethe parameters is also presented and validated. Finally the measured voltage distribution in the winding is compared to the model voltage distribution and the results match, demonstrating the model capabilities. The model describes the intrinsic resonance phenomena and accurately determines the voltage amplification factor.

Foti, P & Berto, F (2019) Evaluation of the strain energy density value for welded joints typicalof turbine runner blades. *Journal of Physics: Conference Series. Francis-99 workshop 3*.

Abstract: The main aim of this work is to investigate the fatigue behavior of welded jointsthrough an energetic approach based on the Strain Energy Density failure criteria. The geometrics, taken from the literature, are typical of turbine runner blades. The results of the fatigue tests on these details were summarised through the Strain Energy Densityapproach. The application of this method to these geometries is the first step of a widerresearch with the aim to provide a suitable tool in FEM code for the lifetime estimationof components characterized by complex geometrics.

Joy, J., Dekhordi, M.R. & Cervantes, M. J. (2019): Numerical Study on Reduced Francis-99 Turbine Model during Part Load Operation. *Conference Proceedings of 15th Asian International Conference on Fluid Machinery, Busan, South Korea.*

Abstract: Numerical investigation was performed on a reduced model of a high headFrancis turbine model at part load (PL) operating condition. Studies performed in thepast on nearly complete Francis-99 turbine model (inclusive of spiral casing, stay vanes, guide vanes, runner and draft tube) reportedly consisted of large number of mesh elements, which increase the computational time and power significantly. In the present paper, numerical study was performed on a standalone model of the Francis-99 elbowdraft tube so as to imitate the flow behaviour inside the draft tube during PL condition.The inlet profiles of the axial, radial and tangential velocity were considered from the study performed on a semi- Francis-99 model (1 stay vane, 2 guide vanes, 1 runner passage and draft tube) considered from NVKS Francis-99 second workshop. Additionally, turbulent kinetic energy (*k)* and turbulent eddy dissipation (*ε)* variables were also considered for better flow prediction inside the draft tube. Two approaches wereimplemented in the present study. In the first approach, the entire planar profile between the runner and draft tube interface was considered and in the second approach, flowvariables along a radial profile at the runner exit was considered together with an axisymmetric flow assumption. The numerical results obtained from the present studywere validated against the experimental results and were found to be in good agreement, both qualitatively and quantitatively, thus, ensuring the fidelity of the numericalmethodology. The present study could be considered useful for mitigation of rotating vortex rope (RVR) studies.

Lazarevikj, M., Stojkovski, F., Iliev, I & Markov, Z. (2019) Influence of the guide vanes designon stress parameters of Francis-99 turbine. *Journal of Physics: Conference Series. Francis-99 workshop 3*.

Abstract: The frequencies with predominant amplitudes in low specific speed Francisturbines are related to rotor-stator interaction and they are calculated on the basis of the runner speed and the number of guide vanes and runner blades. Pressure pulsations in the blade channels can be a reason for noise and vibration in the turbine above allowed level. High pressure pulsations can be caused by certain combination of runner bladesand guide vanes and their modifications are analysed in this paper. The main aim is to determine the impact of the geometry modification (thinner for increased efficiency) of the guide vanes on the Francis turbine stresses by performing numerical simulations. The original Francis-99 turbine guide vane geometry and three modifications consisting of new guide vane shapes are being considered. The numerical investigation of the flow field is based on the k-ω SST turbulence model with 'frozen rotor' approach selected, constituting a quasi-steady state analysis, without taking into account the physical rotation of the runner to obtain Rotor-Stator-Interaction (RSI). Pressure distribution on one guide vane determined by a Computational Fluid Dynamics (CFD) simulation of the turbine is coupled to a Finite Element Method (FEM) simulation in order to analyse thestresses. The results from the one-way fluid-structure interaction analysis give the stresses distribution and deformations of the guide vanes. Moreover, modal-acoustics analysis is conducted to obtain the natural frequencies of the guide vanes in water and comparison is made with the calculated vortex shedding frequencies to estimate the risk of resonance.

Markov, Z, Stojkovski, F, Lazarevikj, M & Iliev, I (2018): Investigation of the possibilities for development of a variable speed hydraulic turbine. *Energetics 2018 Conference Proceedings Book, pp. 333-341*. https://www.h2020hydroflex.eu/wp-content/uploads/2018/11/Markov-et- al.- Investigation-of-the-possibilities-for-development-of-a-variable-speed-hydraulic-turbine.pdf

Abstract: The need of hydropower, as a renewable energy resource, nowadays is increasing more and more. The goal is to obtain more efficient and more reliable power generating equipment for rational and long-term harnessing energy from water. Following the Horizon 2020 goals in the field of renewable energy, the need for development of a variable speed hydraulic turbine was exploited. The potential benefitsof developing such as hydraulic generation unit with variable speed are described in this paper along with the theoretical background used as a starting condition to be taken into account for the further development processes. The “Ss. Cyril and Methodius” University is a partner is a project called HydroFlex, with the aim of developing a variable speed high pressure Francis Turbine, with particular goal to develop the stay/guide vanes cascade to be suitable for such hydraulic turbines.

Storli, P. & Lundström, S (2019): A new Technical Concept for Water Management andPossible Uses in Future Water Systems. *Water 11, 2528;* doi:10.3390/w11122528.

Abstract: A new degree of freedom in water management is presented here. This is obtained by displacing water, and in this paper is conceptually explained by two methods: using an excavated cavern as a container for compressed air to displace water, and using inflatable balloons. The concepts might have a large impact on a variety of water management applications, ranging from mitigating discharge fluctuation in rivers to flood control, energy storage applications and disease-reduction measures. Currently at a low technological readiness level, the concepts require further research and development, but the authors see no technical challenges related to these concepts. Thereader is encouraged to use the ideas within this paper to find new applications and to continue the out-of-the-box thinking initiated by the ideas presented in this paper.

Tang, C. & Thiringer, T. (2019): Thermal simulation of a multichip inverter. *21stEuropeanConference on Power Electronics and Applications (EPE '19 ECCE Europe)*.

Abstract: Life time prediction and thermal management are among the key issues regarding the performance of today's semiconductor devices. And a fast and accuratethermal model can be used to tackle those problems more efficiently. In this paper, different thermal models of an IGBT power module have been established and compared. Firstly, a 3D finite element method (FEM) model is simulated in COMSOL. And then, a lumped parameter thermal model with considering different aspects (heat spreading and thermal coupling) is derived. The simulation indicates that the proposed model can achieve a relatively accurate result within a short simulation time.

Trivedi, C. & Dahlhaug O. G. (2019): A Comprehensive Review of Verification and Validation Techniques Applied to Hydraulic Turbines. *International Journal of Fluid Machinery and Systems12(4), pp. 345-367*.

Abstract: The paper critically reviews the verification and validation (VV) techniquesapplied to investigate hydraulic turbines. Although there are well-established standards such as AIAA G-077-1998 and ERCOFTAC guide for turbulence modelling, majority ofstudies conducted on the turbines are lacking of systematic VV. Results without properVV serve no purpose for safe and reliable designs of turbines. Available standards/guide are for general-purpose industrial applications and have limited scope. Customized VV procedure for the turbine applications is essential to create trust on the obtained results. The present review discusses how available standards/guide can be used to determine uncertainty/error and to demonstrate the credibility of results. The review includes several aspects of VV such as effect of discretization schemes, iterative error, convergence criteria, time-step sizing and impact of passage modeling approaches onthe results. Further, how numerical results mislead the user and its implications are addressed. In the last, open questions on turbine modelling and recommendations onprospective numerical studies are discussed.

Trivedi, C., Iliev, I. & Dahlhaug, O. G. (2020): Numerical Study of a Francis Turbine over Wide Operating Range: Some Practical Aspects of Verification. *Sustainability 12(10)*, 4301.

Abstract: Hydropower plays an essential role in maintaining energy flexibility. Modern designs focus on sustainability and robustness using different numerical tools. Automatic optimization of the turbines is widely used, including low, mini and micro head turbines. The numerical techniques are not always foolproof in the absence of experimental data, and hence accurate verification is a key component of automatic optimization processes. This work aims to investigate the newly designed Francis runner for flexible operation. Unsteady simulations at 80 operating points of the turbine were conducted. The numerical model consisted of 16 million nodes of hexahedral mesh. A SAS-SST (scale adaptive simulation-shear stress transport) model was enabled for

resolving/modeling the turbulent flow. The selected time-step size was equivalent to one-degree angular rotation of the runner. Global parameters, such as efficiency, torque, head and flow rate were considered for proper verification and validation. (1) A complete hill diagram of the turbine was prepared and verified with the reference case. (2) The relative error in hydraulic efficiency was computed and the over trend was studied. This allowed us to investigate the consistency of the numerical model under extreme operating conditions, far away from the best efficiency point. (3) Unsteady fluctuations of runner output torque were studied to identify unstable regions and magnitude of torque oscillations.

Burman, A.J, Andersson, A.G, Hellström, J.G.I & Angele, K (2020): Case Study of Transient Dynamics in a Bypass Reach. In: Water 12(6), 1585; https://doi.org/10.3390/w12061585.

Abstract: The operating conditions of Nordic hydropower plants are expected to change in the coming years to work more in conjunction with intermittent power production, causing more frequent hydropeaking events. Hydropeaking has been shown to be detrimental to wildlife in the river reaches downstream of hydropower plants. In this work, we investigate how different possible future hydropeaking scenarios affect the water surface elevation dynamics in a bypass reach in the Ume River in northern Sweden. The river dynamics has been modeled using the open-source solver Delft3D. The numerical model was validated and calibrated with water-surface-elevation measurements. A hysteresis effect on the water surface elevation, varying with the downstream distance from the spillways, was seen in both the simulated and the measured data. Increasing the hydropeaking rate is shown to dampen the variation in water surface elevation and wetted area in the most downstream parts of the reach, which could have positive effectson habitat and bed stability compared to slower rates in that region.

Felicetti, R. Abrahamsson, C & Lundin, U (2020): The influence of eddy currents on the excitation winding impedance of solid and laminated salient pole synchronous machines. *In: Electrical Engineering Journal.*

Abstract: This work investigates the establishment of steady-state eddy currents in solid and laminated salient poles and rotor rim of synchronous machines due to a periodic excitation voltage. It shows that the presence of eddy currents in the rotor magnetic circuit has the double effect of increasing the excitation winding AC-resistance and decreasing its magnetizing AC-inductance. According to that a simple analytical model ispresented in here which allows a rapid rough estimation of the excitation winding AC- resistance when little information is available about the machine geometry and its electric/magnetic materials properties. The model is then verified by reproducing in frequency the excitation winding AC-resistance and the related power loss measured in two synchronous generators. Finally the limits of reliability and applicability of the model are discussed. The model has implications for periodic field winding current control and voltage regulation in synchronous machines.

Trivedi, C., Iliev, I., Dahlhaug, O. G., Markov Z., Engstrom F., and Lysaker H. (2020): Investigation of aFrancis turbine during speed variation: Inception of cavitation. *Renewable Energy Vol 166, Pages 147-162;* https://doi.org/10.1016/j.renene.2020.11.108

Abstract: Variable-speed operation of a hydro turbine is considered as an alternative option to meet fluctuating energy demand as it allows high-ramping rate. Cavitation can be a limiting factor to utilize the variable-speed technology at full potential in a hydro power plant. This work investigates the cavitation characteristics and unsteady pressure fluctuations as turbine ramps up, to meet the energy demand. The investigated Francis turbine consists of 15 blades and 15 splitters, and the reference diameter is 0.349 m. Numerical model of complete turbine is prepared and hexahedral mesh is created. Rayleigh Plesset algorithm is activated for cavitation modelling. Available experimental data of model acceptance test are used to prescribe boundary conditions, and to validate the numerical results at distinct points. Transient behaviour of the cavitation is studied, and the results are quite interesting. At certain time instants, the cavitation effect is extremely predominant, and as a result of cavitation bubble bursts, the amplitudes of pressure fluctuations are significantly high.

Khanzadeh, B., Tang, C., & Thiringer T., (2020): A Study on the Lifetime of Q2L-MMC-DAB's Switches for Wind Turbine Applications. Fifteenth International Conference on Ecological Vehicles and Renewable Energies(EVER); 10.1109/EVER48776.2020.9243073

Abstract: This paper studies the lifetime of semi-conductor switches of a dual-active- bridge (DAB) DC-DC converter for wind turbine applications. Quasi-two-level operating modular multilevel converters (MMC) are used as the building blocks of the DAB converter. One of the established lifetime models is used for the lifetime estimation of theswitches. Measurement data of an on-shore wind turbine for three hundred days is used as the mission profile. It is shown that the short-term thermal cycles (cycles with frequency in the range of switching frequency) are detrimental to the lifetime estimation of the auxiliary switches of the MMCs' submodules. Thus, neglecting the short-term thermal cycles will overestimate the lifetime of the auxiliary switches by several orders of magnitude. On the other hand, these cycles will not affect the lifetime of the bypass switches considerably. It is also shown that the thermal stress on the secondary-side auxiliary switches is more severe than the primary-side ones. It is suggested that two parallel devices should be used for the secondary-side auxiliary switches; as a consequence, a reasonable lifetime is achieved for the secondary-side auxiliary switches.

Wirtz P., Siemonsmeier, M., Schonefeld M., & Moser A., (2020): Two-step Approach Simulating the Unit Commitment of Highly Complex Hydraulic Systems in the Future European Power System. 17th International Conference on the European Energy Market (EEM); 10.1109/EEM49802.2020.9221898

Abstract: The increase in supply-dependent renewable energy sources and the decommissioning of thermal power plants lead to an increasing need for flexibility in the future European electricity supply system. In this context, hydroelectric power plants represent a mature and renewable flexibility option. The EU Horizon 2020 project "HydroFlex" aims to increase the value of hydropower through increased flexibility. To this end, the project aims to develop a flexible turbine capable of very flexible operation and in particular several start/stop cycles per day. In order to both estimate the operational requirements for hydraulic turbines in the future and to systemically evaluate the flexible turbine developed in the project, a unit commitment model based on a European electricity market simulation is required. Due to the high complexity resulting from the large number of hydraulic interconnections in the Nordics, permissible simplifications are needed to solve the problem in a reasonable computing time. The paper presents a method to simulate the unit commitment of highly complex hydroelectric power plant parks in the future European power system, which is necessary to evaluate the technological advantages of the turbine developed in the "HydroFlex"-project.

Burman, A.J., Andersson, A.G., & Hellström, J.G.I (2020): Investigating damping properties in a bypassriver. *River Flow 2020, Taylor and Francis Group*, ISBN: 9781003110958

Abstract: The operating conditions of hydropower plants in Sweden are expected to change in the coming decades with potentially many hydropeaking events every day. It istherefor important to understand how inherent damping properties in rivers can be used to mitigate potential negative influences on fluvial ecosystems. The effect of the upstream dam closing time and the Manning number distribution in the reach on the transient behavior of the downstream water level and wetted area is investigated. In the study reach the shallow-water equations are solved using the open-source solver Delft3D. The simulations show that the transient change in water level is mainly dependent on the upstream dam closing time. The dynamics of the wetted area is considerably affected by the closing time of the dam. The Manning number has a negligible effect on the transient behavior for the wetted area and the water level. The results in this study can be used for future ecohydraulical applications such as identifyingpotential stranding zones.

Siemonsmeier, M., Wirtz P., & Schonefeld M., (2020): Investigating the Flexibilization of Hydraulic Storage Power Plants in the Nordics. IEEE Electric Power and Energy Conference (EPEC), doi: 10.1109/EPEC48502.2020.9320117

Abstract: The increase in supply-dependent renewable energy sources and the decommissioning of thermal power plants leads to an increasing need for flexibility in thefuture European electricity supply system. In this context, hydraulic power plants represent a mature and renewable flexibility option. The EU Horizon 2020 project "HydroFlex" aims to increase the value of hydropower through increased flexibility. To this end, the project aims to develop a flexible turbine capable of very flexible operation and in particular several start/stop cycles per day. In this paper, different types offlexibility are first analyzed as they are required in the future European power system. Subsequently, the paper presents a method simulating the operation of highly complex hydraulic power plant parks, which is essential to investigate future operational requirements and to evaluate the turbine technology developed within the "HydroFlex" project from a systemic perspective. The focus is, in particular, on the future operation of

hydraulic power plants in the Nordics in order to meet the increasing flexibility demands in the European power system.

Felicetti, R. Abrahamsson, C., & Lundin, U. (2021): An experimentally determined field winding model with frequency-dependent parameters. *IET Electric Power Applications;* https://doi.org/10.1049/elp2.12061

Abstract: Herein, a set of experimental procedures is presented for determining the main electrical distributed parameters of the field winding in salient pole synchronous machines. It applies to the electrical characterisation of iron-core power inductors and transformer windings as well, in a range of frequency useful for power electronics applications. A first estimation of the parameters is obtained by forcing the winding into resonance with capacitors of known capacitance. The obtained estimates are then refined through an iterative process, which makes use of the winding natural frequencies. The presented procedures are applied step-by-step to the field winding of a 60-kVA salient pole synchronous generator with solid poles. The distributed parameters model, featured using the outlined procedures, accurately reproduces the winding voltage distribution in a large range of frequency. Finally, it is explored how the interaction between armature and rotor influences the field winding parameters, pointing to the differences of measuring them with the rotor inside or outside the machine bore.

Joy, J., Raisee, M., & Cervantes, M.J. (2021): Study of Flow Characteristics inside Francis Turbine Draft Tube with Adjustable Guide Vanes. *IOP Conf. Ser.: Earth Environ. Sci.* 774 012018

Abstract: Numerical investigation was performed on a semi-model (one stay vane, two guide vanes, one runner passage inclusive of one main and one splitter blade, and the draft tube) of a high-head Francis turbine model with adjustable guide vanes in the draft tube. The motive of the present study is to investigate the possibility to mitigate the rotating vortex rope (RVR) formed at part load operating condition. Each guide vane in the draft tube consists of two hydrofoils. The upper hydrofoil is adjustable according to the flow angles leaving the runner. The lower hydrofoil is stationary and corresponds to the flow angle at best efficiency point (BEP). The factors considered while designing these guide vanes were a) number of guide vanes, b) chord length, c) span and d) position in the draft tube. The preliminary results indicate that the RVR pressure amplitude was suppressed by 97% compared to the reference model with no guide vanes at part load (PL) operating condition. An 8.7% increment in the draft tube pressure recovery was obtained which indicates that implementation of the guide vanes in the draft tube could positively impact the turbine efficiency beside the mitigation of the pressure pulsations at PL operation.

Marija Lazarevikj, Filip Stojkovski, Zoran Markov, Igor Iliev, Ole G. Dahlhaug (2021): Parameter based tool for Francis turbine guide vanes design using coupled MATLAB - ANSYS approach. Journal of Sustainable Development of Energy, Water and Environment Systems – JSDEWES, doi: 10.13044/j.sdewes.d9.0410

Abstract: The complex geometry of Francis turbine components can be defined parametrically so that automatic optimization techniques based on parametrization can be used. This is convenient for a hydraulic redesign of individual turbine elements. Considering the importance of the guide vane cascade in defining the flow entering the runner, a parametric design tool is established to design the stationary parts of a Francis turbine with variable-speed capabilities and optimize the guide vanes. For a given runner geometry and turbine operating conditions, variety of different guide vane designs may be produced. The calculation procedure for obtaining the curves which are basis for generating the stationary turbine components is performed in the software MATLAB. The script is then connected with the Computational Fluid Dynamics and Finite Element Method analysis software ANSYS Workbench to automate the process of geometry generation, meshing, modeling and simulation of three-dimensional stationary water flow in the turbine and structural analysis of the guide vanes. The tool proves to be very useful for collecting results related to the guide vane hydraulic and mechanical performance, towards obtaining an optimal guide vane design. A model of a Francis turbine is used as a test case.

Jesline Joy, Michel J. Cervantes, Mehrdad Raisee (2021): Reduced Numerical Modeling of a High Head Francis Turbine Draft Tub e at Part Load. International Journal of Fluid Machinery and Systems; 2021 Volume 14 Issue 1 Pages 95-108

Abstract: In the present study, a reduced model of the Francis-99 model turbine was investigated numerically at part load operating condition. The reduced model consists of a standalone draft tube domain of the Francis-99 model turbine. Numerical studies performed in the past on nearly complete hydro-turbine models (inclusive of the spiral casing, distributor domains, runner, and draft tube) reportedly consist of a large number of computational grids. This may increase the computational costs and data storage required to perform numerical analysis, which could be a setback for future research on new design concepts and optimization study of the draft tube domain. The reduced model was developed by mapping the phase averaged axial, radial, and tangential velocity profiles from the runner exit to the inlet of the standalone draft tube domain. Additionally, turbulent kinetic energy (k) and turbulent eddy dissipation (ε) variables were also considered for better flow prediction inside the draft tube domain. Two methods for mapping inlet boundary conditions were considered in the present study. In the first method, the entire planar profile of the runner-draft tube interface was considered. In the second method, the variables along a radial profile at the runner exit were considered with an axis-symmetric flow assumption over the entire draft tube inlet plane. The numerical results obtained from the Francis-99 reduced model turbine were validated against the numerical model of the NVKS Francis-99 model turbine (with available structured mesh) that was also analysed using the passage flow numerical technique and available experimental results. The results were found to be in reasonable agreement, with each other. The present study could be useful for the future mitigation study of rotating vortex rope by modifying the draft tube domain.

Filip Stojkovski, Marija Lazarevikj, Zoran Markov, Igor Iliev, Ole G. Dahlhaug (2021): Constraints of Parametrically Defined Guide Vanes for a High-Head Francis Turbine; Energies; Special Issue Experimental and Numerical Investigations of Hydraulic Machines, 2021, Volume 14, Number, Article number 2667; MDPI

Abstract: This paper is focused on the guide vane cascade as one of the most crucial stationary sub-systems of the hydraulic turbine, which needs to provide efficient inflow hydraulic conditions to the runner. The guide vanes direct the flow from the spiral casing and the stay vanes towards the runner, regulating the desired discharge. A parametric design tool with normalized geometrical constraints was created in MATLAB, suitable for generating guide vane cascade geometries for Francis turbines. The goal is to determine the limits of these constraints, which will lead to future faster prediction of initial guide vane configurations in the turbine optimal operating region. Several geometries are developed using preliminary design data of the turbine and are investigated using CFD simulations close to the best efficiency point (BEP) of the turbine. This research is part of the Horizon-2020—HydroFlex project led by the Norwegian University of Science and Technology (NTNU), focusing on the development of a flexible hydropower generation.

Filip Stojkovski, Marija Lazarevikj and Zoran Markov (2021): Parametric Design Tool for development of a radial guide vane cascade for a variable speed Francis Turbine; 30th IAHR Symposium on Hydraulic Machinery and Systems; EPFL, Lausanne

Abstract: Hydropower as a part of the family of renewable energy sources represents an engineering and scientific field which inspires researchers to work on development of the systems and sub-systems in a way of optimizing the whole energy transformation process to obtain more efficient, flexible and reliable hydropower operation with the best possible water to energy ratio. This research is part of a Horizon 2020 HydroFlex project by the Norwegian University of Science and Technology (NTNU), where the main goal is development of a flexible hydropower generation. The guide vane cascade is one of the most crucial stationary sub-systems of the hydraulic turbine and is a subject of this study. Its re-design for obtaining a quality "flow-feeding" of a variable speed high head Francis turbine is developed. Having this goal in mind, a MATLAB code was generated, based on several key parameters, such as initial energy conditions as net head and turbine discharge at best efficiency point (BEP). Turbine runner geometrical constraints are taken into account during this process, while using recommendations for some initial guide vane calculations such as their number, inlet and outlet diameter, guide vane axis diameter, delivery angles etc. Using an inverse Euler turbine equation, the operating range of the turbine was calculated for a variable speed and discharge conditions, keeping the shock-free flow for all states at the runner's inlet, as it is the most favourable inflow condition. For those operating points, the flow streamlines angles were obtained at the guide vanes leading and trailing edges. With an interpolating mathematical functions between the angles of the leading and trailing edges, the camber lines of the hydrofoils were obtained for further guide vane cascade geometry development. This algorithm can be implemented on any given runner geometry. The guide vane design is then exported into ANSYS Workbench for further numerical tests, such as CFD simulations for verifying the hydrodynamic characteristics and FEM analysis for verifying the structural integrity of this sub-system for variable speed operating conditions.

Tengs Erik, Charrassier Flora, Jordal Maria Rolstad, Iliev Igor (2021): Fully automated multidisciplinary design optimization of a variable speed turbine; 30th IAHR Symposium on Hydraulic Machinery and Systems; IOP Science; EPFL, Lausanne

Abstract: The future electricity market will have large contributions from renewable energy sources such as solar and wind. The intermittent nature of these energy sources creates a need for highly flexible operation of hydropower stations and changes the way we use hydraulic turbines to more off-design operation and more start-stop cycles. These changes challenge the structural integrity of the turbines in a way not seen before, and the next generation of hydro turbines will therefore have to be designed differently to meet this challenge. The goal of this article is to develop a framework for variable-speed Francis turbine design.

A fully automated multi-disciplinary design optimization procedure has been developed. As off-design operation is assumed, the runner do not only have to be optimized from a hydraulic point of view, the structural integrity is equally important. The design optimization is therefore based on a blending function of the hydraulic efficiency and the harmonic stress levels at a series of operating conditions. This is to ensure that the turbine is less prone to fatigue, even at off-design operation.

The process is fully automated, with no need for human interaction. A MATLAB design code is producing the raw design, every design is then meshed and tested at different operating points in a CFD solver. The pressure field from the fluid analysis is mapped onto the structure and evaluated in an acoustic-harmonic analysis to assess the fluctuating stresses in the turbine blades. A global optimization loop consisting of 15 design parameters is driving the process based on an overall optimization function.

The work has been performed as part of the HydroFlex project, and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764011.

Jesline Joy, Mehrdad Raisee and Michel Cervantes (2021): Study of flow characteristics inside Francis turbine draft tube with adjustable guide vane systems; 30th IAHR Symposium on Hydraulic Machinery and Systems; IOP Science; EPFL, Lausanne

Abstract: Numerical investigation was performed on a semi-model (one stay vane, two guide vanes, one runner passage inclusive of one main and one splitter blade, and the draft tube) of a high-head Francis turbine model with adjustable guide vanes in the draft tube. The motive of the present study is to investigate the possibility to mitigate the rotating vortex rope (RVR) formed at part load operating condition. Each guide vane in the draft tube consists of two hydrofoils. The upper hydrofoil is adjustable according to the flow angles leaving the runner. The lower hydrofoil is stationary and corresponds to the flow angle at best efficiency point (BEP).The factors considered while designing these guide vanes were a) number of guide vanes, b) chord length, c) span and d) position in the draft tube. The preliminary results indicate that the RVR pressure amplitude was suppressed by 97% compared to the reference model with no guide vanes at part load (PL) operating condition. An 8.7% increment in the draft tube pressure recovery was obtained which indicates that implementation of the guide vanes in the draft tube could positively impact the turbine efficiency beside the mitigation of the pressure pulsations at PL operation.

Anton J.Burman, Richard D.Hedger, J. Gunnar I.Hellström, Anders G.Andersson, Line E.Sundt-Hansen (2021): Modelling the downstream longitudinal effects of frequent hydropeaking on the spawning potential and stranding susceptibility of salmonids; Science of the total environment, Volume 796, 20 November 2021, 148999

Abstract: Hydropower plant operating conditions are expected to change to be more in tandem with intermittent power production so as to meet the requirements of the Paris Agreement, which in turn may negatively impact ecological conditions downstream of the hydropower plants. The current study investigates how highly flexible hydropower operating conditions may impact several salmonid species (European grayling, Atlantic salmon and brown trout) in the River Umeälven, a major river in northern Sweden; specifically, how changes in hydropeaking frequency may affect the area of the downstream watercourse that is hydraulically suitable for spawning (potential spawning area) and how changes in spill gate closing time may affect the propensity to stranding. River hydrodynamics were modeled using the open-source solver Delft3D, with a range of hydropeaking frequencies (from 10 to 60 starts and stops per day) and a range of spill gate closing times from (1–30 min). Increasing the hydropeaking frequency caused a reduction in potential spawning area, but also a reduction in dewatering of potential spawning area at low flows. Increasing spill gate closing time caused a decrease in propensity to stranding. Effects were dependent on both species and life-stage, and declined longitudinally with distance downstream from the spillway outlet. The modelling approach used here provides an effective method for predicting likely outcomes of flexible hydropower operating conditions, taking into account fish species and life-stages present and watercourse characteristics.

Filip V. Stojkovski, Zoran Markov (2022): Interaction of the guide vane blades shapewith the hydrodynamic parameters and the efficiency of variable-speed Francis turbine; Ss. Cyril and Methodius" University in Skopje; Doctoral Thesis

Abstract: Despite the unstable nature of the unconventional renewable energy sources, the trend of increasing usage of them in Europe and all the scenarios and forecasts made in that direction, lead to the need of balancing energy in the grid and increasing flexibility in electricity production. To address these needs, hydropower plants as hydropower facilities are most suitable to cover these fluctuations. This brought the idea of applying variable speed operation to hydraulic turbines, where adjusting their rotational speed results in more efficient water to energy usage ratio, and increases their operating range at the same time. In this doctoral dissertation the emphasis is on the guide vanes, which are the main stationary distribution element of the turbines and serve to regulate the flow, as well as the power of the machine. The analyses are based mainly at defining the main kinematic flow parameters that are dominant in the vaneless space between the turbine runner and the guide vanes. According to that, a new type non-uniform blades were developed, in order to see their impact on the flow parameters and efficiency at variable speed operated turbine. The analyses were performed with CFD numerical flow simulation on various developed models of guide vanes, from where positive conclusions and directions for further development of this technique for guide vane design are obtained.

Roberto Felicetti (2021): Voltage Transients in the Field Winding of Salient Pole Wound Synchronous Machines: Implications from fast switching power electronics, Licentiate Thesis, Uppsala University

Abstract: Wound Field Synchronous Generators provide more than 95% of the electricity need worldwide. Their primacy in electricity production is due to ease of voltage regulation, performed by simply adjusting the direct current intensity in their rotor winding. Nevertheless, the rapid progress

of power electronics devices enables new possibilities for alternating current add-ins in a more than a century long DC dominated technology. Damping the rotor oscillations with less energy loss than before, reducing the wear of the bearings by actively compensating for the mechanic unbalance of the rotating parts, speeding up the generator with no need for additional means, these are just few of the new applications which imply partial or total alternated current supplying of the rotor winding.

This thesis explores what happens in a winding traditionally designed for the direct current supply when an alternated current is injected into it by an inverter. The research focuses on wound field salient pole synchronous machines and investigates the changes in the field winding parameters under AC conditions. Particular attention is dedicated to the potentially harmful voltage surges and voltage gradients triggered by voltage-edges with large slew rate. For this study a wide frequency band simplified electromagnetic model of the field winding has been carried out, experimentally determined and validated. Within the specific application of the fast field current control, the research provides some references for the design of the rotor magnetic circuit and of the field winding. Finally the coordination between the power electronics and the field winding properties is addressed, when the current control is done by means of a long cable or busbars, in order to prevent or reduce the ringing.

Anton Burman; Hydraulic Modelling of Dynamics in Regulated Rivers; Licentiate Thesis; LTU; 2021

Abstract: The Nordic countries hold a significant portion of the European hydropower production. One advantage of hydropower is its ability to store water in reservoirs in times when the energy demand is low. The readjustment of energy production to renewable energy sources, as required by the Paris agreement, like wind power and solar power is likely going to change the role of Nordic hydropower production. Wind power and solar power are both dependent on the current weather conditions, in times when the weather is not favourable, hydropower can be used to stabilize the electricity grid. Since weather can change rapidly so will the discharge from the hydropower plants, causing hydropeaking events. Hydropeaking rapidly changes the flow conditions in proximity to the power plant. Such changes can be detrimental to the downstream habitats in and along the river.

The study reach in this work is the bypass reach in Stornorrfors in the Ume River. The open-source hydrodynamic solver Delft3D is used to numerically model the flow in the study reach. To validate the simulations water level measurements have been used.

The aim of the thesis is to investigate inherent damping properties in the river reach that can be used to mitigate the influence of hydropeaking scenarios. The influence of parameters such as upstream closing time, manning number distribution and hydropeaking frequency have been investigated.

It is shown that the closing time drastically affects the dynamics of the wetted area. The water surface elevation exhibits a hysteresis like behaviour. Inherent damping increases with the downstream coordinate. The frequency of the flow changes affects the areas upstream more than downstream. As a result, potential habitats in the downstream parts of the reach could become more stable if more frequent flow changes occur.

3 Submitted for publication

WP	Title	Authors	Journal/ Proceedings/ Books series/ Book	Remarks
3	A Novel Guide Vane system Design to Mitigate Rotating Vortex Rope in High Head Francis Model Turbine	Jesline Joy, Mehrdad Raisee and Michel Cervantes	International Journal of Fluid Machinery and Systems	Revised manuscript submitted after adressing reviewers comments
3	Experimental investigation of a Guide Vane System in Francis Model Turbine Draft Tube Part A: Rotating vortex rope mitigation	Jesline Joy, Mehrdad Raisee and Michel Cervantes	This information will be available soon	Manuscript in progress
3	Experimental investigation of a Guide Vane System in Francis Model Turbine Draft Tube Part B: Hydraulic Performance	Jesline Joy, Mehrdad Raisee and Michel Cervantes	This information will be available soon	Manuscript in progress
3	Model for determining the influence of a variable-speed Francis turbine on guide vane structural and stress parameters	Marija Lazarevikj, Zoran Markov	Ss. Cyril and Methodius University in Skopje	Doctoral Thesis; Defence is on 19th May 2022.