The HydroFlex and AFC4Hydro projects are funded by the European Union's Horizon 2020 research and innovation programme under grant No 764011 and 814958.

HydroFlex

AFC 4 HYDRO

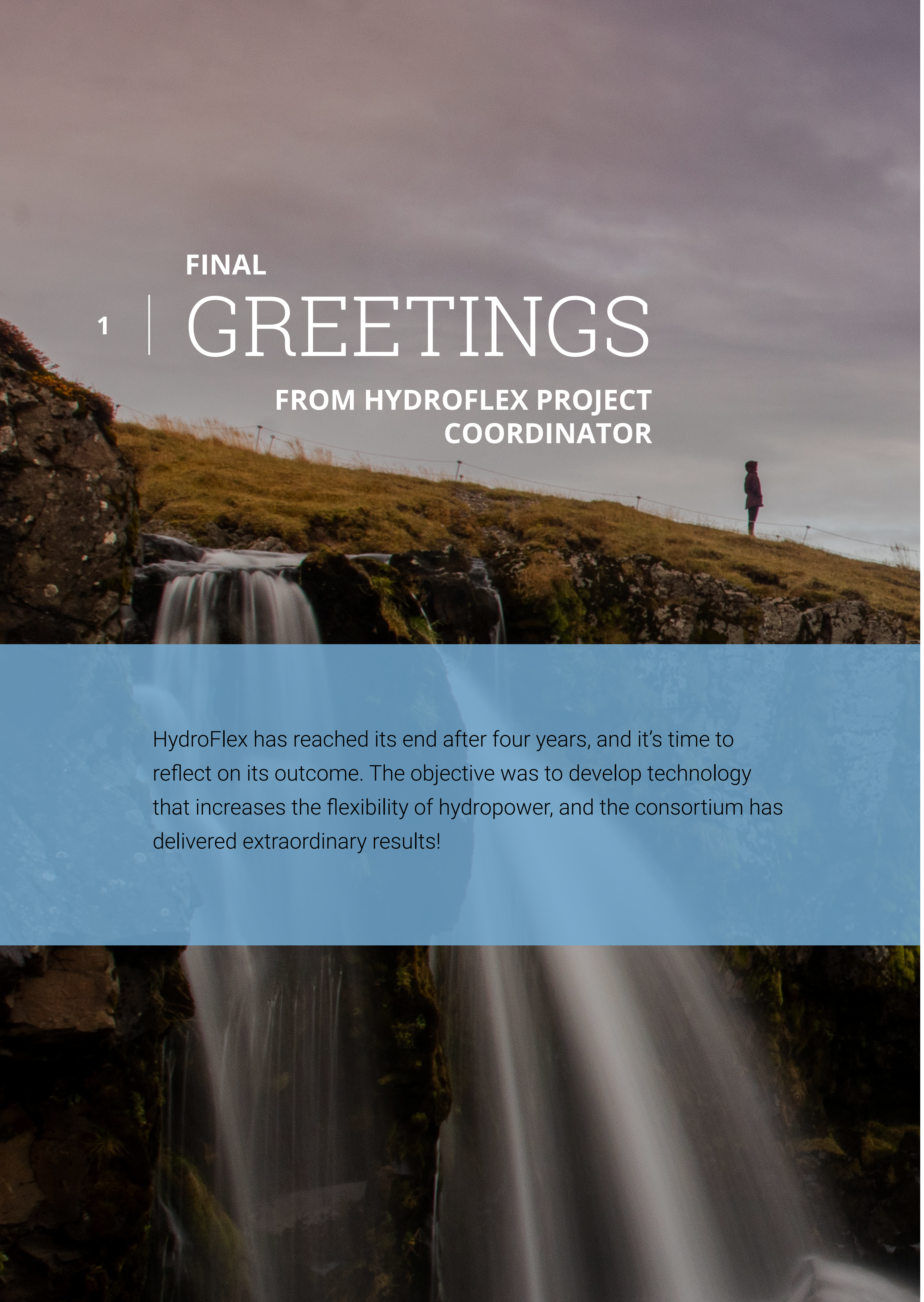
NEWSLETTER APRIL 2022

E-mail:
ole.g.dahlhaug@ntnu.no
wp5@afc4hydro.eu

Web:
h2020hydroflex.eu
afc4hydro.eu

Number:
Newsletter 08
Newsletter 04

Date:
30/04/2022



1

FINAL GREETINGS

FROM HYDROFLEX PROJECT COORDINATOR

HydroFlex has reached its end after four years, and it's time to reflect on its outcome. The objective was to develop technology that increases the flexibility of hydropower, and the consortium has delivered extraordinary results!

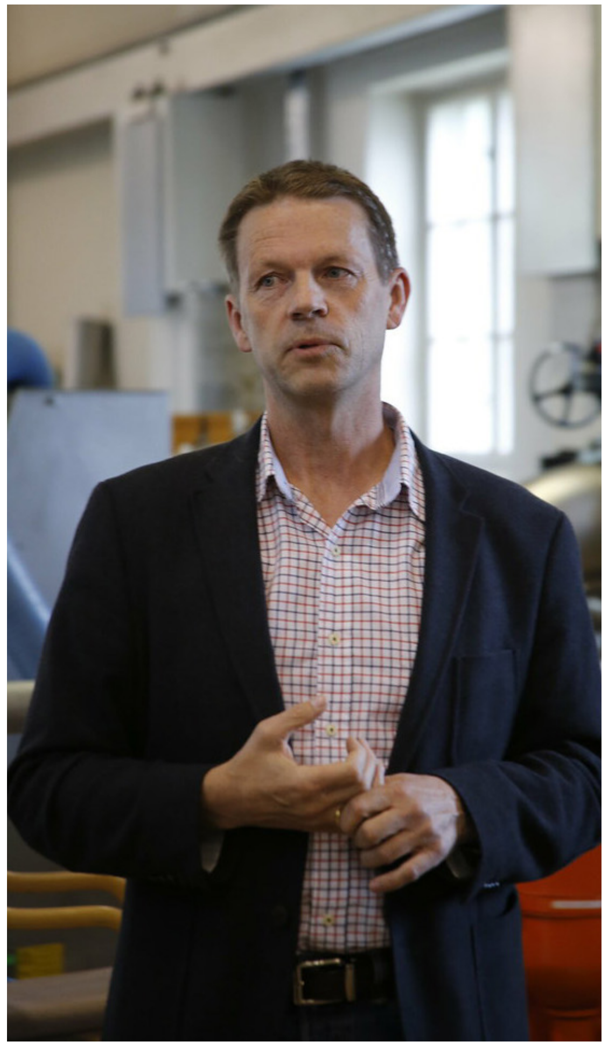
HydroFlex was challenged with a scenario with high ramping rates and 30 start-stops per day for hydropower plants. Due to its technical challenge, environmental impact and lack of social acceptance, many looked at this as unrealistic. Today, we surprisingly see high numbers of mode changes. We might even see 30 start-stops in the future.

Since HydroFlex started in 2018, Europe has increased its level of electrification and introduced large share of intermittent renewable energy sources. This has caused challenges to the safety of energy supply and to the stability of the electrical grid. Due to its capabilities, hydropower will safeguard the electrical system, avoid instabilities and enable more renewables in Europe. This is the main reason why the results from HydroFlex are becoming increasingly important for the ongoing green transition in Europe.

Covid-19 has been present during large part of the project period. There has been less travels and some laboratory work has been delayed, but it had no significant influence of the progress of project. However, it was satisfying to see the consortium in "real life" at the final workshop in Trondheim in March 2022. The results that were presented makes me proud.

I would like to thank all the project participants for the work they have carried out and even more so for the good collaboration. To me it has been an honour to work with a consortium with such high competence, integrity, humour and friendship.

I know that HydroFlex has built relations and friendship between the partners in the consortium, and I am confident that this will give more collaborations in the future.



Thank you,

Project Cordinator
Professor Ole Gunnar Dahlhaug, Department of Energy and Process Engineering, NTNU

2 | GREETINGS

FROM AFC4HYDRO WP3 LEADER XAVIER ESCALER

WP3 is leaded by the Barcelona Fluids & Energy Lab (IFLUIDS) from Universitat Politècnica de Catalunya - BarcelonaTech in Spain. IFLUIDS is a research group of the Fluid Mechanics Department at the Barcelona School of Industrial Engineering (ETSEIB) focused on the fields of renewable energy, fluid mechanics and hydraulic machinery and expert in experimental and numerical approaches.

The objective of WP3 is to build a structural health monitoring system (SHM) which means implementing a characterization strategy for hydraulic turbines with the aim of reducing maintenance costs and extending their life cycle by detecting incipient failures and potential damages. The planned tasks have been defined to advance at three different scales.

The first step has consisted in building a dedicated down-scaled test rig with a simplified rotating and submerged structure at the IFLUIDS laboratory in Barcelona as shown on the left of Figure 1. A series of studies have been carried out to assess the most adequate instrumentation, including innovative fiber optics sensors based on Fiber Bragg grating (FBG) laser technology, to monitor the fluid structure interactions and the structural response. With the use of artificial excitations, the signal transmissibility between on-board and off-board positions has also been evaluated (see the right of Figure 1). Based on the final monitoring set up, acquisition routines and online post processing tools have been developed as well as a controller strategy. Currently, the test rig is being used to validate new methodologies for crack detection and to predict fatigue failures.

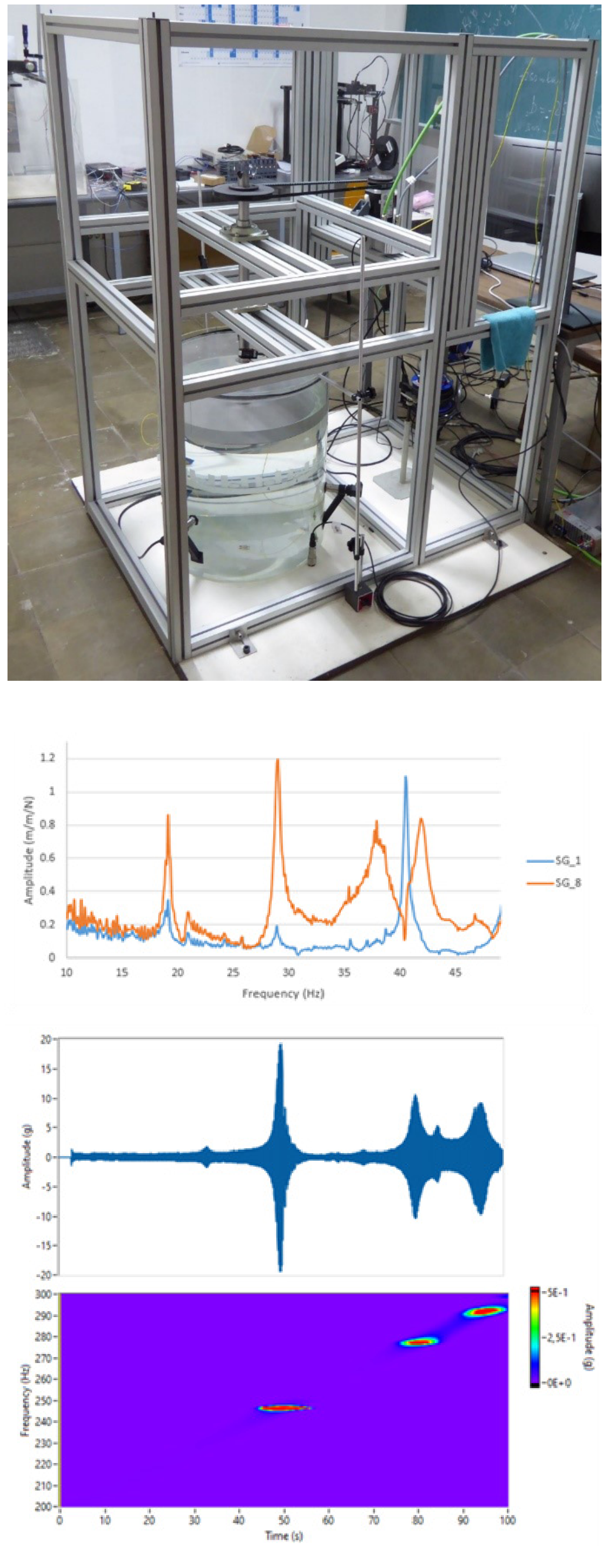
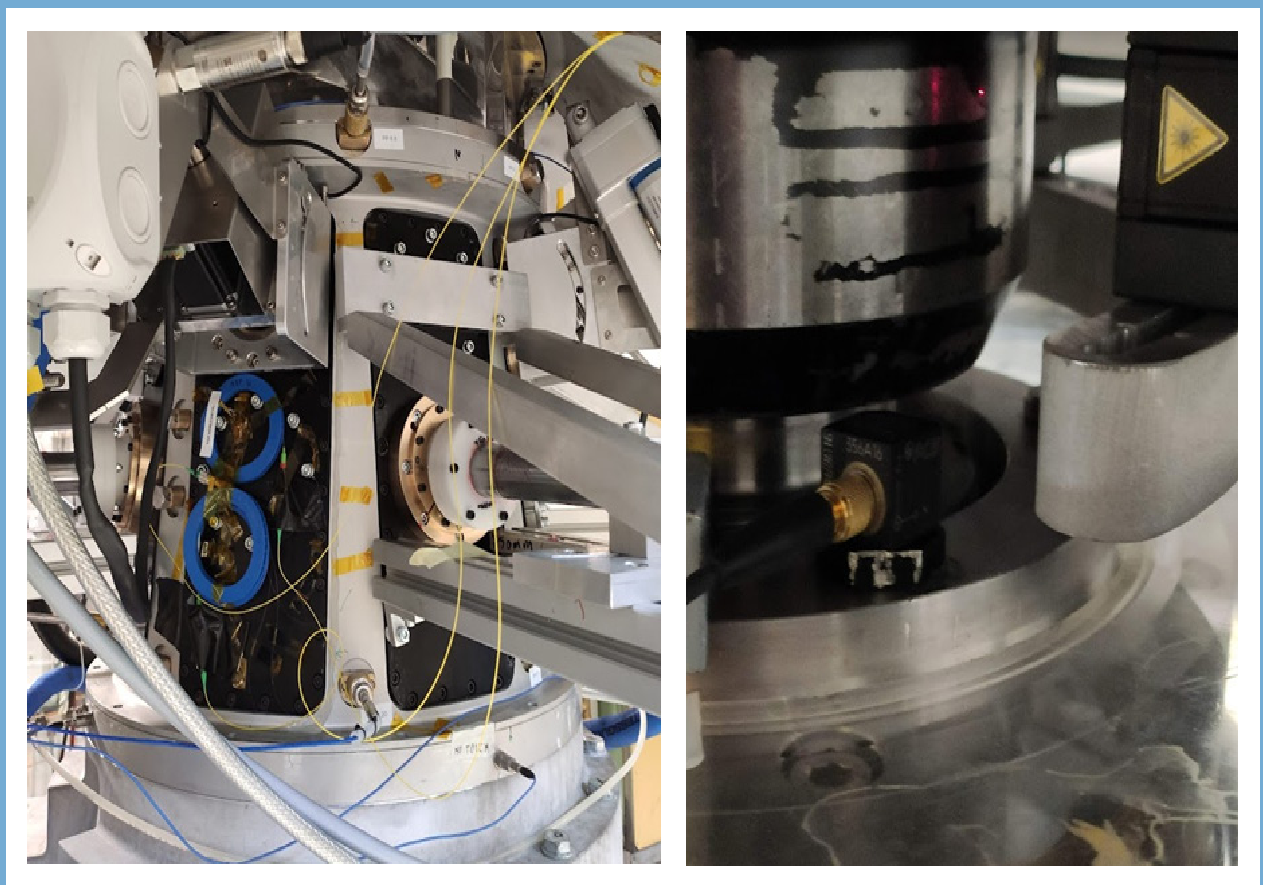


Figure 1. AFC4Hydro test rig at IFLUIDS laboratory in Barcelona (top) and example of some of the results obtained from the measurements carried out to develop the SHM system (bottom).

The SHM system will put special attention to the interaction between the unsteady flow phenomena in the draft tube and the vibrations of the rotating and submerged runner. In this sense, the second step has consisted in an extensive measurement campaign that has been carried out in a reduced scale Kaplan turbine model at the Vattenfall Research and Development facility at Älvkarleby, Sweden.

The objective of the tests has been to monitor and characterize the dynamic response of the machine when it operates in steady and transient conditions in propeller mode by changing the guide vane angle with a fixed blade angle corresponding to the best efficiency point. For this campaign, vibrations, displacements, strains and pressures have been measured both off-board and on-board in order to evaluate the SHM system in front of unacceptable hydraulic behaviors (see Figure 2).

Figure 2. **Photographs of some of the sensors of the SHM set up at the reduced scale Kaplan turbine in Alvkarleby located on the draft tube cone (left) and on turbine bearing (right).**



Moreover, a series of measurements have been carried out to evaluate the performance of the actuation systems inside the draft tube flow, the IPM and ICM, which will serve to develop the complete AFC system with the combination of a suitable controller design.

Finally, the third step is focusing on the validation and optimization of the SHM in relevant industrial environments which are a 10 MW Kaplan turbine in Porjus hydropower plant (in Sweden) and a 200 MW Francis turbine in Oksla hydropower plant (in Norway).

In these full scale prototypes, the effects of the draft tube flow instabilities on the electrical properties of the generated power output will also be investigated in order to incorporate the adequate measurement strategy to the SHM system.

All these experimental works are being complemented with the corresponding numerical models that will permit to understand and predict with good accuracy the structural dynamic response under deleterious flow phenomena occurring inside the turbine and their effects.

Figure 3. **AFC4Hydro team members Rafel Roig Bauzà and Xavier Escaler, from UPC, and Morten Kjeldsen, from FDB, working at the Vattenfall Research and Development center in Älvkarleby, Sweden.**

WP3 leader
Professor Xavier Escaler,
Universitat Politècnica
de Catalunya -
BarcelonaTech

SUMMARY OF RESULTS FROM

3 | HYDROFLEX

WP2 DEFINITION OF SCENARIOS AND REFERENCE CASES

The objective of this work package is to identify and describe the demands hydropower plants will be confronted within future power systems and what effect a flexibilization of hydropower plants could have in the future European power system. The focus is on identifying dynamic loads such as those resulting from providing high ramping rates and frequent start-stop cycles.

In order to achieve this main objective, market simulations to analyse the time interval before physical fulfilment and stability simulations to analyse real-time operations are conducted. The main outcomes of the simulations are:

- There will be only a slightly higher demand for short-term flexibility in the future.

- Electricity generation from PV units in Central Europe has a significant influence on hydropower operation in the Nordics.

- Exchange capacities between the Nordics and Central Europe are usually completely utilized due to high price spreads between the bidding zones.

- Higher flexibility demands are more likely to be expected from the Nordic region itself than from Central Europe.

- Main driver for higher flexibility demands are especially volatile generation plants (e.g. wind turbines) in the Nordics.

- Additional benefit: The technical aging of the individual units of the hydropower parks in the Nordics can be slowed down by a partly flexibilization of the Nordic hydropower.

- Frequency stability is guaranteed for all load and fault situation with respect to the created and considered worst case scenarios.

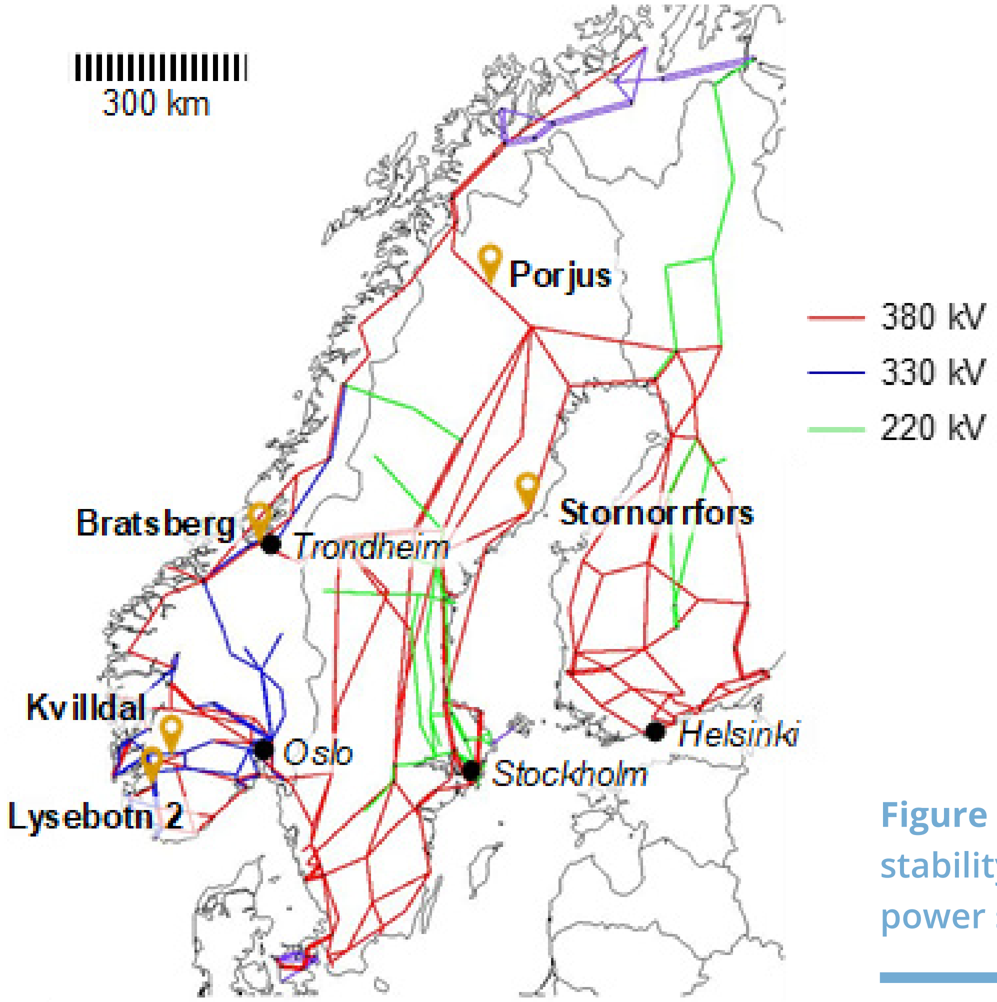


Figure 1. Frequency stability in Nordic power system.

4 | RESEARCHER

XAVIER SÁNCHEZ BOTELLO, UPC

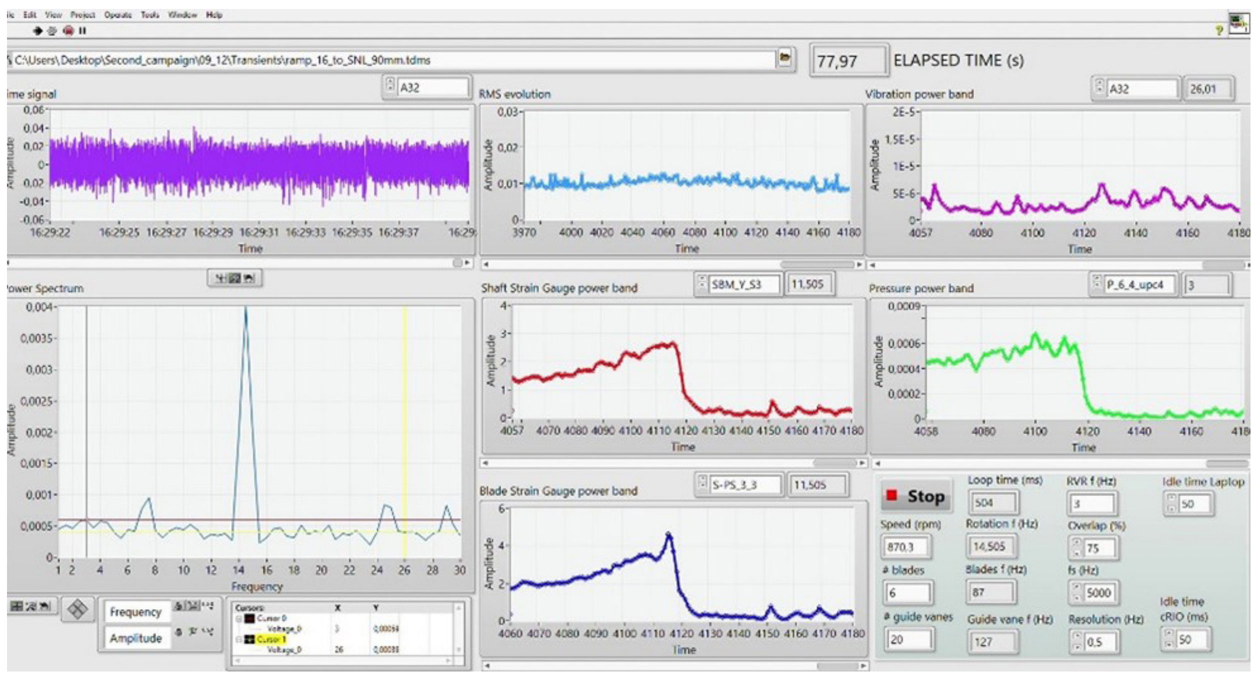
My name is Xavier Sánchez Botello and I hold a double MSc in Industrial Engineering and in Robotics and Automatic Control of the Universitat Politècnica de Catalunya – BarcelonaTech. Currently, I am working for the AFC4Hydro project as a researcher of the IFLUIDS group. In the past, I had already participated in some tasks of WP3 designing and testing a controller to reduce the strain and vibrations of the test rig mounted at the IFLUIDS laboratory. By doing so, I have been able to gain insight on the AFC4Hydro project and work with the UPC team to acquire valuable expertise performing experimental measurements and numerical simulations of fluids, structures and coupled systems. Additionally, I had also designed an acquisition system for a cavitation tunnel, so I am familiarized with different data acquisition systems involving National Instruments (NI) equipment.

In the frame of the WP3, I started working on task 3.3 improving and designing a LabVIEW interface to validate in real time the Structural Health Monitoring system (SHM) under a wide range of operating conditions tested in the reduced scale Kaplan turbine at Älvkarleby. Then, the optimized program has been used in a second measurement campaign to register and monitor in real time the vibration levels of the structure induced by the rotating vortex rope and compute some indicators to feed the controller with this information.

Concretely, with the program we have been able to visualize the temporal evolution of the signals and analyse them in real time by computing their frequency content and tracking the trend of some specifically tailored indicators.

Figure 1 shows the LabVIEW front panel interface in which it can be selected the desired sensor to be monitored and follow the evolutions of the signal temporal evolution, the corresponding power spectrum and the overall RMS value. Additionally, depending on the frequency of the Rotating Vortex Rope (RVR) detected on the power spectrum, the range of frequencies of a narrow band can be adjusted around the RVR peak and calculate the vibration, pressure, blade strain and shaft strain power bands and track their trends.

Figure 1. SHM front panel interface to monitor different indicators of the turbine dynamic response in real time.



I have also participated, in close collaboration with the rest of engineers of the IFLUDS research group, in the analysis of all the collected data during the two measuring campaigns carried out on the model turbine.

Nowadays, we are studying different ways to predict the structural fatigue damage produced by the RVR on the runner blades and shaft, which are based on applying the Rainflow counting algorithm to the strain transducers mounted at different locations of the turbine.

By doing so, we will be able to quantitatively know the beneficial effects that the AFC system with the help of the IPM and ICM subsystems have on the lifetime of the model turbine.

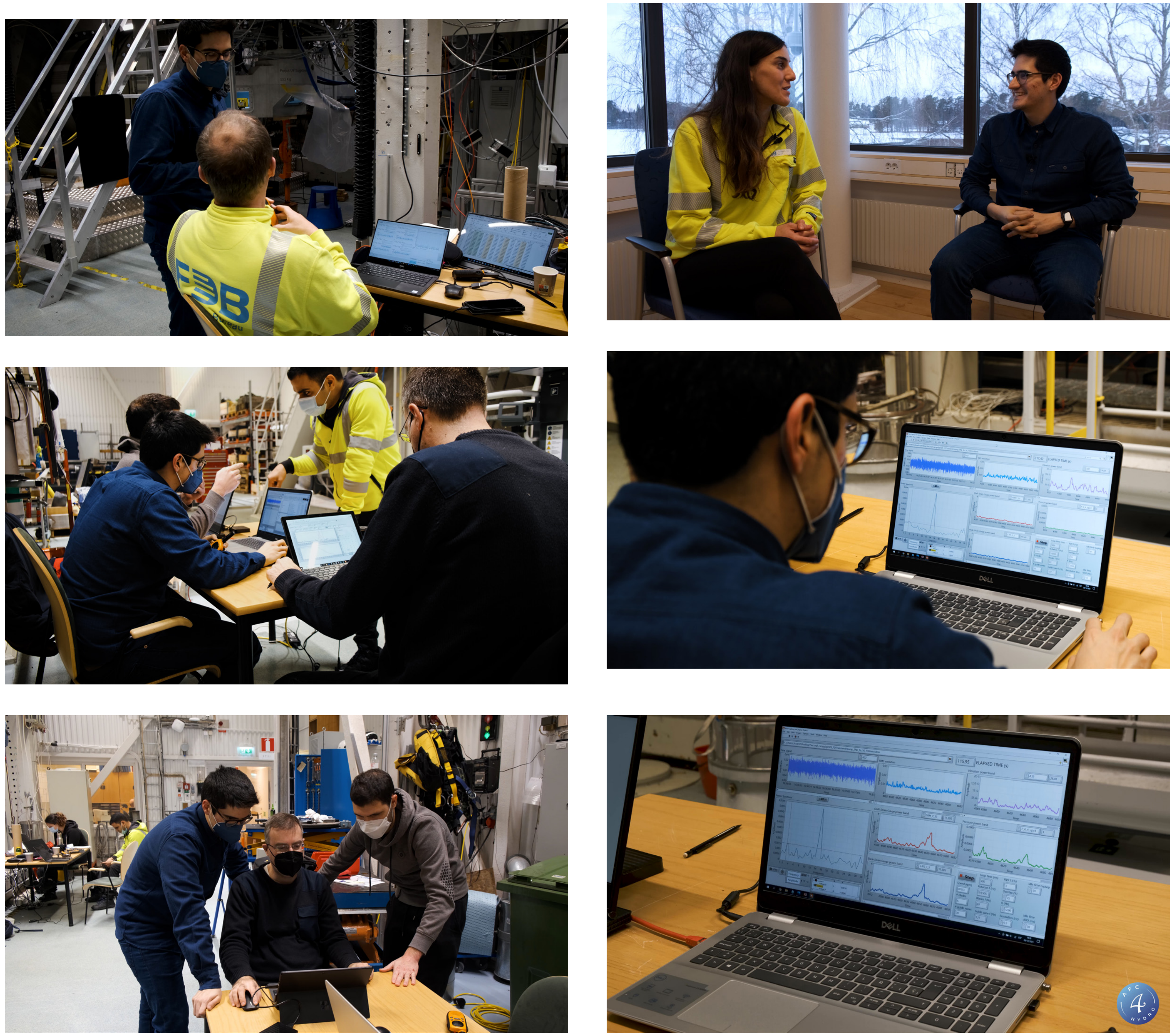


Figure 2. Testing of the Structural Health Monitoring system (SHM) under a wide range of operating conditions in the reduced scale Kaplan turbine at Älvkarleby.

MSc Xavier Sánchez Botello, Universitat Politècnica de Catalunya – BarcelonaTech.

SUMMARY OF RESULTS FROM

5 HYDROFLEX WP3 FLEXIBILITY OF TURBINES

In WP3, we focused on mitigating the key factors that are reducing the flexibility of Francis turbines, i.e., the pressure pulsations and the resulting fatigue damage. Ideally, the flexible operation should allow for a wide and stable operating range, increased off-design efficiency, more start/stops daily, and no significant lifetime reduction.

Dealing with such multi-disciplinary challenge, the hydraulic and mechanical designs of the turbine were prioritized, so one task was to develop a design tool that considers the hydraulic and mechanical performance of the turbine components, in particular the runner and the guide vanes.

Separately from the design tool, a special type of guide vanes in the draft tube were also developed to investigate the possibility to guide the flow downstream the runner.

As a follow-up task, model turbine components such as the runner, the guide vanes, and draft-tube vanes, were designed, manufactured, and tested in the Waterpower Laboratory to confirm their performance and to collect valuable hydraulic and structural data for validation and improvement of the numerical methods that were used in the design tool.

One last task was to develop methods and tools for lifetime estimation due to fatigue loads. In this task, fatigue S-N curves were measured for various test specimens made from typical turbine steel.

This tool can perform the necessary calculations using transient stress/strain data from either numerical simulations or on-site strain gauge measurements.

All these results and developments have their specific value and importance in addressing the future needs of increased flexibility of hydropower plants.

Figure 1. New design of the draft tube vanes (a) and runner blade (b).

Figure 1. (a)

Figure 1. (b)

RECENT UPGRADES IN THE LTU TEST RIG AT ÄLVKARLEBY

The small-scale test rig at LTU, built at a 1:15.5 scale of the U9 prototype, has been in operation since autumn 2020.

We have used the test rig a lot for developing the IPM system says Joel Sundström from LTU.
Since the test rig is very small, we can quickly modify it if we want to test a new strategy, and in addition, the worst thing that can happen if something unintended happens is that we spill some water on the floor.
We have also performed particle image velocimetry measurements (PIV) at part-load operation in order to characterize the rotating vortex rope (RVR).
These measurements were conducted in collaboration with the Swedish hydropower centre (SVC), and besides being useful for RVR characterization, they served as a practicing test case for upcoming PIV measurements to be performed by SVC at Vattenfall's test stand in Älvkarleby. Besides research studies, a number of master's thesis projects have been conducted in the test rig as well.

During winter 2022, a master's student developed a program to automate the measurement procedure, and the goal is to integrate that work into a PLC system that will be installed during spring 2022.

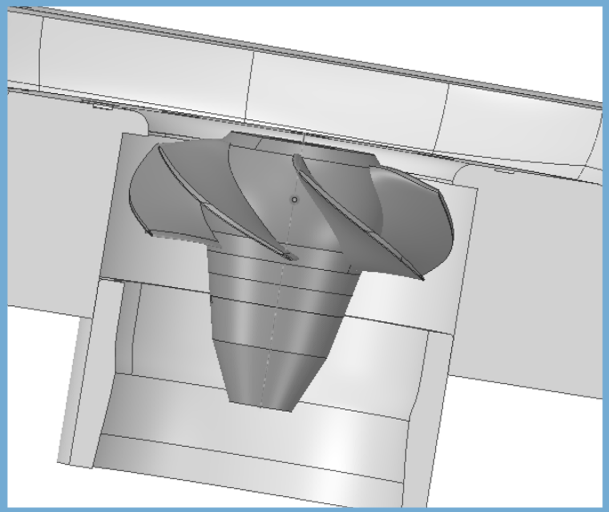
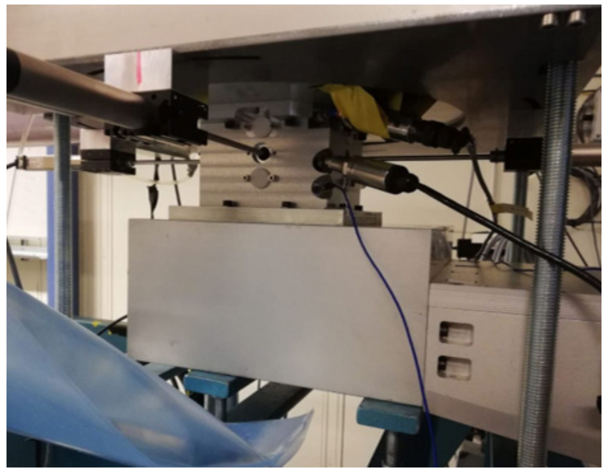
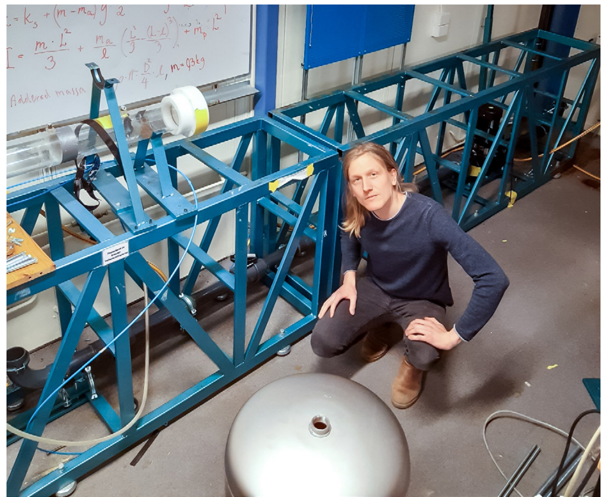


Figure 1. 3D Model of the LTU Test Rig Runner Blades.

Since commissioning, the test rig has undergone various upgrades to improve its performance. Owing to small inertia of the rotating system, we found that the turbine was susceptible to RPM variations. The remedy to these variations was to install a flywheel on the turbine shaft, thus increasing the inertia of the rotating system with a net effect of stabilizing the turbine RPM. We also integrated a new RPM measurement system into the flywheel to further improve the RPM control. During our initial studies, we also realized that the way we estimated the turbine torque, namely through the control signal to the RPM controller, was not accurate enough so we decided to install a rotating torque sensor on the turbine shaft.

Figure 2. LTU test-rig.
Figure 3. First assembling in 2020.





In the beginning of 2022, a leakage from one guide vane shaft was observed. Fixing the leakage required quite a large effort and it was therefore decided to combine the guide vane maintenance work with a few other major upgrades. In addition to re-designing the guide vane sealing system, we decided to modify the runner chamber and the turbine shaft-to-runner connection. In its original design, the runner chamber was integrated into the spiral casing, which resulted in an excessive clearance between the runner and chamber to facilitate mounting of the turbine runner.
After upgrade, the runner chamber has been manufactured as a socket that can be mounted in the spiral casing after the runner, thus resulting in a smaller tip clearance. We hope that these modifications lead to an even more stable and repeatable RVR.

When the turbine is up and running again, we aim at continuing our IPM studies and a development of our experimental program is that we will perform velocity measurements while we run the IPM system. By measuring the velocity while mitigating the RVR, we hope to gain further understanding on how the IPM rods affect the RVR, and why this leads to mitigation. 2022 has potential to be a very interesting year for the LTU test rig, because in addition to the planned IPM studies, the intention is to perform ICM studies as well Joel Sundström finishes.

Joel Sundström,
Postdoctoral
Researcher, LTU

SUMMARY OF RESULTS FROM

7 | HYDROFLEX

WP4 FLEXIBILITY OF GENERATOR AND CONVERTER

WP4 started with the ambition to *"Develop new power station electrical layouts, generator rotor, magnetization systems and power electronic converters and control for increased flexibility and strong grid support"*.

In this quest we have investigated the electrical components in a variable speed unit and how they should be controlled.
Different topologies of the converter have been studied and losses play a vital part in the design. Inside the generator the insulation will have to be enhanced when operating a converter driven unit.

There is also a possibility to simplify the construction and increase the efficiency of the generator using modern power electronics to control the field current more actively and faster compared to present methods.

Variable speed operation opens up for enhanced system services from Hydropower units and the addition of speed as control parameter means that more benign ways to start and operate pumped hydropower storage both in generating and pumping mode is possible.

Did we get to fulfill the ambition? We are happy to say that the project delivered on the ambitious goals formulated 5 years ago. Hydroflex is an arrow pointing giving guidance for the future hydropower and we have built a foundation of knowledge and competent people upon which giants will stand.

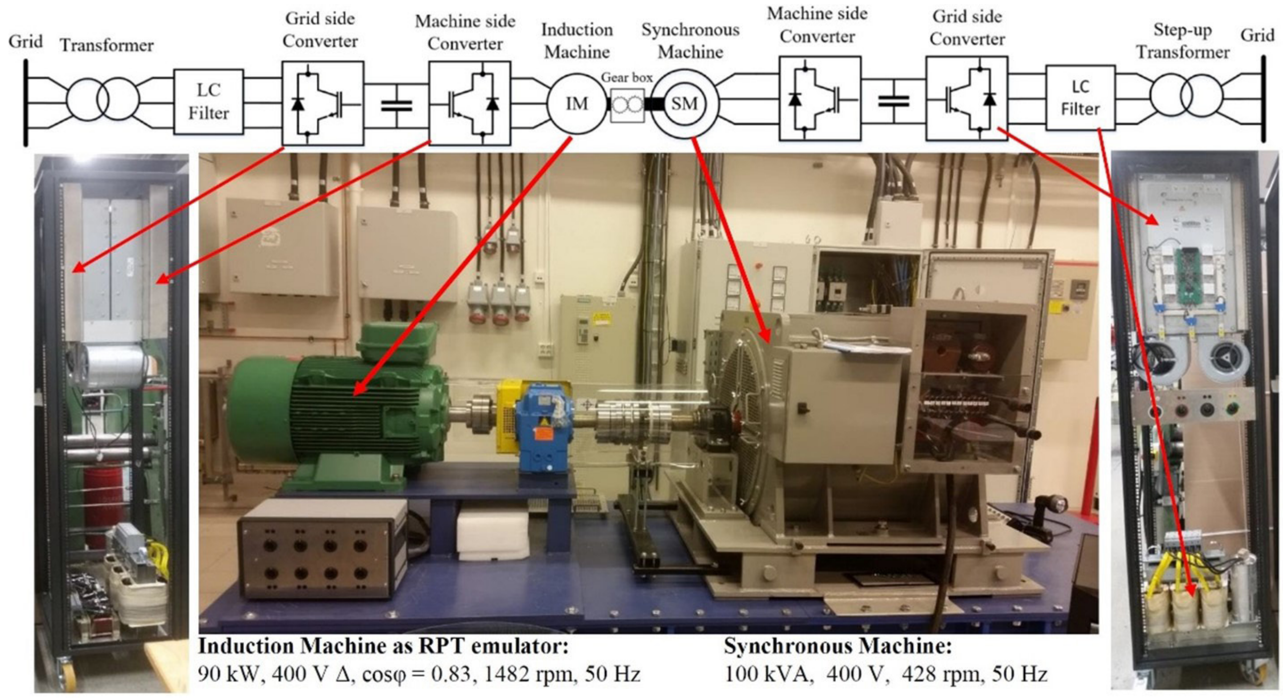


Figure 1. New power station electrical layout.

SUMMARY OF RESULTS FROM

8 | HYDROFLEX

WP5 SOCIAL ACCEPTANCE AND MITIGATION OF ENVIRONMENTAL IMPACT

In the WP5 the final river stretches of Nidelva and Ume älv were in focus. Regarding ecological flows there are two distinct features that separates these rivers. The averaged flow rate is 450 m3/s in Ume älv and 94 m3/s in Nidelva. In Nidelva there are rapids down-stream the last power-station while in most of the final river stretch of Ume älv the water level is set by the sea level. Hence in Ume älv also a fish migration bypass (the old riverbed) was studied.

Main results for Nidelva are that the ACUR technology can decouple the production flow and the discharge to the river, increasing operational flexibility while still providing the required environmental flow. The operation plan and outflow hydrograph shapes can be optimised. The model Ib salmon facilitates modeling population dynamics of Atlantic salmon in rivers, however, to increase the spatial resolution to investigate stranding mortality, a new model have been developed. Such a refined flow-fish model can give more accurate input to ACUR and will be presented as open source.

Main result for Ume älv is that the ACUR technology is, at this stage, less suitable for the Stornorrfors hydropower plant mainly due to the large discharges. Studies of the flow in the old riverbed shows that natural damping can be effective. Also, increasing the hydropeaking frequency causes a reduction in potential spawning area, but on the other side the increase in frequency reduces dewatering of potential spawning area at low flows. Down-stream Stornorrfors, flexibility may affect fish migration rather than habitat and may also affect other species. Public is generally positive but have some concerns about flexible hydropower.

Fig 1. (left) Nidelva, (right) Ume älv.

AFC4HYDRO ACTIVITIES

NEW VIDEO

FROM TESTING AT VATTENFALL CENTER

Testing the Active Flow Control System on a turbine model

From September to December 2021 the first joint test campaign of the AFC4Hydro project took place at the Vattenfall Research and Development center, in Älvkarleby, Sweden, where we got to test our Active Flow Control System on a turbine model.

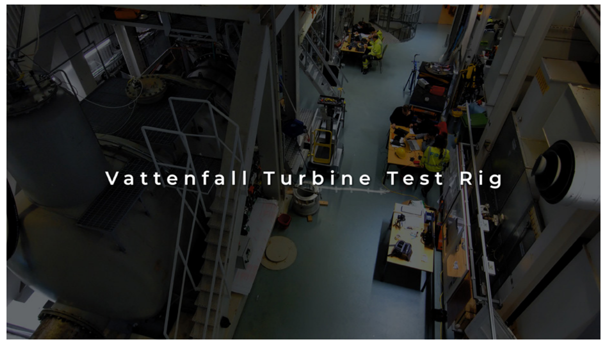
The whole process has been documented and a video with interviews has also been recorded, for all of you to watch! Here AFC4Hydro members from LTU, FDB, UPC and VATTENFALL talk about they experience in Älvkarleby and discuss some of the results they achieve during this measuring campaign.

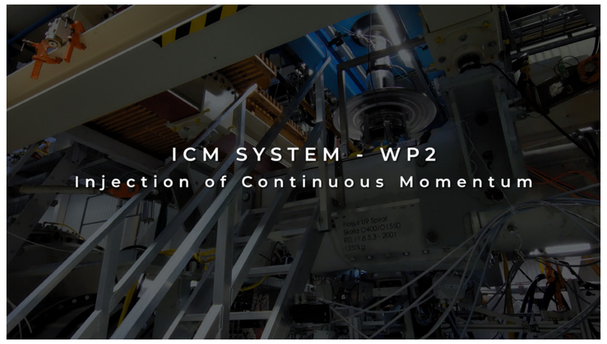
Check out the entire video here!

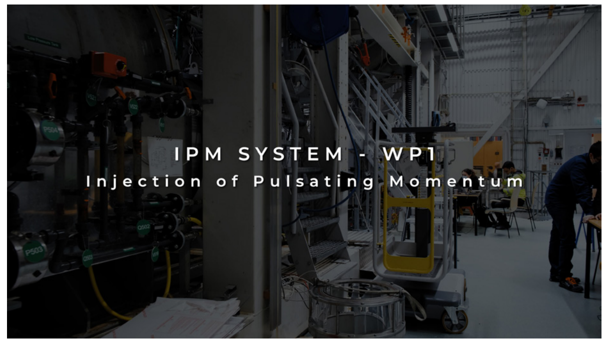
In the video the following people were interviewed:

- Carl Maikel, Vattenfall AB, R&B
- Shahab Shiraghaee, LTU, PhD student
- Alessia Fabbri, LTU, researcher
- Morten Kjeldsen, FDB, WP2 leader
- Xavier Escaler, UPC, WP6 leader
- Rafel Roig Bauzà, UPC, PhD student
- Xavier Sánchez Botello, UPC, researcher

Filming and editing were provided by Claudia Pia, FDB, WP5 leader.







Claudia Pia,
WP5 leader
FDB

HYDROFLEX ACTIVITIES

10 | 4TH PUBLIC WORKSHOP

The fourth HydroFlex workshop took place on March 23, 2022 in Trondheim, Norway and was arranged by NTNU.
The overall question raised in the workshop was:

The role of flexible hydropower in the future energy system?

The aim of HydroFlex project is to increase the value of hydro power through increased Flexibility. In this public workshop, organized in conjunction to the last plenary meeting of the project, some of the key results from the project were presented:

• How flexible can a Francis turbine be operated?
• How to increase flexibility of the generator?
• Can we analyse and understand the trade-off between increased flexibility and environmental impact?
• And what is the public acceptance for more flexible operation?

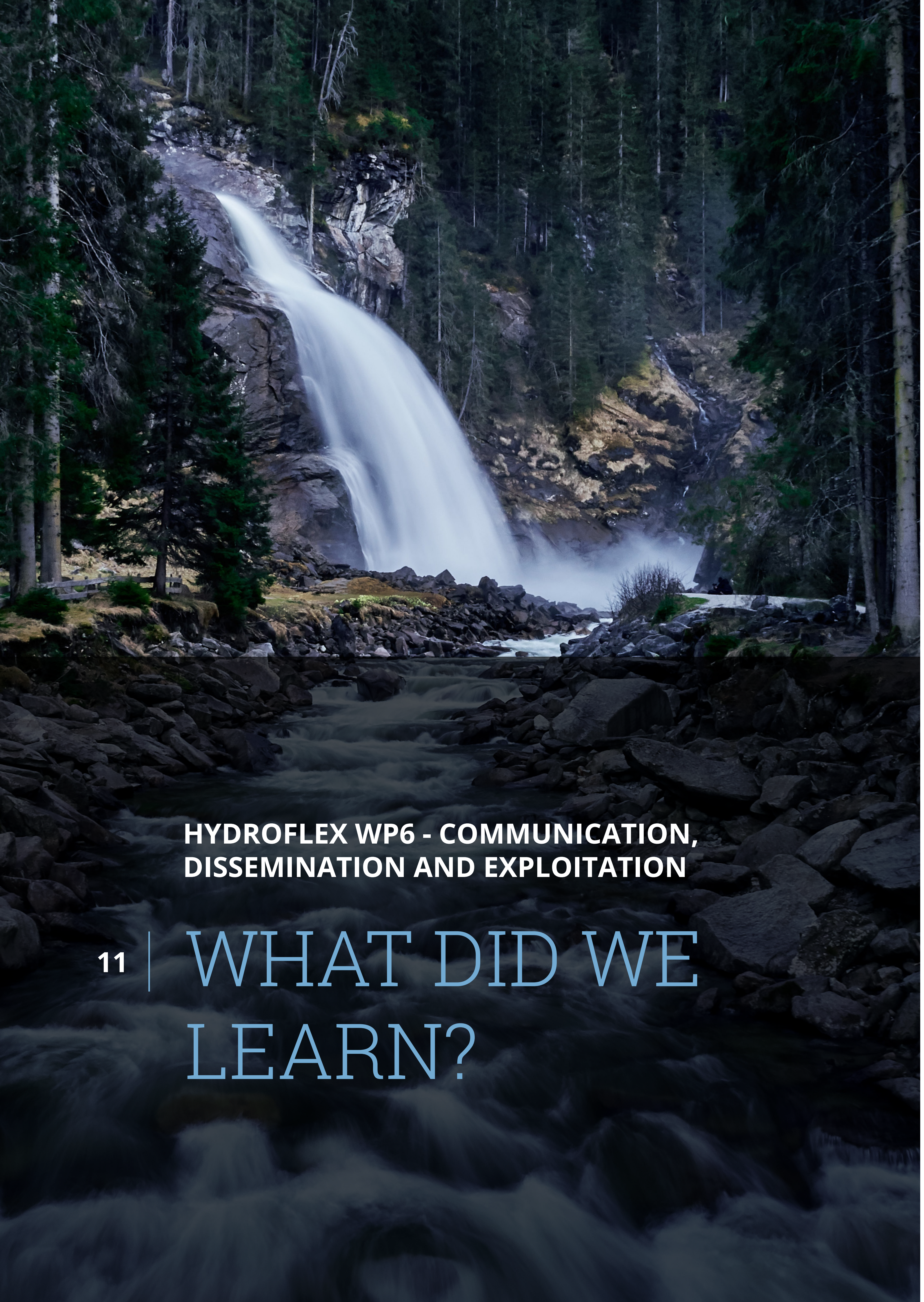
After a winter with unprecedented price peaks and high volatility, the question of the role of highly flexible hydropower is more pertinent than ever.

Time	Title	Presenter
09:00	Welcome physical and digital participants	Ole Gunnar Dahlhaug
09:15	Presentation of HydroFlex project	Ole Gunnar Dahlhaug (NTNU)
09:25	Hydropower in the European energy system: Future flexibility requirements (WP2)	Peter Wirtz (RWTH Aachen University)
10:30	Increasing Flexibility of Francis Turbines (WP3)	Igor Iliev (SINTEF)
11:00	Converter controlled synchronous machines, overcoming challenges in generators to switches (WP4)	Urban Lundin (Uppsala University)
11:40	Mitigation of environmental impact from flexible hydropower (WP5)	Staffan Lundström (Luleå University of Technology)
12:10	To flex or not to flex? – that is the question (WP6)	Multiconsult
12:35	Panel discussion	
13:50	Closing remarks from Project Officer	Sebastien Mortier
14:00	Closing remarks from Project Coordinator	Ole Gunnar Dahlhaug
14:10	End of program	

Figure 1. Panel Discussion. Photo: Shreejana Poudyal. From Left: Igor Iliev (SINTEF), Liv Randi Hultgreen (HydroCen), Urban Lundin (UU), Ole Gunnar Dahlhaug (NTNU), Peter Wirtz (RWTH Aachen), Staffan Lundström (LTU), Mats Billstein (Vattenfall), Bjarne Børressen (Multiconsult)

Figure 2. Program of the workshop

Check out the recordings of the public workshop here!



HYDROFLEX WP6 - COMMUNICATION, DISSEMINATION AND EXPLOITATION

11

WHAT DID WE LEARN?

As a European research project, the core task of HydroFlex is research. In work package 6, Communication, Dissemination and Exploitation, there are no research activities.

Traditionally research is communicated through peer reviewed publications. This is important to ensure independent validation of the results.

The research topics of HydroFlex are close to practical application and the energy industry needs to be aware of the results.
Industry is not always cognizant of what is published in scientific journals. Thus, it is important to communicate the results through other channels.

In the HydroFlex project we have utilized everything from social media, webpage, business venues, online events, public workshops, and popularized articles. In collaboration with Upsala University we also organized a short training course for PhD students and post docs engaged in the project on “How to popularize your research”. Through these efforts we are proud to have reached thousands of potential users of the research, from all continents in the world.

Nevertheless, the conclusion remains that you can always do more to communicate the research results and potential application and impacts for the power system to a wider community. Only when the research is exploited in practical applications can we truly say that we have been successful.

Fig 1. HydroFlex Workshop, 23 March 2022, Clarion Hotel, Trondheim. Foto: Maren Agdestein, NTNU.

THANK YOU

EUROPEAN COUNCIL

NTNU

UPC

UPPSALA UNIVERSITET

CHALMERS UNIVERSITY OF TECHNOLOGY

SPV

LULEÅ UNIVERSITY OF TECHNOLOGY

FDB Flow Design Bureau

SINTEF

RAINPOWER

University of Strathclyde Glasgow

Lyse

NINA Norwegian Institute for Nature Research

VATTENFALL

Statkraft

Multiconsult

ABB

EDR MEDESO

IAEW Institute of Power Systems and Power Economics

RWTH AACHEN UNIVERSITY