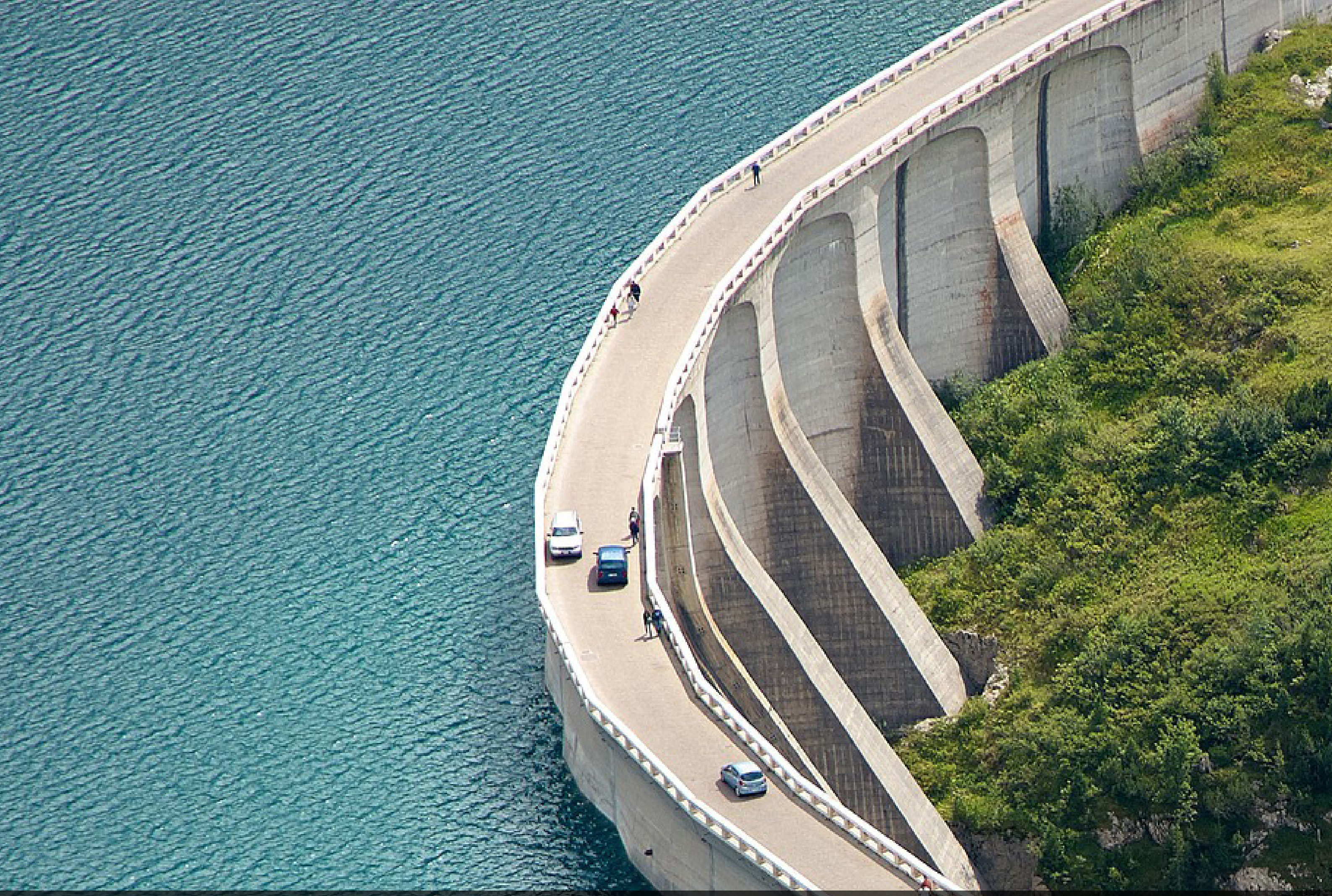
2021 NEWSLETTER
ALPHEUS PROJECT

ALPHEUS

communication@alpheus-h2020.eu



INTRODUCTION TO
ALPHEUS PROJECT

ALPHEUS is a €5m project funded by the European Union's Horizon 2020 program. It will improve reversible pump/turbine (RPT) technology and adjacent civil structures needed to make pumped hydro storage economically viable in shallow seas and coastal environments with flat topography.

Three promising technologies will be considered: shaft-driven variable-speed contra-rotating propeller RPT – avoiding guide vanes in a two-way device improves overall efficiency, rim-driven variable-speed contra-rotating propeller RPT – rim driven configuration avoids the complexity of a shaft assembly, decreasing noise, vibrations, switching time, and maintenance costs, positive displacement RPT – fish friendly and seawater-robust, low cost technology.

WELCOME FROM
THE CHAIRPERSON OF ALPHEUS' EXTERNAL ADVISORY BOARD

It is my pleasure to introduce the first Newsletter of the ALPHEUS research project – an EU Horizon 2020 program funded project – to you.

The project's intention is to optimize the reversible pump / turbine technology and to adapt the adjacent civil structure to rather flat coastal areas. It is common understanding that the high increase of intermittent renewables in connection with the agreed energy transition towards a zero-carbon energy sector challenges the grid stability. Hydro storage capacity and in particular pumped storage hydropower will play an essential role in this context. The project wants to contribute to the grid stability by improving a pump / turbine technology in view of its use in other sites than mountainous regions.

Get inspired by insight glances into the work of a multi – national research consortium with partners from the scientific community and the industry. I hope you enjoy reading this Newsletter.

Sincerely Yours,
Bettina Geisseler, GEISSELER LAW / Germany, Chairman of the External Advisory Board

11 PARTNERS
FOR ACHIEVING THE PROJECT

Collaboration amoung partners ensures the smooth running of the project. We make targeted use of the expertise of our partners in order to achieve the ALPHEUS project.

The ALPHEUS team is composed of the following partners.

Advanced Design Technology

CHALMERS UNIVERSITY OF TECHNOLOGY

UNESCO IHE DELFT

NTNU Norwegian University of Science and Technology

Technische Universität Braunschweig

TU Delft

Università degli Studi della Tuscia

University of Stuttgart Germany

Université de Pau et des Pays de l'Adour

Uppsala Universitet

Ghent University

DESIGN OF THE
PUMP / TURBINE MODEL

The counter-rotating pump-turbine under development in ALPHEUS is of axial type, which is more suitable for low-head applications. It has no guide vanes, but instead there are two counter-rotating runners that interact to give the best possible conditions at all time.

As the difference in elevation of the water levels at each side of the power plant changes, at the same time as the need of electric power varies, the rotational speeds of each of the runners can be set individually to meet the needs under the present conditions at optimal efficiency. The runner blades are designed to work efficiently with flow in both directions, either pumping water to the elevated reservoir or extracting energy from the flow in pump mode. It is based on a concept that is used in marine applications, and experiences, materials and components from those applications can be used also in the application of the developed pump-turbine in sea-water conditions.

What is great about the pump / turbine the ALPHEUS project is developing? In order to find a fish friendly configuration for the ALPHEUS project, a low rotation speed machine was considered as a latent solution. That is why a positive displacement machine such as the lobe pump-turbine was considered a potential option for low-head applications.

Plus, unlike dynamic pumps, a PD machines can maintain nearly constant flow rate and efficiency regardless of significant changes in pressure.

What tools do you use to design the pump / turbine? The design is developed using a set of numerical tools. ADT has designed and optimized the initial model scale prototype of both the shaft driven and rim driven contra rotating propeller RPT for the ALPHEUS project. ADTs inhouse software TURBOdesign Suite served as the design tool for the design and optimization of the initial prototype. Meanline design is performed using ADT's TURBOdesign Pre software. The blade design is carried out using TURBOdesign1 which is a unique software utilizing a 3D inverse design methodology.

Design evaluation is performed using CFD analysis, Ansys Turbogrid was used for meshing and Ansys CFXwas used as the solver. The optimization method of the model scale prototype involved a Design of Experiments method for the shaft driven RPT.

A workflow is created in Ansys Workbench to obtain a design matrix with various design variations are generated and CFD evaluation results of each design. Blade designs are generated using

TURBOdesign 1 which is integrated with Ansys Workbench through ADT's TURBOdesign Link Workbench software. A surrogate model based approximation of the generated data and optimization using Multi-objective Genetic Algorithm was performed using Dassault Systemes Isight software. Final optimized designs are generated using TURBOdesign 1, based on the design parameter values obtained as a result of optimization and evaluated in CFD.

For the rim driven design, optimization is performed based on manual design iterations involving blade designs using TURBOdesign 1 followed by CFD analysis using Ansys CFX. FEA analysis of the various designs are performed using Ansys Workbench.

How will the design be implemented in the lab and in real life? The machine will be manufactured in lab-scale, for tests of a wide range of operating conditions at Chalmers. The experimental results will be used to validate the numerical results at NTNU, so that the numerical results can be trusted for investigations that are not feasible in the lab. Up-scaling to prototype scale will be done numerically, yielding results that are to be expected in real life application of the machine. The outcome of the project will give important input to future manufacturers of counter-rotating pump-turbines for low-head sea-water applications. It shall inspire manufactures and encourage them to invest in this new energy storage solution.

ABOUT THE AUTHORS

Professor Håkan Nilsson, Chalmers University of Technology, has been doing research on CFD for hydropower applications since 1997, together with 7 PhD students, 5 post-docs, and a number of master thesis students. In the ALPHEUS project, he is mainly responsible for numerical studies of transient operation of the novel counter-rotating pump-turbine concepts, together with PhD student Jonathan Fahlbeck.

Pål-Tore Storli is an Associate Professor at the Waterpower laboratory at the Norwegian University of Science and Technology. He is the leader of Workpackage 2 – Turbine Design, and directly involved in the part concerning the Positive Displacement machine that's being investigated for energy storage applications.

Luiz Henrique Accorsi Gans holds a double degree in Mechanical Engineering. With 5 years of previous experiences in CAE (CFD and FEA), Luiz is now a PhD candidate at the Norwegian University of Science and Technology and is part of the Work Package 2 – Turbine Design on the ALPHEUS project. He is responsible for the CFD simulations and design optimization of Positive Displacement RPT.

Professor Mehrdad Zangeneh is founder and managing director of Advanced Design Technology and Professor of Thermofluids at University College London. His research interests cover development of computational design methods based on 3D Inverse Design and automatic optimization to a variety of turbomachinery applications. He is also involved in WP 2 – Turbine Design.

Melvin Joseph is working as a Turbomachinery Design Engineer at ADT, where he designs different kinds of turbomachinery for various customers worldwide. He graduated in 2014 with an Aerospace Propulsion specialization. In the ALPHEUS project, he is involved in the hydraulic design and optimization of model axial CR RPT and upscaling to full scale prototype as part of WP2 (Turbine design).

WHAT YOU NEED TO KNOW ABOUT **ALPHEUS PROJECT**

What components does the ALPHEUS project consist of? Like traditional hydropower, the ALPHEUS project consists of something to generate the water elevation difference (dam and penstocks), a pump / turbine, a motor / generator, and electrical equipment to interface between the motor / generator and the power grid. Based on market analysis, the requirement for electricity grid stabilization at a location close by solar or wind power generation offshore, envisaged for an extended time period (decennia) starting 5-10 years from now. Business model also showed a sound ROI and an attractive public profile in comparison with alternative solutions. A pre-feasibility report covering technical, economical, environmental, legislative and conceptual designs, soil material balance, pump / turbine technology options, dam safety and stability assessment, grid connection description. Economical: cost of construction (CAPEX), operation and maintenance cost (OPEX), production capacity, RoI. Environmental: EIA, Flood safety assessment. Legislative: permitting possibility. Financing: availability of investors offering LT low interest rates.

Where can the ALPHEUS project be built? The ALPHEUS project can be built in a shallow sea or lake, where water is plentiful, but where no natural topography (such as cliffs or dunes) exists to facilitate traditional pumped hydro storage: offshore at water depths of 10-20 m where soil and wave conditions match requirements and where spatial planning is possible.

The economic feasibility of the ALPHEUS project depends on the water depth present, and research in WP5 currently focuses on assessing that economic feasibility.

What obstacles does the ALPHEUS project face? Financing and permitting are likely to be large obstacles. As with all hydropower and other large infrastructure projects, the ALPHEUS project has large upfront capital costs, with a long payback period. This makes private investment difficult to obtain, and would do well with government investment or guaranteed electricity tariffs so that private investors would have enough confidence to invest. Another obstacle is permitting, especially with regards to fish mortality. Fish screens will be necessary.

ABOUT THE AUTHORS

With 40 years of work experience in the water sector, **J.R. (Roelof) Moll** from Delft University of Technology is the executive project manager who leads the ALPHEUS team in close cooperation with the Technical Committee, The Steering Committee and the Advisory Board.

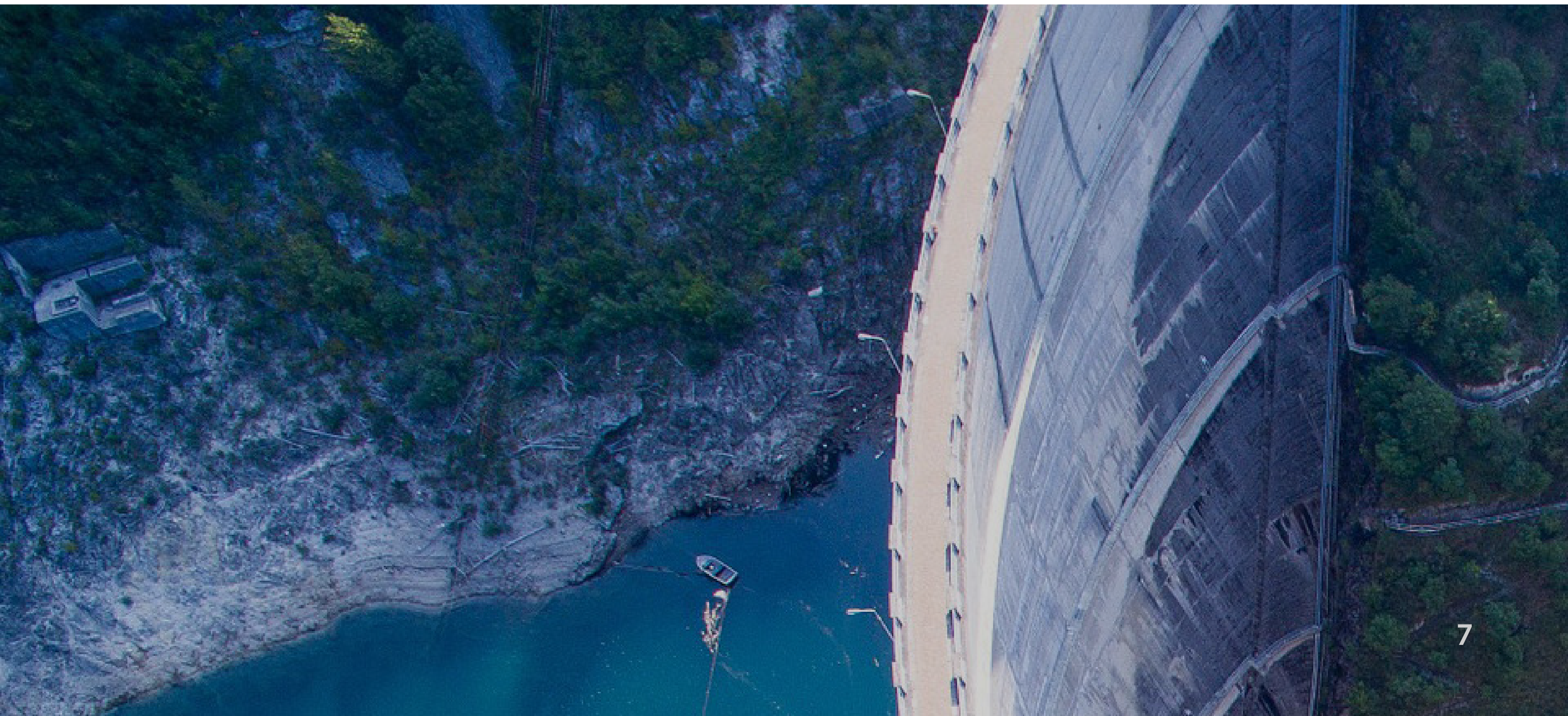
Jeremy Bricker, from Delft University of Technology, is the scientific coordinator of ALPHEUS, he keeps track of the mechanical, electrical, and civil engineering components of the project to make sure that everything fits together smoothly.

WHY DOES THE ELECTRICITY GRID **NEED ALPHEUS?**

The pan-European power grid is experiencing a rapid upheaval in the nature of its energy supply side. An ever-increasing penetration of Variable Renewable Energy (VRE), such as wind and solar energy, pose new challenges regarding the grid stability and security of supply. Without further measures, the fluctuating and non-dispatchable nature of these VRE would turn them, in most of the cases, unsuitable for providing the ancillary services (AS) needed for ensuring a safe and reliable operation of the power system.

Today's supply infrastructure is reliant on rotating synchronous generators which play a fundamental role in ensuring the transient stability of the power system. By means of their rotating inertial mass, they inherently provide inertia to the grid. In case of sudden frequency mass to maintain rotational speed is significantly contributing to stabilising the system. However, as the modern power grid is gravitating towards a converter-dominated system, these must also be able to replicate this characteristic, by means of a "synthetic inertia".

While energy storage systems are capable of significantly satisfying the high demand for synthetic inertia, their ability to offset the intermittency of renewable energy sources is turning them into a key technology for the power grid of the future. Among the different energy storage technologies, Pumped Hydro Storage (PHS) can be identified as particularly convenient, given its cost-effective implementation and considerable lifespan, in comparison to other technologies. Europe ranks second worldwide in installed hydro power capacity, only after Asia, thus underscoring the vast application field of using low-head PHS as a means of stabilising the system.



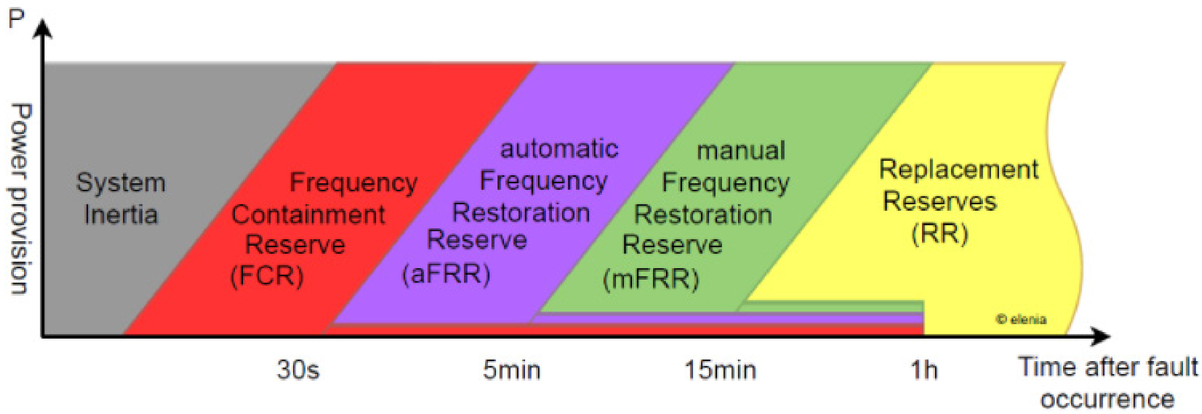


Fig. 1. The typical frequency control measures in the European Network of Transmission System Operators for Electricity (ENTSO-E) area.

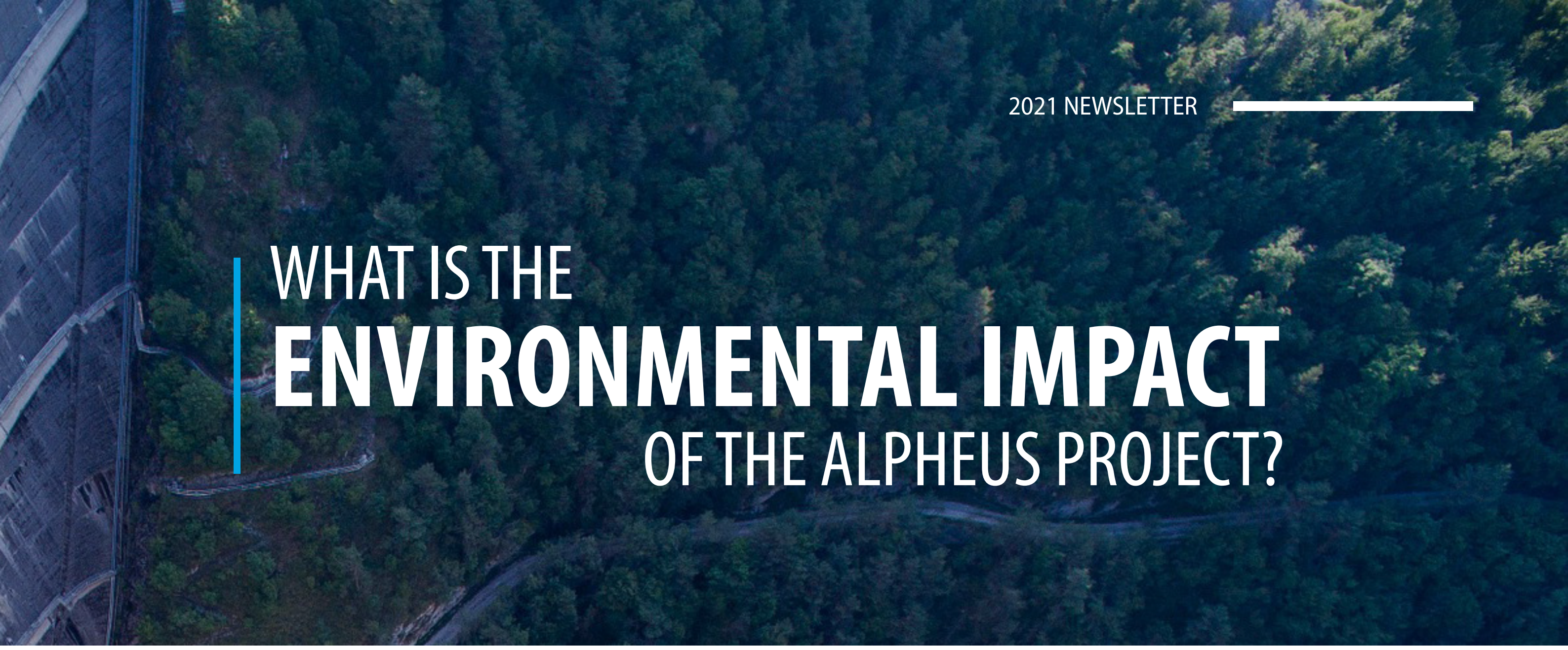
PHS is based on storing energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation, which makes this technology only available provided suitable topographic conditions. The EU-funded ALPHEUS project (Augmenting Grid Stability Through low-head Pumped Hydro Energy Utilization and Storage) will improve reversible pump / turbine (RPT) technology and adjacent civil structures needed to make PHS economically viable in shallow seas and coastal environments with flat topography. This RPT will be coupled with a Grid-forming controlled converter, which can control voltage and frequency. Thus, contributing to stabilising the power grid.

In order to maintain stable system frequency, the frequency control consists of sequential balancing reserves within a definite time frame, the typical frequency control measures nowadays in the European Network of Transmission System Operators for Electricity (ENTSO-E) area are as shown in **Fig. 1**. The system inertia in **Fig. 1** in today's grid from the directly-coupled synchronous generators could be replaced by introducing a new operating reserve "synthetic system inertia" (from inverters / storage) and fFCR from the low-head PHS system developed in ALPHEUS to equalize the power difference until frequency containment reserves (FCR) is activated. For this reason, a grid-forming-converter coupled with the low-head PHS system developed in ALPHEUS could significantly contribute to stabilising the grid stability by providing different AS, especially frequency control through the provision of synthetic system inertia, as well as fast frequency containment reserves (fFCR).

ABOUT THE AUTHORS

Bernd Engel is a Professor in the field of Components of Sustainable Power Systems at TU Braunschweig, Germany since 2011. As a board member of various committees forming future national standards, he contributes his expertise in the field of grid integration to the project. He is the leader of the work package 6 "Grid Integration" of the ALPHEUS project.

Mohammed Qudaih is a research associate in elenia Institute for High Voltage Technology and Power Systems at TU Braunschweig, Germany. His research include active distribution grid, electric grid dynamics and stability. He is working on work package 6 "Grid Integration" of the ALPHEUS project.



WHAT IS THE ENVIRONMENTAL IMPACT OF THE ALPHEUS PROJECT?

Hydropower applications pose a series of environmental impacts on ecologically sensitive areas, and for this reason require careful site planning. The study of environmental aspects (siting and land use) is paramount in ALPHEUS and ALPHEUS-like projects.

The Marine Strategy Framework Directive (MSFD) imposes the monitoring and the assessment of European marine waters quality against 11 qualitative descriptors for the achievement of a Good Ecological Status (GES).

Hydro pump plants affect: water quality such as turbidity and alteration in sediment transport (which is evaluated by MSFD descriptors "D6 Seafloor integrity", "D7 Hydrographical conditions" and "D8 Contaminants"), aquatic ecology e.g., friendliness to biota and loss of nearshore habitats (MSFD descriptors "D1 Biological diversity" and "D3 Commercial fish and shellfish") and may induce physical alterations (MSFD descriptor "D11 Energy and marine noise").

In the planning and construction phases of new pumped hydro plants, only sites where impacts can be mitigated to acceptable levels are selected; mitigation may be achieved by scaling down or relocating the project site as well as by applying additional measures to reduce the impacts either at the source or at the receptor.

How does the ALPHEUS project affect fish? Fish passing through operating hydropower turbines can be subject to lethal injuries due to collision, rapid decompression and shear stress (which may also include turbulence), resulting either in immediate or delayed mortality.

Delayed mortality may also occur as a result of non-lethal injuries and elevated stress levels.

Indirect turbine impacts consist in higher susceptibility to diseases, increased predation and adversely affected behavior (e.g. disorientation) and are potentially negative effects that fish are more likely to experience downstream hydropower installation. Both direct and indirect effects ultimately result in ecologically significant impacts to natural fish populations and, in case of long-distance migrators (e.g. salmon, eel), the disruption of migrating patterns for feeding or reproductive purposes.

How can fish be protected from the ALPHEUS project? Hydropower impacts on local and migratory fish may be primarily mitigated by designing so-called fish-friendly turbines, which differ from conventional turbines in terms of turbine speed and operating scheme, number and geometry of blades and reduced gaps between rotating and stationary components, and by installing / building fish protection screens / fishways, which allow the bypass of hydroelectric plants or dams.

Hydropower-related impacts are usually assessed in terms of survival and injury rates using a variety of approaches such as netting / electrofishing seasonal surveys, mathematical modelling, underwater cameras and sensor fish, radio tagging and recapture techniques, and acoustic telemetry. Within ALPHEUS, we also suggested that proxies of acute stress be evaluated to clarify the role of hydropower plants on the physiological status of fish. All the above methods must first be calibrated based on conditions of minimal anthropogenic impact pre-installation.

ABOUT THE AUTHORS

Giuseppe Scapigliati is Full Professor of zoology and Cellular and Molecular Biology of Animal cell since 2011 - Università della Tuscia. His research is centered on the fields of evolutionary biology, comparative immunology, animal physiology, cell biology and biotechnologies. Within ALPHEUS, he is implementing tasks 2.5 (Fish survival parameters) and 4.4 (Monitoring of fish mortality, stress levels and behavior) of WP 5 (Civil Structure Design).

Marco Marcelli, Università della Tuscia, is an Associate Professor of Biological Oceanography , applied oceanography and applied ecology since 1999 and coordinates the research activities of the Laboratory of Experimental Oceanology and Marine Ecology. His research is centered on the study of coastal and pelagic marine ecosystems and mainly concerns. His role in ALPHEUS is to supervise task 2.5 and to actively implement all tasks of WP 5.

Andrea Miccoli is a fixed term researcher in Zoology since January 2019 - Università della Tuscia. He obtained his PhD in Marine Biology and Ecology in 2017. His current lines of applied research are mainly centered on animal physiology and comparative immunology. Within ALPHEUS, he acts as the principal investigator for Tuscia University and is personally involved in the implementation of tasks 2.5 and 4.4.

Antonio De Luca is a PhD student in Science, Technology and Biotechnology for Sustainability since February 2021 - Università della Tuscia. His PhD activities and research within ALPHEUS are focused on the implementation of tasks 2.5, 4.4, 5.4 (Assessment of environmental issues for the commissioning of low-head hydropower plants) and contribution to task 5.5 (Geographical Information System Tool as a knowledge base for users and stakeholders).

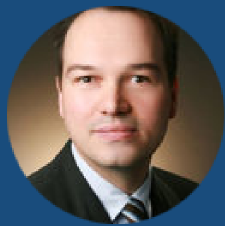
WHAT CHALLENGES DO YOU FACE **IN BUILDING THE ALPHEUS** PUMP / TURBINE MODEL?

One of the biggest challenges during the mechanical design of the pump / turbine was to combine the wishes and goals of the consortium with the manufacturing and mechanical limitations. At the largest operating points of the design, very large torques are generated compared to the size of the design. The transmission of the torque through the bevel gears represents the most critical point. The space available at this point is particularly small, since all components must not be larger than the body of the runner. Due to their operating principle, the bevel gears require a particularly large amount of space. This trade-off between size and torque was a particular challenge during the design process. In order to cover both aspects, special solutions and approaches were necessary, in which IFAS could and had to contribute its many years of experience in the field of prototype engineering. Furthermore, not only manufacturability but also the assembly had to be considered during the design. Due to the limited installation space and because a hollow tube is located in a pipe, which must be sealed, a strict sequence is required during assembly.

What do you hope to learn from the measurements taken on the completed model?

First and primarily, the experiment should provide data that our colleagues can use to validate their CFD simulations. To reach this goal, the measured values should be reproducible and consistent. Furthermore, the different positions of the measurements should provide insights into the flow and the runners.

ABOUT THE AUTHORS



Head of the Institute of Jet Propulsion and Turbomachinery (IFAS) is **Prof. Dr.- Ing. Jens Friedrichs**. In ALPHEUS he leads the working group dealing with the mechanical design of the RPT unit. Due to his many years of experience, he gives important input in meetings and in all decisions.

Dr.- Ing. Heiko Schwarz is the head of the Research Group "Hydraulic Machines: Components & Seals". With his many years of practical experience in the field of pumps, he contributes to the mechanical design of the RPT unit in ALPHEUS.

Jonas Oldeweme is a PhD student at IFAS. He is responsible for the design and construction of the RPT unit in ALPHEUS. In close coordination with the Leichtweiß-Institute for Hydraulic Engineering and Water Resource, he creates the CAD design. This involves creating drawings for manufacturing, parts lists and assembly instructions to ensure a smooth transition between IFAS and LWI.

WHAT HAZARD DOES
THE ALPHEUS PROJECT FACE?

The Université de Pau et des Pays de l'Adour is represented by the E2S chair HPC-Waves and is involved in the ALPHEUS effort trough WP5.

The chair HPC-Waves (High Performance Computing of Waves) is part of the college of engineering at UPPA's Anglet campus in SW France. The chair is lead by Volker Roeber, a coastal engineer and wave model developer. The chair's work focuses on the theoretical and numerical development of nearshore wave models with attention to high performance computing. The objective is to improve both accuracy and speed of numerical wave models catering to a representative and complete description of coastal wave processes. These include generation, propagation, and run-up, as well as the waves' impact on structures and their potential for MRE extraction. This work is complemented by field and laboratory studies.

The chair's team will help the consortium to assess the local flood hazards through numerical modeling. The seawater Pump Hydro-Storage facility (PHS) is intended to be integrated into existing flood control structures or potentially to be designed as a multi-purpose structure, which serves as additional protective feature in a flood-prone area. The vicinity of the structure to the ocean is exposing it to similar hazards as conventional coastal structures. It is understood that extreme events such as storm surges pose the most significant threat and can lead to catastrophic failure of the structure.

Quantitative assessment of the hydrodynamic forces is therefore necessary through the use of state-of-the-art modeling in conjunction with statistical extreme value analyses. Other hazards, which are not immediately evident are high tides in combination with large swell waves that can occur on a more frequent basis and therefore bare the potential for long-term scouring of the structure's foundation.

Obviously, there exists also the potential of a failure of the PHS structure itself, i.e. a failure of the retaining dam that subsequently could lead to the discharge of large amounts of water into the neigboring area. This scenario would be similar to a classic dam failure as it has happened in the past (e.g. the Malpasset dambreak). These events can be efficiently computed with a numerical model built around the well-known shallow water equation.

The chaire HC-Waves is actively developing a robust and efficient nearshore wave model, which is based on the foundation of the Shallow Water Equations.

The model uses a 2nd order upwind scheme with a semi-implicit solution of the governing equations that achieves robust but low-diffusive solutions with a lean and efficient scheme without the use of computationally demanding numerical features such as Riemann solvers. The code has been verified with several analytical solutions and also validated with data obtained from a survey after the Malpasset dambreak.

The model results are in close agreement with the measured data and comparable to previously compyted results from hydraulic models, which were particularly designed to handle dambreak flood problems. The chair's code is highly efficient, since it computed the solution in a highly-parallel fashion on a GPU (graphics card) and herein achieves fast computations on consumer-grade hardware without the need for computer clusters.

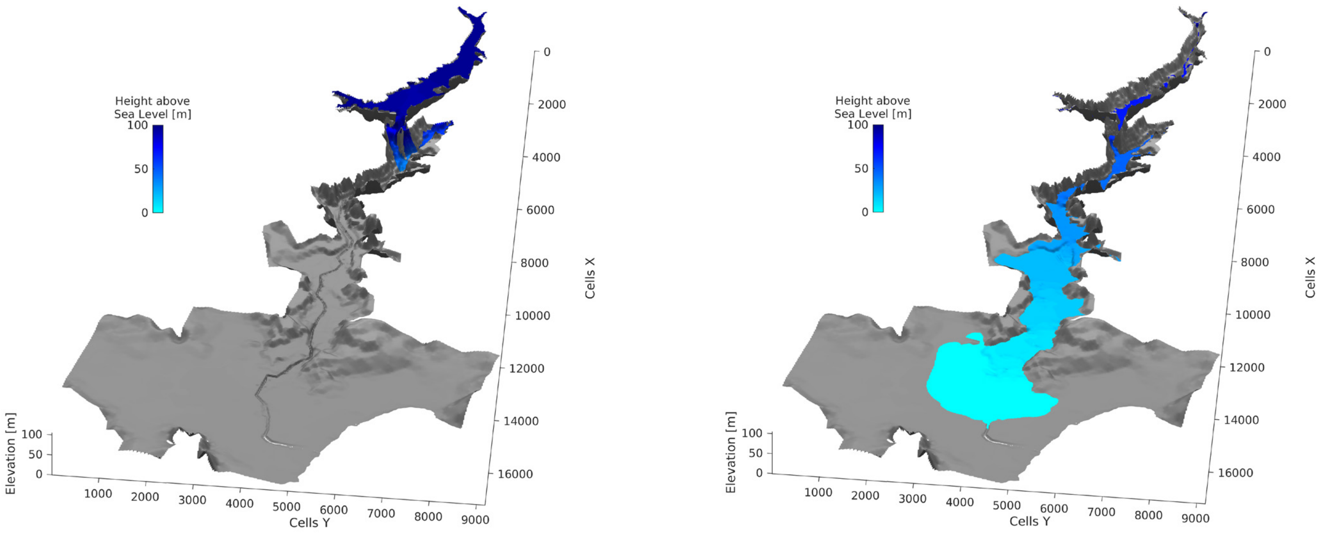


Fig. 2. Figure illustrating the SWE model's solution for the Malpasset dambreak problem.

ABOUT THE AUTHOR

Volker Roeber is in charge of the chair HPC-Waves, a chair of excellence within the E2S (Energy Environment Solutions) framework, at the Université de Pau et des Pays de l'Adour (UPPA). The chair focuses on the theoretical and numerical development of nearshore wave models with attention to high performance computing. Especially operational numerical models require both accuracy and speed for a representative and complete description of coastal wave processes including generation, propagation, and run-up, as well as the waves' impact on structures and their potential for MRE extraction. This chair's work is complemented by field and laboratory studies.

CHALLENGES TO COMBINE **MECHANICAL & ELECTRICAL** COMPONENTS

To shift the operating range of PSH into the low-head region, ALPHEUS proposes a novel system comprised of several newly developed components. Each of these components is aiming to push the technology into the next development stage, improving its capability to provide bulk energy storage and ancillary services while being economically viable. The development is split into a number of work packages: turbine design (WP2), power take-off (WP3), civil structures (WP5), grid integration (WP6) as well as integration and validation (WP4).

Examples of the developed concepts consist of a novel contra-rotating turbine design, axial-flux motor generators and a dedicated grid- and generator-side control. Integrating these components requires in-depth understanding of their individual interaction and influence on system characteristics and performance. The interaction as well as performance and dynamic behavior of the system employing these novel components is not yet known. Understanding these will enable improvements on a system level and eventually lead to an increased ability to perform grid stabilization.

Detailed models of hydrodynamics, mechanics and electrical systems allow for in-depth simulation of their behavior. However, to integrate the individual components such as the runners and motor-generators, it is required to not just study their isolated behavior but also how they affect each other. In a low-head application, as the one proposed by ALPHEUS, larger masses of water under a reduced head power the turbomachinery. This leads to increased torque on the runners and motor-generators. Moreover there is a potential for an increase in risk of water hammer and cavitation as well as changing motor-generator loss properties.

"Practically, this integration will happen for the first time during a series of experiments in collaboration with the TU Braunschweig."

A 50kW model-scale of the proposed system is being designed and constructed. The diameter of the counter rotating RPT is scaled down to approximately 30cm exposed to a head around 9m between the elevated and lower tank. The spillway allows to adjust this head. When scaling down such a system, it needs to be decided which components should be accurately represented; in this case, the priority lays on the hydrodynamics in combination with integrating and testing the axial-flux motor-generators.

The initial setup will test the optimized design of both runners but will not include the dedicated motor-generators that are being developed. The goal of the first set of experiments, projected to start towards the end of 2021, will be to validate CFD simulations and numerical models in steady state conditions. This will also give first results towards the hydraulic performance evaluation. If the simulations and models are validated, the performance of a full-scale prototype can be accurately predicted. In a later stage of the experiments, the motor generators developed by WP3 will be integrated and tested.

Aside from steady state results, to understand the interaction of the components, covering the system dynamics and studying transients would be of great value. Testing the dynamic behavior when switching between operating modes and ramping power could significantly help to evaluate the capabilities of the proposed system to provide energy balancing and the provision of ancillary services.

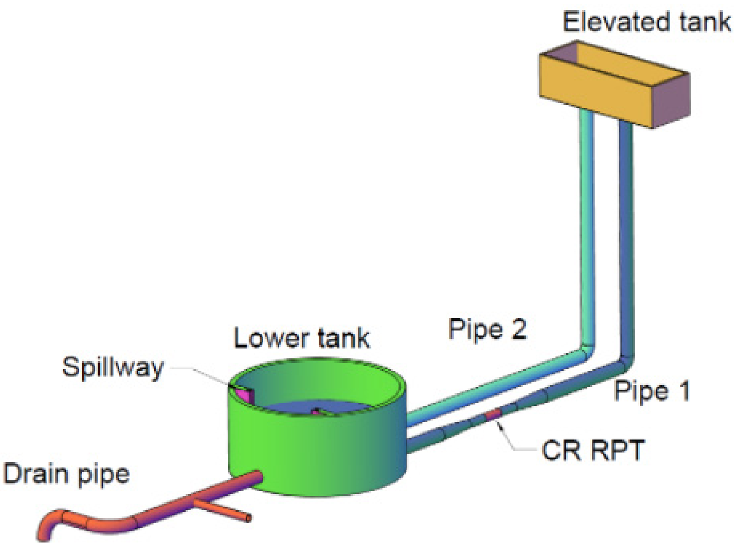
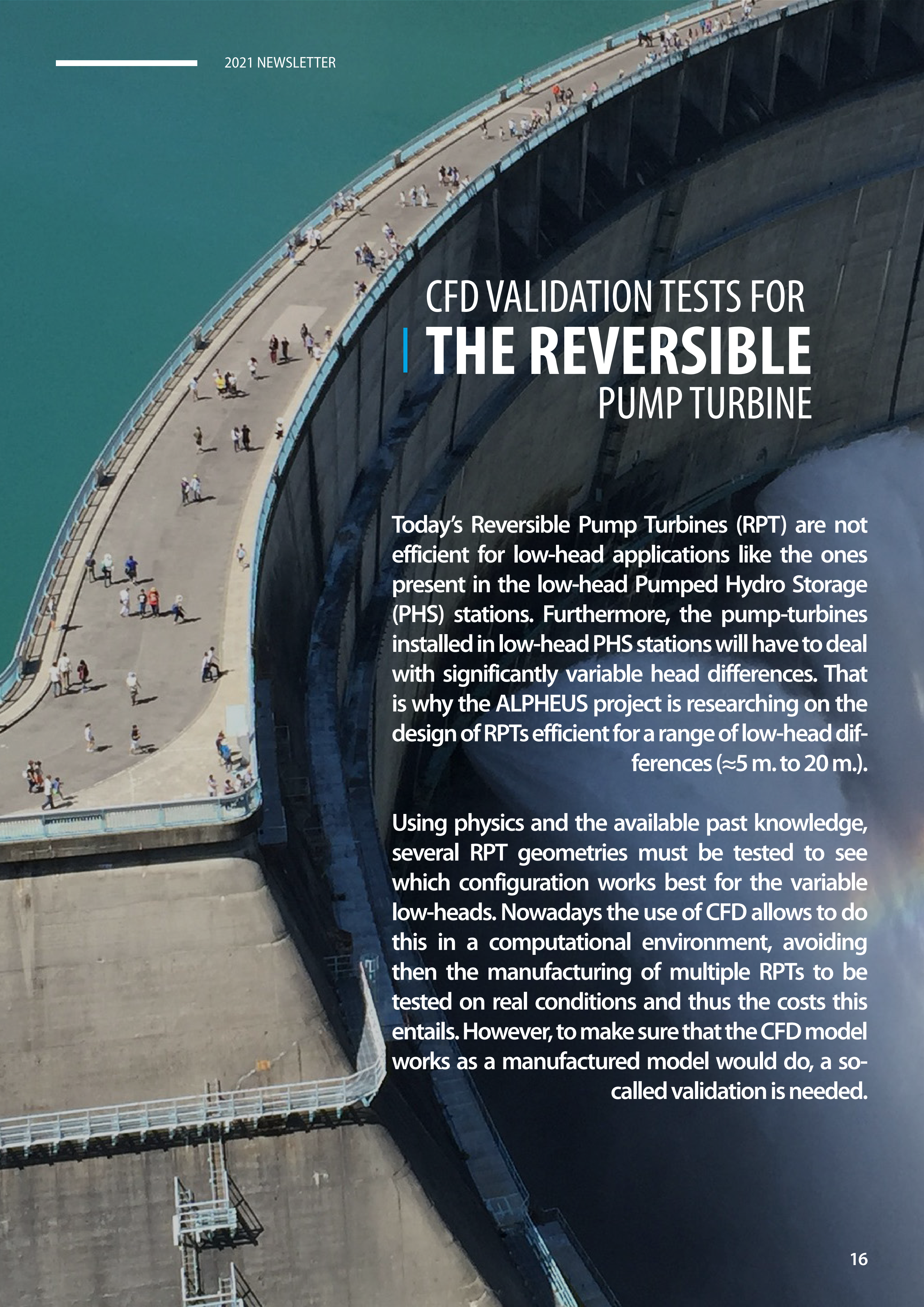


Fig. 3. Model of the Laboratory Setup.

ABOUT THE AUTHORS

Dr. Antonio Jarquin-Laguna is currently working as a an Assistant Professor at the department of Maritime and Transport Technology – Delft University of Technology in the Netherlands. His research interests include offshore renewables, energy storage solutions and physical modelling. Within the ALPHEUS project, Antonio is taking the lead of WP4 regarding the turbine and PTO system integration.

Justus Hoffstaedt is a PhD candidate within the department of Maritime and Transport Technology at Delft University of Technology. The ongoing PhD project is part of ALPHEUS' WP4 at the TU Delft. The scope of this PhD is to aid the integration by developing a comprehensive system model and participate in validation through the experiments conducted at the TU Braunschweig.



CFD VALIDATION TESTS FOR THE REVERSIBLE PUMP TURBINE

Today's Reversible Pump Turbines (RPT) are not efficient for low-head applications like the ones present in the low-head Pumped Hydro Storage (PHS) stations. Furthermore, the pump-turbines installed in low-head PHS stations will have to deal with significantly variable head differences. That is why the ALPHEUS project is researching on the design of RPTs efficient for a range of low-head differences (≈5 m. to 20 m.).

Using physics and the available past knowledge, several RPT geometries must be tested to see which configuration works best for the variable low-heads. Nowadays the use of CFD allows to do this in a computational environment, avoiding then the manufacturing of multiple RPTs to be tested on real conditions and thus the costs this entails. However, to make sure that the CFD model works as a manufactured model would do, a so-called validation is needed.

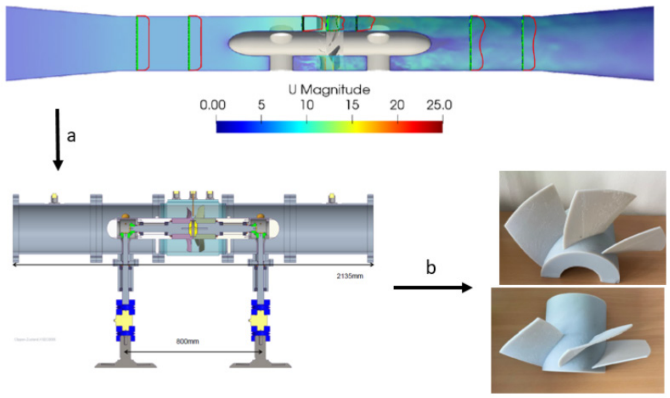


Fig. 3. Representation of the cycle: CFD design (Jonathan Fahlbeck, 2020), mechanical design (Jonas Oldeweme, 2021) and manufacture. Notice that the manufacture process is not yet ready so just an initial 3D printed version of the runner is shown here.

A model validation is the process by which a model is tested in real conditions to confirm that the model predicts the on-field results. To do that, first a CFD model was developed by Chalmers University of Technology and Advanced Design Technology, Ltd. This model includes an efficient RPT geometry. To manufacture this RPT unit, a mechanical design was performed by the Institut für Flugantriebe und Strömungsmaschinen (in English, Institute of Flight Propulsion and Turbomachinery) of the Technische Universität Braunschweig. Later, the RPT unit will be manufactured at the Leichtweiß-Institut für Wasserbau (LWI) (in english, Leichtweiß-Institut of Hydraulic Engineering) of the same university. Once the RPT unit is manufactured, it will be included within the newly built test setup of the LWI developed for testing the RPT unit.

From the test setup, data about water velocities and static water pressures can be obtained in regions next to the runners. Data will be taken at steady state for multiple head differences and discharges.

Additionally, the data during the start-up and shut-down sequences will be recorded. To figure out if the model represents reality, the velocity, pressure, rpm and torque values measured at the lab will be compared to the data obtained from the CFD model. It is expected that some parameters of the CFD model will be modified to adjust the CFD values of velocity, pressure, rpm and torque to the ones measured at the laboratory. After some iterative rounds, the CFD model will reproduce reality with precision.

At this point, the model is said to be validated. Then, we can use the CFD model to test different runner geometry configurations with the aim of finding the most efficient one.

ABOUT THE AUTHORS

Since 2018 **Nils Goseberg** is the professor of hydromechanics, coastal and ocean engineering, heading a division of the Leichtweiß-Institute for Hydraulic Engineering and Water Resources. Additionally, he is the managing director of the Coastal Research Center (Forschungszentrum Küste), a joint research facility with Leibniz University Hannover. His expertise is quite multidisciplinary having interests in wind-waves, tsunami engineering, costal protection, sediment transport and offshore aquaculture, among others. Ruben and Nils are mainly contributing in Work Packages (WPs) 2, 4 and 5.

Since June 2020, **Ruben Ansorena Ruiz** is a PhD student at the Hydromechanics, Coastal and Ocean engineering department of the Leichtweiß-Institute for Hydraulic Engineering and Water Resources under the supervision of Nils Goseberg. After studying civil engineering in the Universidad de Cantabria, he completed a MSc in Technische Universiteit Delft in the field of Hydraulic Structures and Flood Risk. The development of his MSc thesis on the conceptual design of a Low-Head Pumped Hydro Storage Station for the DELTA21 plan, enhanced his interest in large-scale renewable energy storage which then lead him to join the ALPHEUS project.

APPLYING THE KNOWLEDGE FROM WIND POWER TO HYDROPOWER

Both wind power and hydropower systems contain a turbo machine interacting with a fluidum. Also, both applications are high torque and low speed in nature, and experience an extant axial force. As for capacity, the 10 MW design goal in the ALPHEUS project corresponds to the rated power of modern large wind turbines.

Furthermore, a Permanent Magnet Synchronous Machine (PMSM) with a fully rated power converter offers advantages in both research fields because of its high power density and efficiency under variable power operation. Therefore, we aim to apply advancements in wind power technology to the hydropower applications in ALPHEUS. This includes the torque and speed control of a PMSM, Maximum Power Point Tracking (MPPT) methods and Model Predictive Control (MPC) algorithms. Next to the machine control, innovations in the use and design of high density and high torque Axial Flux PMSMs (AF-PMSM) and bearing arrangements offer great possibilities for the proposed reversible pump-turbines (RPT).

Naturally, this knowledge is to be extended and adapted to successfully develop the PTO within the project. Next to the existing similarities, the contra-rotating RPTs (CR RPTs) have additional features that make for an exciting challenge in this project's research. E.g. the CR RPT has two actuators, which interact with each other through the fluid. Furthermore, an inlet valve can be used to control the flow rate, resulting in a control system with three degrees of freedom.

What is unique and beneficial about the powertrain that you are developing for ALPHEUS? Both actuators of the RPT are separately driven by two electrical machines. Therefore, their controllable speed ratio can be exploited to achieve a maximal dynamic response to grid changes, while maintaining optimal efficiency at different operating points. The AF-PMSMs with YASA topology have a high power and torque density and have no stator iron, which significantly reduces weight.

Further efficiency improvements to the AF-PMSMs can be made by using segmented rotor magnets, concentrated pole windings and grain-oriented material in the stator teeth. The ALPHEUS concept will contain a bulb in which the drivetrain is housed. Two coaxial shafts provide transmission between the turbo machines and the electrical machines. This drivetrain architecture retains hydraulic efficiency, while allowing optimal accessibility and reasonable bearing loads.

What challenges might you face scaling up the model motor for real-world application? The biggest challenge in realizing a real-world application is the reliability. To support the grid, it is essential that the machine is available at all times. The dynamic operation and reliability will be thoroughly investigated. Proper scaling laws will be used to ensure the reliability in real-world application.

A significant advantage of using AF-PMSMs with a high pole number is the possibility of using a modular machine drive, which separately controls all stator windings. If a fault occurs in one of the windings, the drive can compensate for this with the other modules and the machine can resume operation with slightly reduced dynamics and efficiency until the problem is resolved.

How do you control the operation of the pump/turbine? To control the machines' rotational speeds and torques, Field Oriented Control (FOC) is used due to its fast dynamic torque response. The speed or torque setpoints result from a higher level control. In a first stage, an indirect MPPT method will be used. Here, the rotational speeds and inlet valve angle are tabulated for each measured head height between the reservoirs and power setpoint. This power setpoint results from the grid state.

Once a detailed model of the RPT is attained, the high level control can expand to MPC, predicting the most optimal speed and angle setpoints to achieve the wanted power setpoint as fast and efficient as possible.

ABOUT THE AUTHORS

Jeroen De Kooning coordinates the work on the ALPHEUS Power Take-Off (PTO). It is our aim to realize a cutting edge PTO hardware and control architecture that maximizes efficiency under variable power operation, while simultaneously ensuring the strong dynamics needed to provide ancillary services to the grid. For this, we will leverage our experience with the design and control of wind turbine drivetrains.

The role of **Johan Abrahamsson** – University of Uppsala, in the project is to work on the parts of the Power Take-Off system that deals with boundary conditions for the machine-side control as well as to investigate different power-electronic architectures. He has a background in high-speed machines and advanced control of power-electronic systems.

To take up the challenge of investigating the Power Take-Off system in the ALPHEUS project is in line with the motivation **Daan Truijen** has as a master of science in electrical engineering. That is, to contribute to the energy transition, in which hydropower has great potential. His aim within his PhD research is to realize the drivetrain and control system for the different reversible pump-turbine concepts in ALPHEUS. The PTO will maximize efficiency and dynamic response to increase the grid stability and provide ancillary services.

COMMUNICATION AROUND THE ALPHEUS PROJECT

ALPHEUS is a project funded by the European Union's Horizon 2020 program. The Europe's leaders and the Members of the European Parliament agreed that research is an investment in our future and so put it at the heart of the EU's blueprint for smart, sustainable and inclusive growth and jobs.

By coupling research and innovation, Horizon 2020 is helping to achieve this with its emphasis on excellent science, industrial leadership and tackling societal challenges. The goal is to ensure Europe produces world-class science, removes barriers to innovation and makes it easier for the public and private sectors to work together in delivering innovation.

When it comes to pumped hydro storage, the core technologies needed to decarbonize the power section already exist and are in the form of renewable energy: wind, water and solar are now the fattest-growing sources of new generation.

By applying pumped hydropower energy storage, a growing share of intermittent renewable energy sources grid stability can be maintained, and flexibility is enhanced.

Therefore, the ALPHEUS project aims to improve reversible pump / turbine (RPT) technology and adjacent civil structures needed to make pumped hydro storage economically viable in shallow seas and coastal environments with flat topography.

The importance of communication within the ALPHEUS project: Effective communication is very important for the success of any project. One of the objectives of the Work Package 7 is to inform about the ALPHEUS project. The goal of this task is to coordinate and maintain the external communication about the project and this is done through a variety of communication channels, including the website, newsletter, social media, press releases, virtual and in person events.

Whether it's online marketing (e.g. social media) or during events, the ultimate goal of any communication is to inform a specific audience about the existence of the project and to maintain a close relationship with the public.

Thanks to different platforms, we are able to communicate about the activity progress and how close the team is to achieve the entire project.

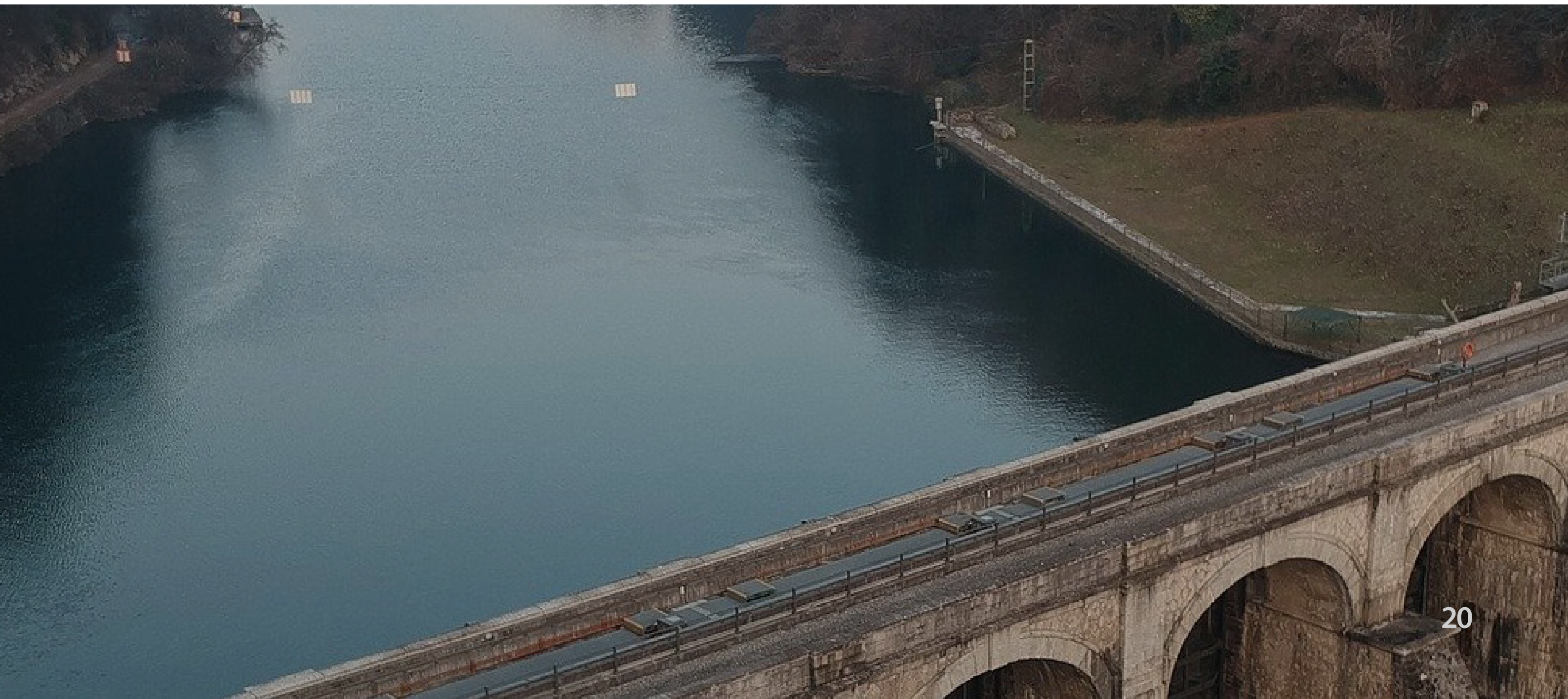
Since the beginning of the project, the ALPHEUS team has shared four papers on ResearchGate: The Contribution of Low Head Pumped Hydro Storage to a Successful Energy Transition, Flow Characteristics of Preliminary Shutdown and Startup Sequences for a Model Counter-Rotating Pump-Turbine, Drivetrain Architectures for a Mechanically Decoupled Contra-Rotating Reversible Pump-Turbine and Numerical Analysis of an Initial Design of a Counter-Rotating Pump-Turbine, which have a total of more than 800 reads. On the digital side, we count a thousand visits to the website since April 2021 with more than two thousand page views, coming from all over the world. Europe being at the first position, followed by Asia and Americas. Our social media channels are also growing, over 120 users are now following ALPHEUS on LinkedIn and Twitter.

Get to know more about the project by following us on LinkedIn, Twitter, or on Research Gate and ALPHEUS website. Subscribe to our newsletter, so you'll never miss an update!

ABOUT THE AUTHORS

Lorenzo Bossi leads WP7 – Dissemination and Exploitation for ALPHEUS project. He holds a MSc of Sciences from Neoma Business School in Reims, France and is currently the Chief Operating Officer for Advanced Design Technology, Ltd. in London where he leads the global sales, marketing and operation efforts for the company.

Camille Gatti is working as a Digital Marketing Specialist at Advanced Design Technology. Her role is to determine unique ways to spread awareness and to create relevant and original content for promoting the business's products and services. In the ALPHEUS project, she is in charge of the external communication as part of WP7 – Dissemination and Exploitation.



THANK YOU