2022 NEWSLETTER
ALPHEUS PROJECT

ALPHEUS

communication@alpheus-h2020.eu

WHY THE ALPHEUS PROJECT?

The signs of global warming are everywhere, and are more complex than just climbing temperatures. Warming also stresses ecosystems through water shortages, increased fire threats, drought, weed and pest invasions, intense storm damage and salt invasion… Just to name a few. These impacts threaten our health by affecting the food we eat, the air we breathe, the water we drink and the weather we experience.

Renewable energy, especially wind and solar, is essential for our global efforts to decarbonize and slow the rate of global warming. However, the consumption of energy by industries and individuals often does not coincide in time with the generation of energy by the wind or sun.

In wet mountainous regions such as Norway and the Alps, Pumped Hydro Storage (PHS) is used for this purpose. The water is pumped up to reservoirs on mountaintops during times of excess power generation, then run through turbines back down to reservoirs in valleys during times of excess power consumption. However, the Netherlands, Denmark, and other low countries do not have the natural topography needed for PHS. Therefore, utility-scale backup supplies are almost exclusively fossil fuel (gas, coal, oil, or diesel) thermal power plants. The development of PHS feasible for the low countries would be beneficial for both the environment and the economy.

Challenge to pumped hydro storage in the low countries include the lack of suitable Reversible Pump-Turbine (RPT) technology that can operate with high efficiency in both pump and turbine modes at low heads, the cost of dam and powerhouse construction in the sea, and the potential for impacts on fish.

But… How would low-head pumped hydro storage help? Low-head PHS technology is a very innovative concept which grows out of two existing technologies: high-head PHS and seawater tidal energy generation. The working methods are similar, but instead of obtaining energy from a large head difference, it is obtained from the large amount of water that passes through the pump-turbines.

ALPHEUS aims to discover whether low-head PHS is a feasible technology in the North Sea to cope with the problem of large-scale renewable energy storage. The €5M ALPHEUS project is funded by the European Union's Horizon 2020 program, and coordinated by the Delft University of Technology.

The project sets out to develop two novel RPT and drivetrain technologies for high efficiency at low heads in both pump and turbine modes, conceptual designs of dam and powerhouse structures, assess impacts on fish, and predict the resulting effect on grid stability.

WELCOME FROM
THE EXTERNAL ADVISORY BOARD

It is my pleasure to introduce the second Newsletter of the ALPHEUS research project to you. With the so-called "Green Deal" the EU adopted quite ambitious targets of climate neutrality in Europe by 2050 and a reduction of net greenhouse gas emissions of at least 55% by 2030, compared to 1990 levels.

When the first Newsletter had been published in December 2021, no one has foreseen the political developments of this year and their impact on the energy sector with dramatically increasing prices for energy and electricity and the need to secure the energy supply without endangering the overall emission targets. The EU's answer to the current political situation is the REPowerEU Plan, providing for among other measures an increase of the 40 % target of the renewables' share in the energy production mix to 45 % by 2030. At the same time the EU continues promoting a sustainable economic growth helping industry to be resilient and competitive on a long–term basis.

Key driver for the transformation of the energy and industry sector will be innovation. And here, the ALPHEUS project can help: with a technology allowing countries without significant altitudes to use the pump storage technology and to contribute to the target of "clean energy".

Since the Newsletter 2021, the work of the Consortium has well advanced. I would like to thank all members of the Consortium and their collaborators for the enormous research work they have done. The Newsletter presents the recent research results and gives you an insight view from the design of the turbines to the dam design and the discussion on finding suitable sites. Enjoy the reading!

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

EXTERNAL ADVISORY BOARD
TO SUPPORT ALPHEUS PROJECT

To support the work of the consortium and the Steering Committee, an External Advisory Board is established. The task of the External Advisory Board is to monitor adherence of project deliverables to the needs of the sector and to facilitate a quick market uptake.

The External Advisory Board is comprised of internationally recognized experts within the hydro power industry, research, policy making and regulation, representing the entire value chain.

Bettina Geisseler
GEISSELER LAW

Ann Overmeire
The Blue Cluster

Antoine Libaux
EDF Hydro

François Lempérière
HydroCoop

Peter Hoffmann
TenneT

Anton Schleiss
Hydropower Europe

Henning Lysaker
Jan Tore Billdal
Rainpower

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

SITE INDENTIFICATION FOR LOW-HEAD PUMPED HYDRO STORAGE

based on Operation Simulations and Geospatial and Use Characteristics

Operation Simulation

To identify a suitable sea depth to guarantee an efficient operation of the LH PHES and to determine optimum size of the reservoir for a specific operation scheme, a simulation model is developed. The LH PHES model is arranged in such way that the ring dam (Figure 1) serves as the lower reservoir and the sea serves as the upper reservoir. The reversible pump-turbine (RPT) is located in the middle of a horizontal tunnel that connects the reservoir and the sea.

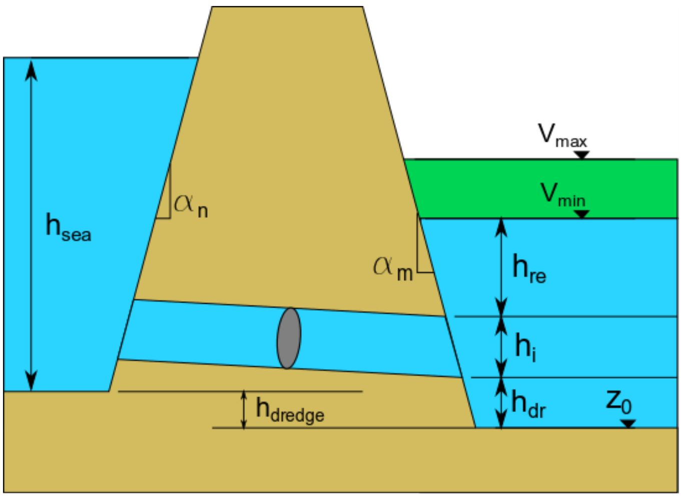


Figure 1 - Vertical Dimension of powerhouse components

The model mainly calculates the water balance inside the reservoir and determines the operation point of the RPT for each time step. The operation point is determined in the RPT performance map (that is developed in corporation with WP2), taking the generated/consumed power and the fallhead as input.

The operation point determines the RPT discharge and the speed of runners. The hydraulic loss is calculated based on the RPT discharge and the tunnel characteristics.

The net fallhead is then calculated identifying the new operation point. This routine is done iteratively to finalize the operation point and the RPT discharge to recalculate the reservoir filling. An example of the simulation can be seen in Figure 2, in which the LH PHES operates in turbine mode and continues in pump mode for 4 hours each.

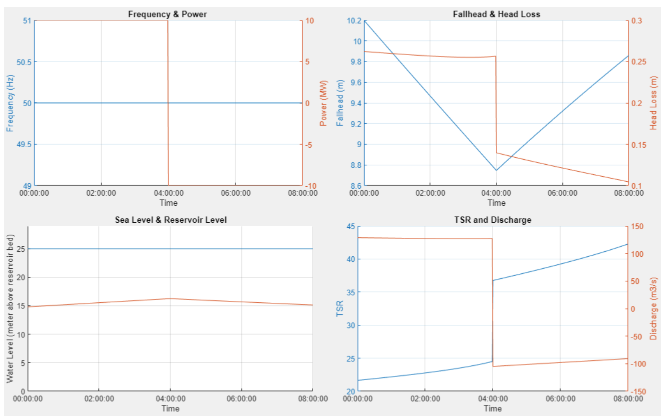


Figure 2 - Example of operation simulation (incl. machine operation data from cooperation with WP2, ADT)

For cases in which simulation results show that the size of the reservoir is too small, the water too shallow or the RPT operation is outside the specifications of the performance map the simulation returns `unfeasible`.

Geospatial and Use Characteristics

Once a suitable sea depth range is determined, a site investigation for the LH PHES can be conducted. The goal is to identify a suitable site for the offshore reservoir placement.

A study of the region is necessary to consider the parameters and restrictions of the Greater North Sea. The parameters are site specific, use specific and related to the installed Reversible Pump Turbine (RPT) unit.

Since the Greater North Sea is used for many different purposes, the planned reservoir cannot intercept areas where a priority for another use has already a priority.

Figure 3 - EEZ of countries of interest [1]

The geospatial and use varies strongly in the Greater North Sea Area. The site specific parameters are depending on the hydrography and geography, and include the bathymetry, the tidal conditions as well as the geology of the seafloor.

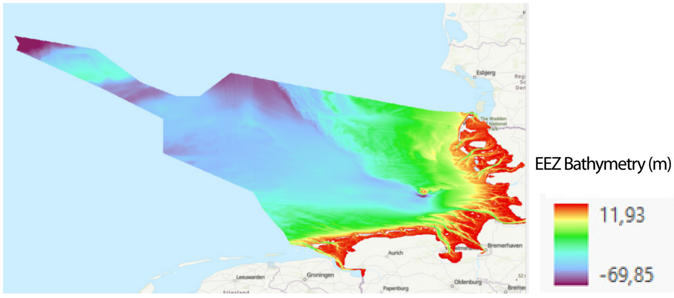


Figure 4 - Bathymetry of the German EEZ (LAT) [2]

The use specific parameters consider the Marine Spatial Planning (MSP) of each country, which can include the shipping lanes, the protected areas, the military areas, the marine extraction areas, fishing areas and underwater cables and pipelines.

However, since the MSP is specific for each country, the study should be conducted for each country individually.

In the scope of the ALPHEUS project, one part of the site identification is carried out as detailed study for Germany, France and the United Kingdom.

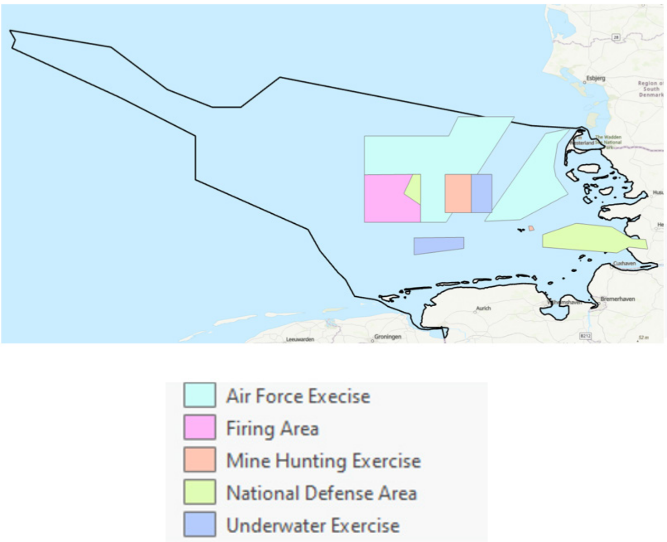


Figure 5 - Military activities in the German EEZ [3]

The site identification can be achieved based on georeferenced data by optimizing the search with an automated search routine.

References

[1] Flanders Marine Institute (2019). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 11. Available online at https://www.marineregions.org/. https://doi.org/10.14284/386

[2] EMODnet Bathymetry portal - http://www.emodnet-bathymetry.eu.

[3] EMODnet Human Activities - https://www.emodnet-humanactivities.eu/

ABOUT THE AUTHORS

Dr. Kristina Terheiden is the head of the Research Group "Structural Engineering and Hydropower" at the Institute for Modelling Hydraulic and Environmental Systems at University of Stuttgart.

She leads the WP5 investigating the site identification and the civil structure design of the LH-PHES plant also taking the legal, regulatory and environmental issues into account.

MSc. Matthieu Aouad and **MSc. Eksa Bagas Prasasti** are PhD candidates within the Research Group of Kristina Terheiden at the Institute for Modelling Hydraulic and Environmental Systems at University of Stuttgart.

They are involved in the research on the site identification of the LH-PHES based on the operation characteristics of the CR-VS-RPT units and the geospatial and use specific restrictions. Furthermore, they work on the conceptual civil structure design and the related costs of the overall plant.

RIM-DRIVEN CONTRA-ROTATING **REVERSIBLE PUMP TURBINE** DESIGN STUDY

Sensitivity Analysis

In the Deliverable 2.2, an initial design of the Rim-Driven Contra-Rotating Reversible Pump-Turbine (RD-CRRPT) was derived with ADT's TURBOdesign suite. Then, the initial design was scaled to model scale and optimized in an iterative manner to increase the efficiency of the machine. The average efficiency of the final design is increased by 7.7% in pump mode and 2.8% in turbine mode compared with the initial design. This final design provides a good start point for the further investigation and is selected as the baseline case for the optimization procedure. Before running the full optimization, a sensitivity analysis is first performed to identify the critical parameters which influence the performance mainly.

Initial Number of Parameters

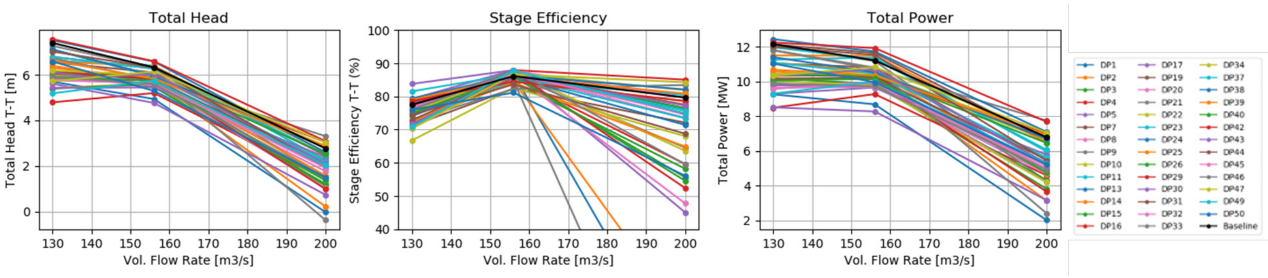
The blade design is parameterized by a number of input parameters in ADT's TURBOdesign suite. In this sensitivity analysis study 24 design parameters are chosen and distributed in the design space with the Latin Hypercube Sampling. The blade meridional geometry for both rotors is symmetrical and is parameterized by 7 parameters. The shroud radius and gap between rotors are fixed. Another 14 parameters are selected to control blade loading and rotor work and 3 more parameters are related to the blade stacking and RPM ratio. In total, 50 samples are simulated at three operation points for both pump and turbine modes.

Sensitivity DoE Results

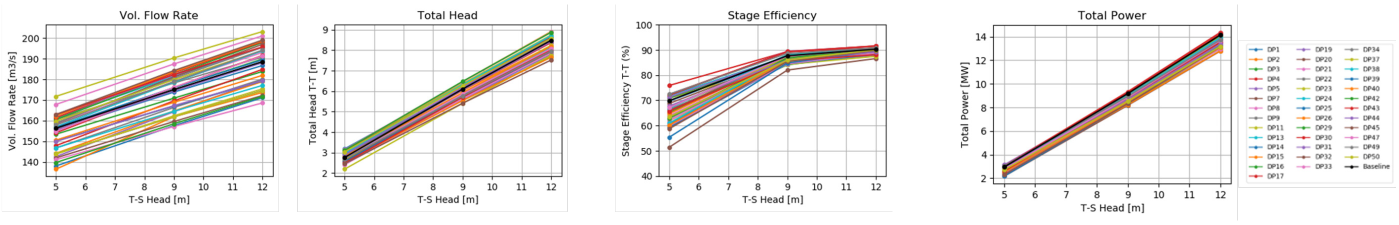
The sensitivity DoE results of pump and turbine mode are shown in Figure 1. The design space covers a wide range in terms of head, efficiency and power. In pump mode, most of the designs have peak efficiency near the design flow and the baseline case is close to the highest level of efficiency. In turbine mode, the baseline design also shows good efficiency performance among all the designs. A linear regression is then performed by using linear DoE results and a sensitivity bar chart is generated by comparing the coefficients of linear regression as shown in Figure 2. It can be seen that the dominant parameters that effect stage efficiency are similar in pump and turbine mode.

Important Parameters

The sensitivity analysis results indicate that 13 parameters have more influential on the stage efficiency in both pump and turbine mode. These include six spanwise rvt* parameters that determine the rotor work, one RPM ratio that control the speed ratio between rotor1 and rotor2, four leading edge loading parameters to adjust the incidence and two meridional geometry parameters to control the hub chord length of both the rotors. In the next stage, the key parameters from the sensitivity study will be used to run the full Design of Experiments (DoE) and optimize the design by using the surrogate model.



a) Pump mode DoE results



b) Turbine mode DoE results

Figure 1 - Sensitivity DoE results

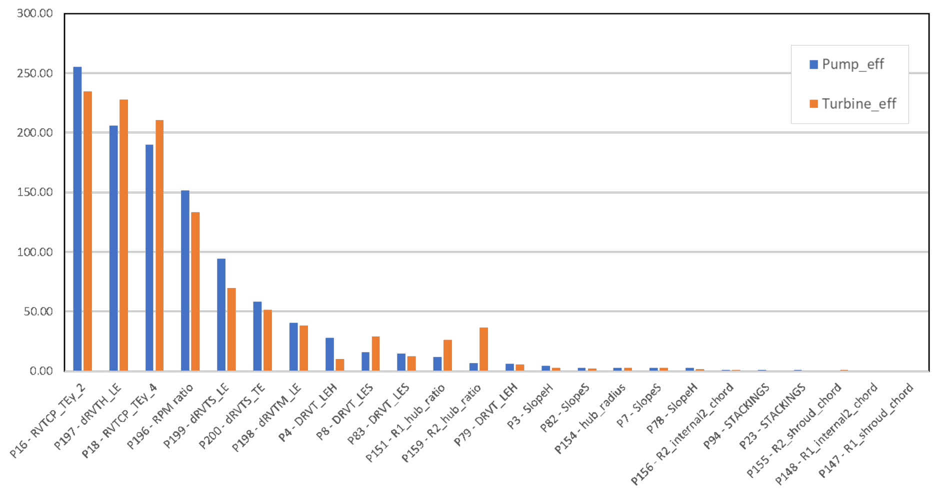


Figure 2 - Sensitivity Analysis for Stage Efficiency

ABOUT THE AUTHORS

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).

Dr Xin Miao is a Turbomachinery Design Engineer at Advanced Design Technology. He is currently working on rim-driven contra-rotating pump-turbine (RD-CRPT) design which is a part of ALPHEUS project WP2. The aim of this task is to increase the efficiency for a wide range of operating conditions in both pump and turbine modes based on numerical sensitivity analysis and multi-objective optimization.

POSITIVE DISPLACEMENT REVERSIBLE **PUMP TURBINE** LOBE MACHINE

In Work Package 2, a positive displacement reversible pump turbine (PD RPT) is investigated as a fish friendly design. The first assessment was presented by RONAMIC, who designed a three-lobe machine that could operate both in pump and turbine modes, investigated in model scale both numerically (NTNU) and experimentally (Chalmers).

A reversible lobe pump-turbine machine was constructed in model scale in a closed loop configuration at Chalmers Laboratory of Fluid and Thermal Science. Two three-lobe rotors with cycloidal profile were manufactured in PMMA (acrylic) and installed inside an acrylic box filled with water. Each rotor was fixed over a shaft which were mounted within an external gearbox, whose timing gears are responsible for synchronizing the rotors and guarantee they do not touch each other when they rotate. The gearbox provided the torque in pump mode.

Different water heads could be simulated by using a valve, where the lowest equivalent head is produced when the valve is fully opened, and higher values could be achieved by partially or fully closing that valve.

A flowmeter was used to measure the flow rate in the system and a differential pressure sensor indicated the pressure difference between the lobe machine inlet and outlet.

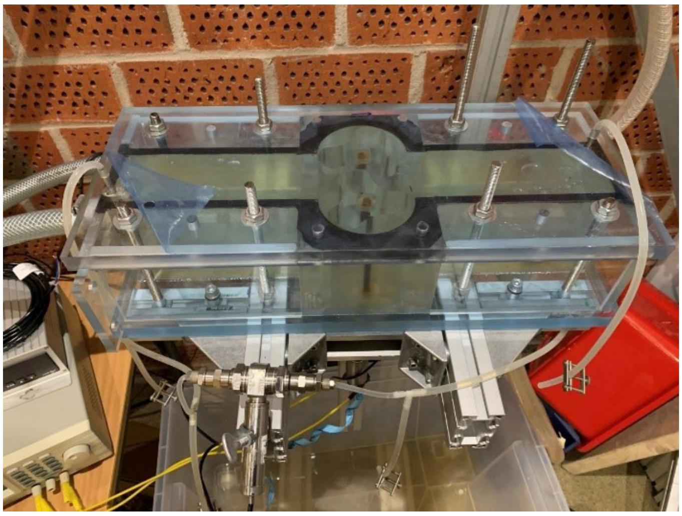


Figure 1 - Lobe pump in model scale

Different rotation speeds were imposed to the rotors, and in combination with the position of the valve, we could generate a characteristic curve for the pump mode.

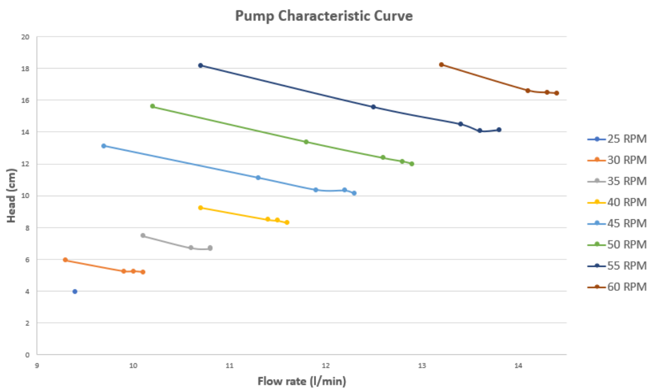
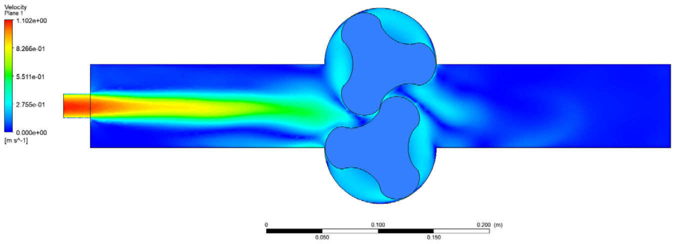


Figure 2 - Lobe pump characteristic curve

In Figure 2, we present the pump characteristic curve produced by the lobe machine and it shows a linear relation between flow rate and head, as expected from a positive displacement machine.

The aim of the experiment at Chalmers was to generate data that could validate the numerical setup, which is still under investigation. Up to this point the numerical simulations have presented the same linear behavior, but they failed to provide accurate results.

Possible reasons for this are the variation in actual gap sizes between rotors over a complete turn, and the low momentum source scaling factor used in the immersed boundary method simulations.



To simulate the turbine mode, an external pump was used to impose a given flow rate. However, the small scale of the model test rig made turbine mode difficult to measure as frictional effects were significant. This issue will be resolved in a larger scale setup at TU Braunschweig, which installation is being planned and will be soon constructed.

ABOUT THE AUTHOR

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 contra-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.

Valery is a Research Professor at the Division of Fluid Dynamics. Since 1996 he is working in experimental fluid dynamics and has experience and knowledge in the most of modern experimental flow analysis and measurement techniques. Currently he is in charge of Chalmers Laboratory of Fluid and Thermal Science which is a Chalmers research infrastructure for flow, temperature and motion measurements in air, water and solid objects.

CFD OF TRANSIENTS FOR THE **CONTRA-ROTATING** PUMP-TURBINE

Highly resolved numerical simulations of the fluid flow is made with transient computational fluid dynamic (CFD) simulations. The CFD give detailed information of the flow field for the contra-rotating pump-turbine.

However, since CFD is both time-consuming and requires large computational resources the blade element momentum (BEM) method was developed for the CRPT. BEM is a fast method to which is frequently used tool within windpower to get real-time estimates of the performance. In Figure 1, the developed BEM method for the CRPT is compared to CFD results. The results indicate promising results by BEM, however some differences are noted, which concludes that the BEM implementation must be further developed to be used in a real case.

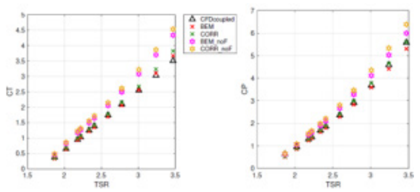


Figure 1 - Pump Runner 1

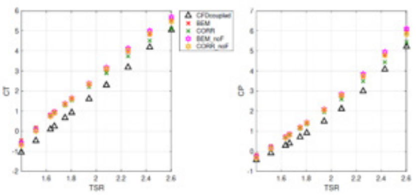


Figure 1 - Pump Runner 2

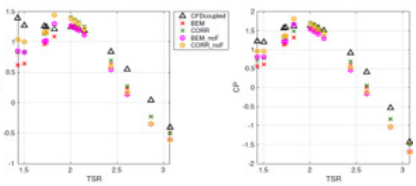


Figure 1 - Turbine Runner 1

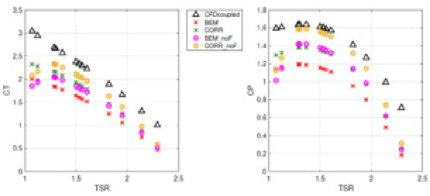


Figure 1 - Turbine Runner 2

To further understand the complex fluid flow behaviour that the model scale CRPT is subjected to under changing operating conditions, transient CFD simulations were carried out on preliminary pump-mode startup sequences. In the preliminary sequence, the startup is controlled by the speedup of the runners themselves.

The force and torque graphs in Figure 2 show that the two runners may be subject to substantial load variation during the pump-mode startup phase. Hence, the startup procedures must be further analysed for the CRPT.

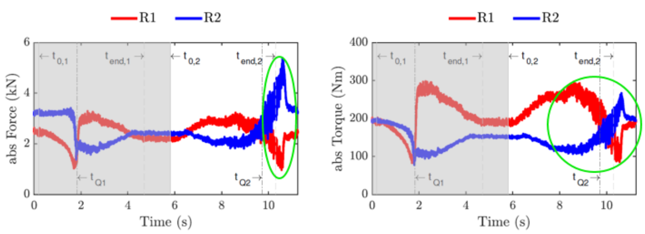


Figure 2 - Axial force and torque as a function of time

By analysing the pressure pulsation between the runners, showed in Figure 3, the dominating frequencies are determined. Judging by the power spectral density from the figure, it is showed that the blade passing frequencies of the two runners are the most dominating. Furthermore, harmonics and linear combinations of the blade passing frequencies are visible.

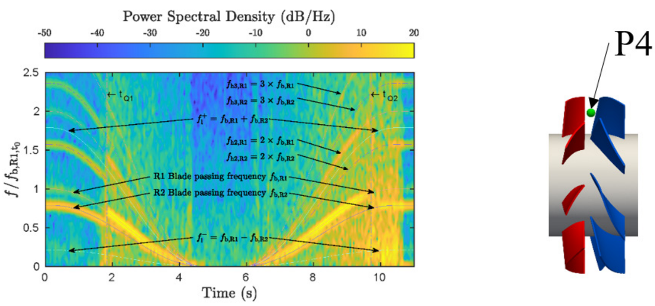


Figure 3 - Frequency analysis

Since the preliminary startup sequence did not show promising results, a more traditional startup sequence was evaluated. In this sequence, the two runners rotate at their final rotational speed, and a valve is slowly opened. In the numerical simulations, the valve was modelled as a head loss. In Figure 4, the axial force and torque response of the runners are showed for the traditional startup. However, a large force spike arises during the startup phase, which may lead to wear and premature failure of the machine.

Hence, a traditional might not be suitable for the CRPT.

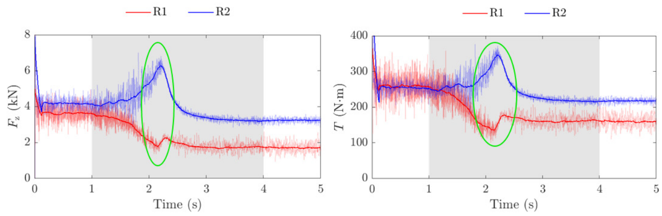


Figure 4 - Force and torque during traditional startup

In addition to the traditional and preliminary startup sequences, it is suggested that the valve opening, and runner speedups should be part of the sequence. The time of the startup sequence is furthermore and important factor when estimating the loads that the runners and bearings must withstand. The variation of axial force and torque for various startup times between 3 – 30 s are depicted in Figure 5. By using a relatively fast startup time of 10 s, most of the high peak loads are avoided.

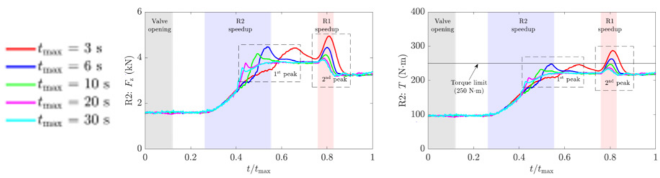


Figure 5 - Time effects during pump mode startup

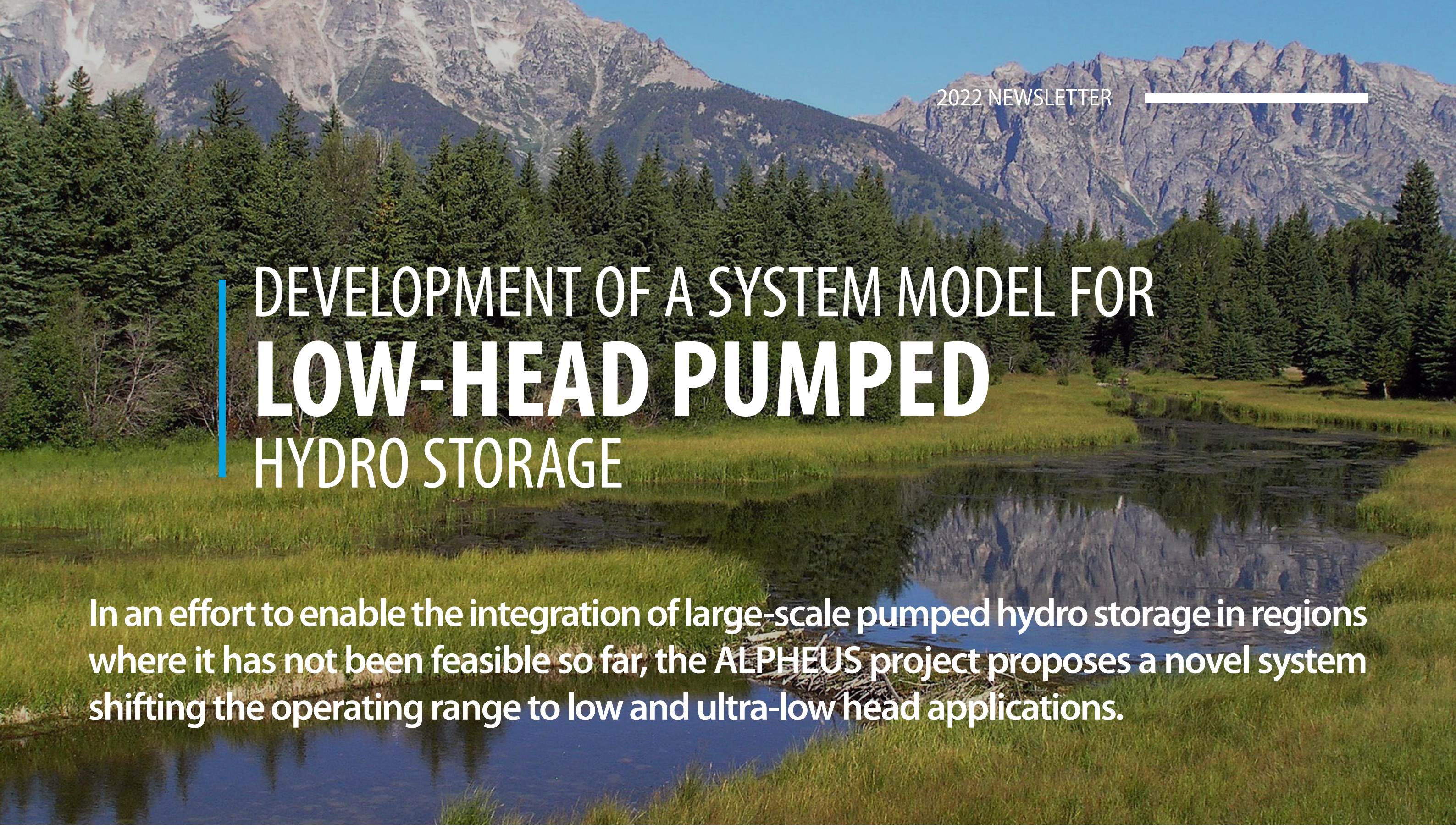
ABOUT THE AUTHORS

Professor Håkan Nilsson is a professor in Fluid Dynamics. In the ALPHEUS project, he is mainly responsible for numerical studies of transient operation of the novel contra-rotating pump-turbine concepts, together with PhD student Jonathan Fahlbeck.

Jonathan Fahlbeck is researching with simulating the flow in hydropower under unsteady and variable load conditions. In the ALPHUES project, he is focusing on the contra-rotating pump-turbines intended for low-head hydropower energy storage.

Saeed Salehi is pursuing a post-doc in Mechanics and Maritime Sciences, Divisioin of Fluid Dynamics at Chalmers. His research focus is to develop, in OpenFOAM, the required methods that are needed to study transients in hydro turbines.

Hamidreza Abedi has a PhD in thermodynamics and flow theory (Chalmers) with a focus on wind power. His research interests are flow fields and heat transfer using computational fluid dynamics,development computational methods for wind power aerodynamics.



DEVELOPMENT OF A SYSTEM MODEL FOR **LOW-HEAD PUMPED** HYDRO STORAGE

In an effort to enable the integration of large-scale pumped hydro storage in regions where it has not been feasible so far, the ALPHEUS project proposes a novel system shifting the operating range to low and ultra-low head applications.

This includes a newly developed reversible pump-turbine technology consisting of two contra-rotating runners. These are each coupled to their individual variable speed axial-flux motor-generators. Together with a dedicated control, the system aims to provide energy balancing and ancillary services. To achieve this, short switching times between pump and turbine mode as well rapid power ramp rates are desired.

To study the transient behaviour of the proposed low-head pumped hydro storage system during such dynamics, numerical simulations and experiments are conducted within ALPHEUS. CFD simulations and experiments can deliver accurate results but are resource intensive and therefore limit the amount of scenarios that can be tested.

To investigate the dynamic interaction of the hydraulic, mechanical and electrical components and allow for the simulation of a wide range of operating conditions, one of the goals of WP4 is to develop a comprehensive system model. Such a tool can cover the more relevant system dynamics at significantly reduced computational cost.

To verify this approach, model results are compared to CFD simulations in collaboration with WP2.

For this, the model is applied to the scaled-down version of the system that will be used for the experimental validation at the TU Braunschweig. Two cases are compared. The first one is a start-up of the system in pump mode over the period of three seconds. The second case is a rapid change of operating points simulating a fast reduction in power input over one second.

The results including the flow rate and pressure head over the computational domain for both the proposed model and CFD simulations are shown in Figure 1. Generally, there is a good match in dynamic behaviour and steady state results. Some deviations are introduced through slightly varying loss approximations as well as inaccuracies when characterising the runners for the model.

Both the results of the CFD simulations and the proposed model will be validated through the experiments planned later this year.

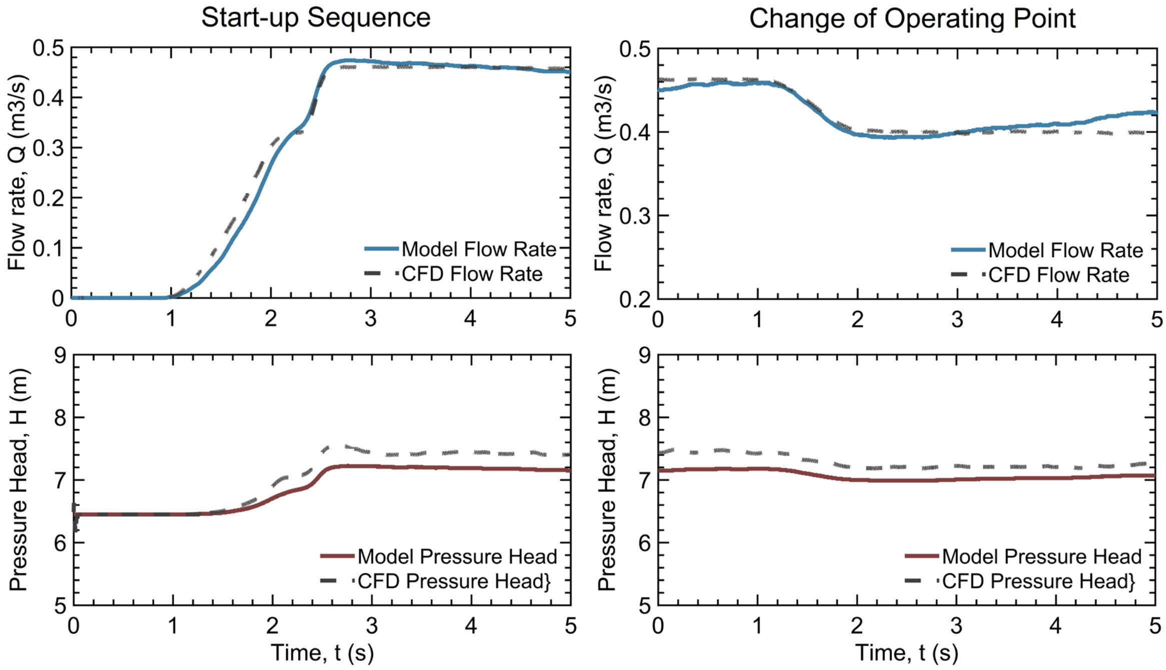
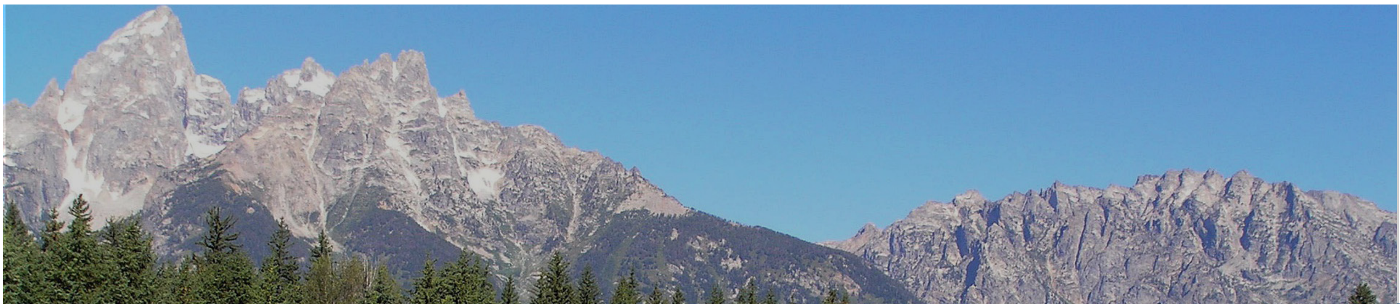


Figure 1 - Comparison of the CFD and Modelling Results



ABOUT THE AUTHORS

Dr. Antonio Jarquin-Laguna is currently working as a an assistant professor at the department of Maritime and Transport Technology from 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. The aim of this WP is to provide measurement results from laboratory experiments of the complete model scale machine set for validation of the numerical models developed in other WPs as well as the assessment and monitoring of fish behaviour.

Justus Hoffstaedt is a PhD candidate within the department of Maritime and Transport Technology at Delft University of Technology. His background lays in sustainable energy systems with a focus now on energy storage.

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.

DYNAMIC AND PARAMETRIC POWER TAKE-OFF DESIGN FOR ALPHEUS REVERSIBLE PUMP-TURBINE CONCEPTS

Three different Reversible Pump-Turbine (RPT) concepts are investigated in the ALPHEUS project, for which we study the design of the Power Take-Off (PTO) systems.

These PTOs are designed to enable the dynamic control actions needed to provide ancillary services to support the grid, such as Frequency Containment Reserve (FCR), while being reliable over a long lifetime.

Fatigue analysis

When the grid frequency deviates from its nominal value, the power output of the Reversible Pump-Turbine (RPT) is changed to support the grid. Changing the power output of an electric machine inevitably leads to time-varying mechanical stresses and thereby additional fatigue on various parts of the system. In order to quantify this extra fatigue, a close collaboration between different partners in the ALPHEUS project resulted in a methodology that can be used for different RPT designs, FCR capacities and control architectures.

At Ghent University, a control architecture is developed that lets the system reach a power setpoint fast and efficiently. Next, the power reserve for grid support is defined, which results in a power setpoint that changes with the grid frequency in time. Using historic frequency datasets of the European grid, the power response of the system is simulated.

At Advanced Design Technology (ADT), Finite Element Analysis is performed to find the magnitude and locations of the maximum stress points on the RPT propellers. Multiple operating points that are found from the machine response are analysed.

Combining the machine response to the grid frequency and the maximum stresses at these operating points, the stochastic stress cycles in the RPT are found as a function of time. Uppsala University developed a methodology using rainflow counting to analyse the different stress cycles and perform fatigue analysis.

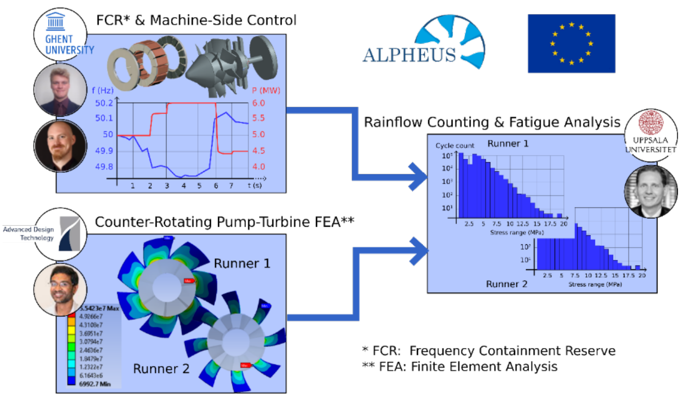


Figure 1 - Overview of the developed fatigue analysis methodology

Power Take-Off Design

For all three ALPHEUS RPT designs, the Axial-Flux Permanent Magnet Synchronous Machines (AF-PMSM) are used due to their high efficiency, power density and high diameter-to-length ratio.

By using a double rotor Yokeless and Segmented Armature (YASA) topology, the predominantly axial magnetic flux path averts the stator yoke's use, further reducing iron losses and weight. Other efficiency improvements are made by using grain-oriented electrical steel, segmented rotor magnets and concentrated stator windings.

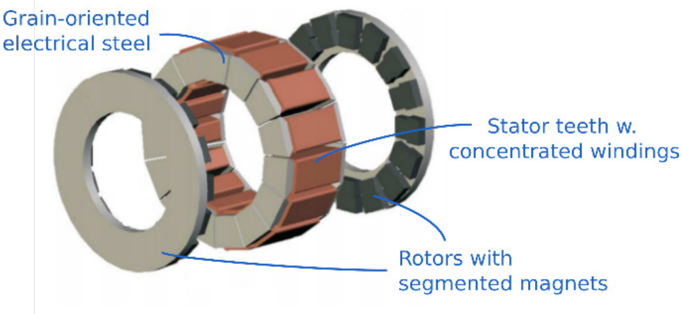


Figure 2 - Main components of the used YASA topology AF-PMSM

For both the shaft-driven and the rim-driven contra-rotating RPT, a variable speed ratio between the runners increases efficiency over a large operating range. Therefore, a gearbox is averted and a separate AF-PMSM is used for each runner. For the shaft-driven RPT, a comparison was made between different PTO topologies in a recent paper.

The optimal PTO comprises two coaxial contra-rotating shafts, so that the AF-PMSMs and the full PTO are placed on the pump outlet side of the RPT. The PTO is placed inside a bulb, located in the water stream, which is accessible through its struts. This topology minimises impact on the hydraulic efficiency, while retaining allowable constructional and bearing loads. To allow scaling of the PTO design to different RPT designs, a design tool was developed that proposes shaft lengths, shaft diameters, bearing arrangements and electrical machine dimensions based on the given RPT properties.

This design is validated in a realistic dynamic scenario, where the RPT is used to provide ancillary services to the grid.

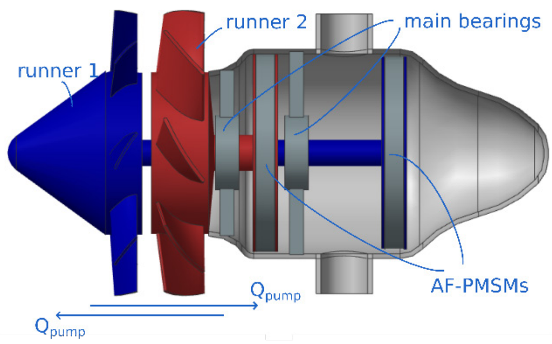


Figure 3 - PTO for the shaft-driven contra-rotating RPT

The main benefit of the rim-driven contra-rotating RPT is the absence of shafts and any PTO-imposed hydraulic losses, as the AF-PMSMs, bearings and seals are all built around the periphery of the RPT.

As the inner diameters of the electrical machines are constrained by the RPT diameter, the AF-PMSM outer diameters are large (6.87 m), compared to the shaft-driven PTO (≤4.2 m). However, due to the greater difference in inner diameter, it was found that the rotary mass and the total mass of the rim-driven PTO are respectively three times and six times lower than that of the shaft-driven RPT, while the permanent magnet usage remains similar.

One of the great remaining challenges of the rim-driven PTO is the bearing type. Commonly used roller bearings impose drawbacks in reliability and could prove uneconomical at such high diameters. Therefore, active hydrostatic bearings are proposed for this PTO, as they combine the benefits of hydrostatic and hydrodynamic bearings.

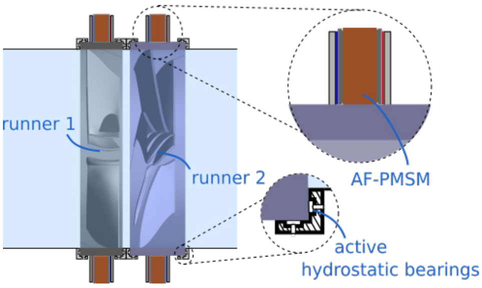


Figure 4 - PTO for the rim-driven contra-rotating RPT

Finally, the positive displacement RPT is discussed. In this RPT, the runners' position must be carefully controlled in order to preserve the small gap between them.

Traditionally, this is achieved by using timing gears. However, these timing gears introduce friction and wear into the system, lowering mechanical efficiency and reliability. In ALPHEUS, a novel PTO design is proposed, which uses two separate AF-PMSMs for the two lobes and perform accurate position control in order to manage the water gap.

However, in extreme dynamic scenarios, which are prominent in a grid supporting system, the timing gears are still present as a backup.

This way, in normal circumstances, no torque is transferred between the timing gears, averting their losses.

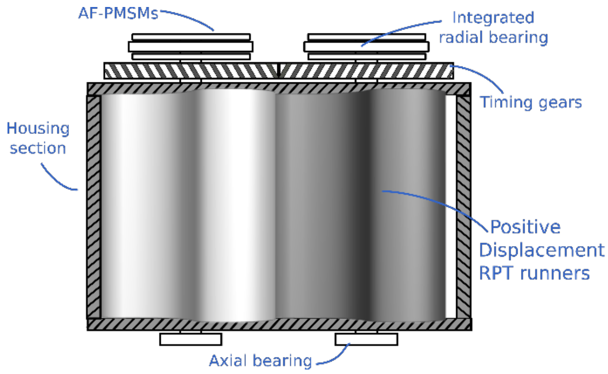
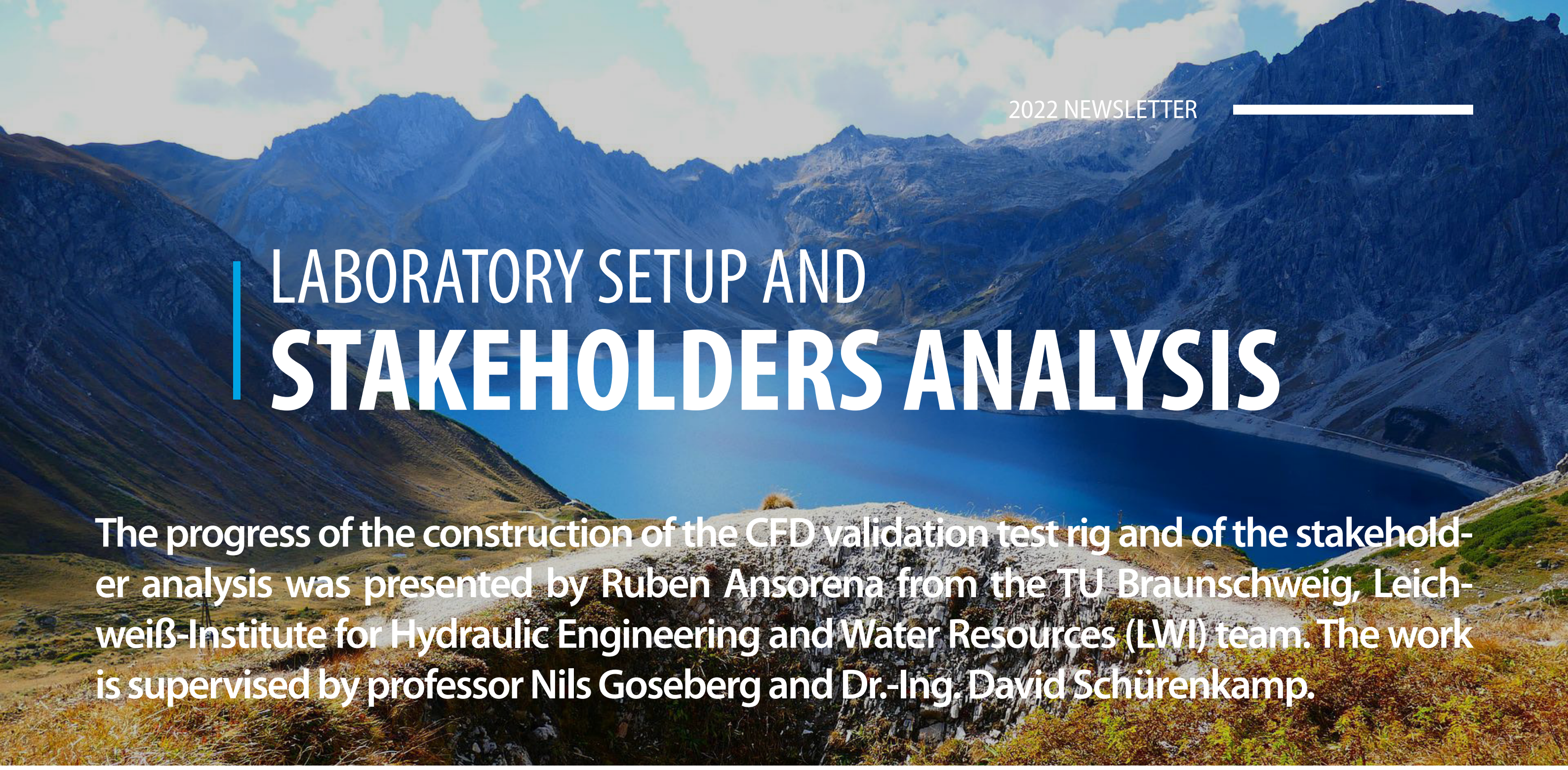


Figure 5 - PTO for the positive displacement RPT

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.

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.



LABORATORY SETUP AND **STAKEHOLDERS ANALYSIS**

The progress of the construction of the CFD validation test rig and of the stakeholder analysis was presented by Ruben Ansorena from the TU Braunschweig, Leichweiß-Institute for Hydraulic Engineering and Water Resources (LWI) team. The work is supervised by professor Nils Goseberg and Dr.-Ing. David Schürenkamp.

The CFD validation test rig construction is on its final stages. As the name indicates, the test rig is constructed to validate the CFD models used for the design of pump-turbine devices suitable for variable low-head operation. The test rig allows for operation in both turbine and pump modes. It uses the height difference between two tanks to provide head, which is a singularity of this test setup compared with the conventional high-head test rigs that use pumps for this purpose.

The Figure 1 and Figure 2 below show how is the water flow (red arrows) within the test rig for the different test modes:

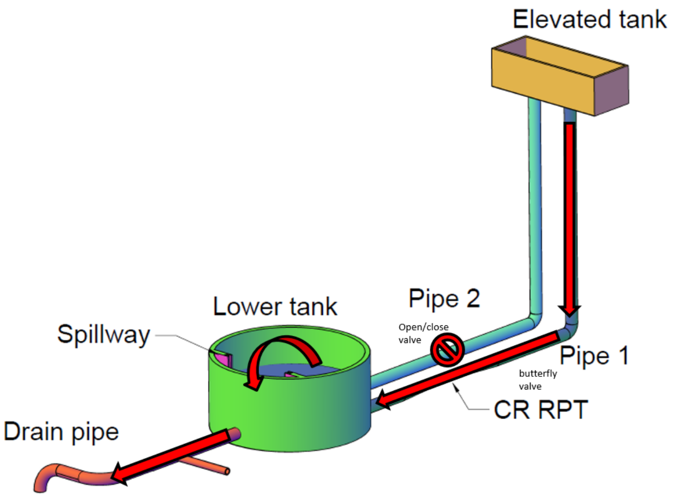


Figure 1 - Flow of water during the turbine mode tests

During the turbine mode tests shown in Figure 1, the valve in pipe 2 is closed. The water flows from the elevated tank within pipe 1 and through the RPT into the green tank. Then it overflows the spillway (which sets up the water height inside the green tank, and thus the head difference between the two tanks) and leaves via the drain pipe to be later recirculated into the elevated tank.

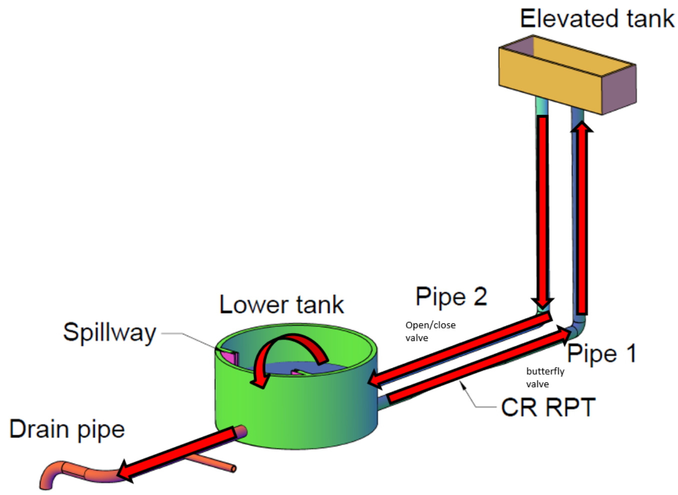


Figure 2 - Flow of water during the pump mode tests

During pump mode tests, the water flows from the elevated tank into the green tank via pipe 2. Then, the RPT acting as a pump takes the water up to the elevated tank. The discharge into the lower tank will be a 10% larger than the one being pumped via the RPT into the elevated tank to ensure that some water overflows the spillway. Thus, there will be a constant water level within the Green Tank during operation of the pump tests.

The Contra-Rotating (CR) Reversible Pump-Turbine (RPT) device is currently being manufactured and assembled at the workshop of the LWI laboratory. Some pictures of the current progress (09.06.2022) are shown below:

Figure 3 - Manufacture progress of the CR RPT device at the TU Braunschweig, LWI workshop

When the manufacture of the RPT is finished, it can be incorporated within the test rig. And then, finally the electrical elements necessary for operation of the RPT runners will be installed. These will be delivered on September (due to global chain issues) and installed as soon as possible to start with the tests. The tests will then happen between November and December of 2022. The data that will be recorded and analyzed is the following:

- Water discharge within pipe 1
- Absolute water pressures at different points in the proximities of the RPT runners
- Water velocities at different points in the proximities of the RPT runners
- Torque at the axis of the RPT device
- RPMs at the axis of the RPT device

On the other hand, a stakeholder analysis is ongoing. The analysis is developed with a twofold goal in mind:

- To show ALPHEUS technology
- To open stakeholder participation in the development of the ALPHEUS project: to analyze techno-economic feasibility and scalability of the ALPHEUS technology based on stakeholder expertise, and to identify challenges respecting legal, regulatory and environmental processes.

The stakeholder analysis of the ALPHEUS project will cover the following steps:

1. Stakeholder identification: 190 potential stakeholders have been identified. A broad number since the ALPHEUS project involves technologies from civil, mechanical and electrical engineering. Besides, collaboration with governments and local groups will be necessary to discuss implementation of the low-head pumped hydro storage technology.

2. Stakeholder classification: this is a classical tool of the stakeholder analysis in which stakeholders can be classified according to their power and interest in the project.

3. Stakeholder involvement: In our case, ALPHEUS will develop two questionnaires and organize two stakeholder meetings:

- Stakeholder questionnaire 1
- Technical stakeholder meeting
- Stakeholder questionnaire 2
- Regulatory and environmental stakeholder meeting

The first stakeholder questionnaire was already developed and filled in by 34 stakeholders. It was developed to make a first contact with stakeholders and to analyse the general stakeholder views on the low-head PHS technology. In general, the stakeholders showed interest in the technologies being researched by ALPHEUS (Figure 4) and so far, they showed no red lines for its construction (Table 1).

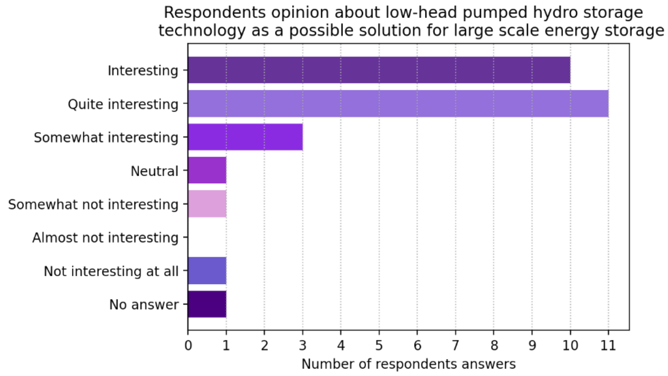


Figure 4 - Respondents opinion about low-head pumped hydro storage technology as a possible solution for large scale energy storage

Answer	Counts	Percentage from total
Yes, if in general brings benefits to the community/region/country	5	38%
Yes, in any case	3	23%
Yes, if landscaping is performed	2	15%
Yes, if I can access it (restaurants/breaches/recreation areas)	0	0%
No, I do not want to see anything at the coasts	0	0
No, I am afraid it could be dangerous	0	0
No, these plants may be too ugly	0	0
I don't know	2	15%
No answer	1	8%

Table 1 - Participant's views on having a low-head Pumped Hydro Power station in the coastal area next to your residence, work and/or usual beach

Further results of this questionnaire are still to be published. Then, the technical stakeholder meeting is currently being organized. This meeting will happen on November 4th and will have the goals of:

- Show ALPHEUS technology
- Get stakeholder feedback on
- Techno economic feasibility of the project
- Scalability of the technology
- Research and innovation fields that are of interest for both ALPHEUS and stakeholders

The second stakeholder questionnaire will be developed to assess the legal, regulatory and environmental issues for the commissioning of example sites. More details on this are still to come. As so as for the last stakeholder meeting that will gather regulators and environmental experts.

ABOUT THE AUTHORS

Since June 2020, **Ruben Ansorena Ruiz** is a PhD student at the Hydromechanics, Coastal and Ocean engineering department of the Leichtweiß-Institute under the supervision of Nils Goseberg. After studying civil engineering at 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.

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, 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.

Since 2011, **David Schuerenkamp** is working in research and teaching at the Leichtweiß-Institute of the TU Braunschweig in the division of hydromechanics, coastal and ocean engineering, since 2018 as senior research associate. He is leading the work group "Natural Hazards and Coastal Protection" including research projects regarding coastal structures, coastal protection and natural hazards. He supervises Ruben´s work for ALPHEUS together with professor Goseberg.

FISH MORTALITY
TO BE EXPECTED FROM PROTOTYPE SCALE TURBINE

In the EU, a whole series of Directives govern where a hydropower plant can be built, such as the Water Framework Directive, Habitats and Birds Directives. The safeguarding of biological diversity at the species, habitat and ecosystem level is of considerable importance. Assessing the environmental impacts, in particular the consequences of entrainment or the involuntary passage of fish through the turbine, is fundamental during the planning process and operation of all hydropower facilities.

Injury and mortality can occur through several means from hydroelectric components (e.g., freefall from passing over a spillway, mechanical strikes from turbine blades, injuries from turbulence and water pressure associated injuries) (Figure 1). The severity of the impact of turbine passage is dependent on technical characteristics such as the rotation speed, turbine diameter, number of blades and blades angle.

Resulting injuries include spine deflection, amputations, hemorrhages, bruises, emboli and scale loss. There are no generally applicable standards for a classification of various injury types and intensities at different body parts, which would be necessary to assess the fish-friendliness of all hydropower techniques.

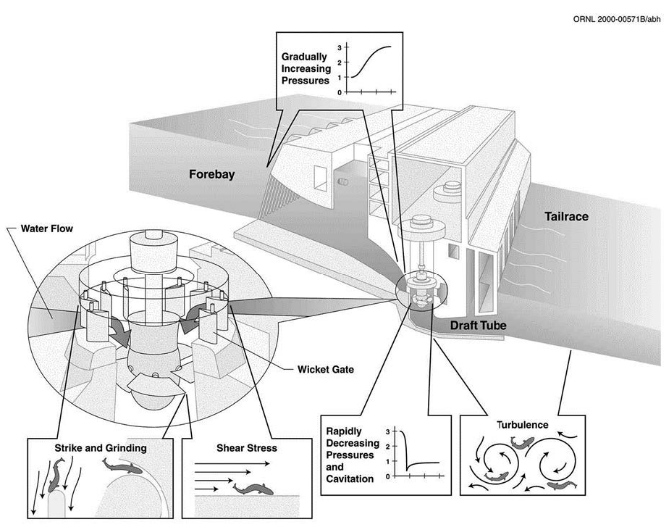


Figure 1 - Locations within a hydroelectric turbine at which particular injury mechanisms to turbine-passed fish tend to be most severe. (Čada, Glenn F. "The development of advanced hydroelectric turbines to improve fish passage survival." Fisheries 26.9 (2001).)

One of the principal aims of ALPHEUS project is the study of the applicability of turbines optimized for highest efficiency and lowest fish mortality. Fish friendless is estimated using a software called Biological Performance Assessment (BioPA) developed by Pacific Northwest National Laboratories (PNNL). BioPA estimates the relative risk of adverse effects that fish may experience during turbine passage. It is based on the use of computational fluid dynamics (CFD) and fish dose-response relations, to: simulate a representative flow field and associated hydraulic stressors throughout the passage route, calculate the expected trajectory of fish from a given starting location, use the exposure history along the trajectories to develop a frequency-of-exposure estimate and adverse-effect estimate for each hydraulic stressor.

Mechanism	P0 R1 10 MW	P0 R2 10 MW	P0 R1 5 MW	P0 R2 5 MW	P1 R1 10 MW	P1 R2 10 MW
Rapid decompression	0.00%	0.00%	0.00	0.00%	0.00%	0.00%
Fluid Shear	0.00%	0.00%	0.00	0.00%	0.00%	0.00%
Collision	4.73%	3.04%	5.71%	0.00%	8.34%	0.00%

Mechanism	P0 R1 10 MW	P0 R2 10 MW	P0 R1 5 MW	P0 R2 5 MW	P1 R1 10 MW	P1 R2 10 MW
Rapid decompression	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%
Fluid Shear	47.01%	42.82%	49.97%	42.74%	56.32%	35.69%
Collision	8.13%	4.93%	19.39%	0.00%	15.54%	0.12%
Turbulence	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%

Figure 2 - Probability of adverse passage for Anguilla anguilla and Salmo salar.

Anguilla Anguilla - body lenght: 30cm (top), Salmo Salar - body lenght: 15cm (bottom).

For this preliminary study, two Shaft-Driven variable-speed Contra-Rotating propeller Reversible Pump Turbine (SDCRRPT) prototypes design elaborated by Advance Design Technology were chosen. Both prototypes P0 and P1 have been simulated in CFD for an operating condition in turbine mode with power output of 10 MW and 5 MW. Every prototype has two rotors. Anguilla anguilla and Salmo salar are the two target species selected, based on conservation importance and different sensitivity to stressors. Both species were analyzed for mortality to rapid decompression, shear stress and collision. The probability of adverse passage shows that rapid decompression is the least impacting stressor, regardless of the species considered. Both rotors in all operating conditions produced high values of nadir pressure, which were related to minimum risk of mortality and injuries (Figure 2). The stressor raising the greatest concern is shear, mortal injury rates in the simulated passage of salmon ranged from 42.82 to 56.32%. For eels is near zero.

Combining the exposure probability (Pe) of stressors determined through CFD stream trace sampling with biological adverse response at a given exposure models information (Pm) obtained from laboratory studies, BioPA returns a performance score, or Passage Quality Index (PQI), a relative risk of fish damage. The PQI is a relative performance score that can be used to make relative comparisons between run conditions or design solutions.

The decompression and shear stress PQIs for eels had the highest values in all simulated runs. The PQI values for collisions ranged from 458 to 500, with rotor R2 always resulting more fish friendly than the corresponding rotor R1 within the same operating condition.

In all simulated configurations, maximum decompression and turbulence PQIs were returned for salmon. As in the case of eel, the greater fish friendliness of rotor R2 compared to rotor R1 was confirmed. The lowest PQI values were related to shear exposure: while PQIs of the P0 runs at 10 MW or 5 MW were similar, the difference between

PQI values resulting from R1 and R2 simulations of P1 was much more pronounced. Very large ranges of PQI values were also shown in collisions. For rotor R2, they ranged from 475 to 500; for rotor R1, the lowest values were found for P1 - 10 MW with 422 and for P0 - 05 MW with 403.

The cumulative PQIs for salmon and eel follow a similar trend to those of the individual damage mechanisms, confirming the higher fish friendliness of rotor R2 than rotor R1. The difference between the two rotors is more evident in the case of salmon, especially in the configuration P1 - 10 MW and for prototype 0 in the 5 MW condition.

For eel, no marked differences were reported among operating conditions, prototypes or rotors, and the PQIs values were always very high (Figure 3).

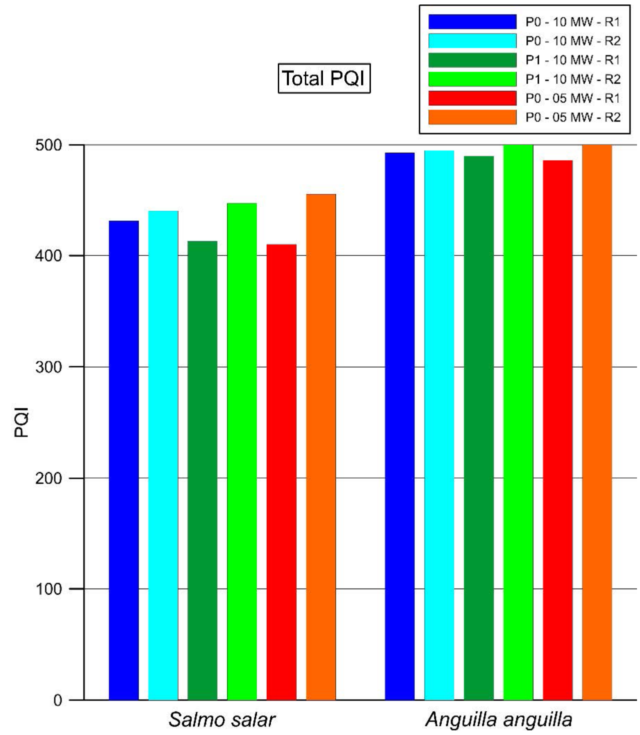


Figure 3 - Cumulative Passage Quality Indexes per target species, operating condition and rotor.

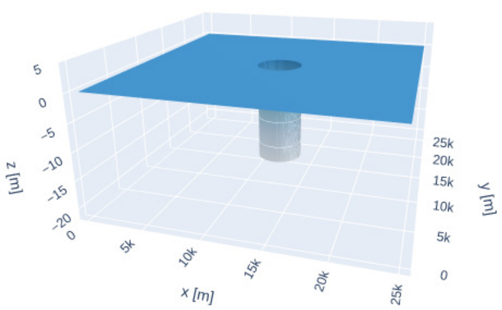
ABOUT THE AUTHOR

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).

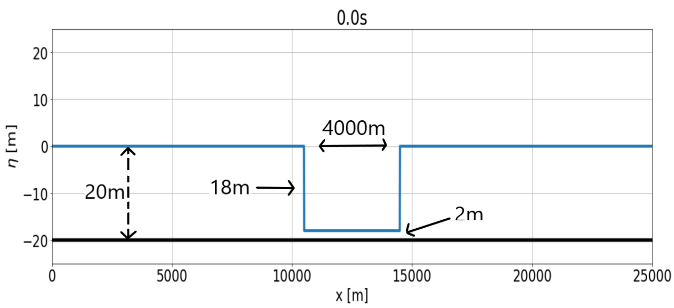
DAMBREAK SCENARIOS FOR **ASSESSMENT OF OFFSHORE** HYDROPOWER BASINS

Before an artificial island with low-head pump storage facilities can be realized in the North Sea, the construction of the circular dam and location must be evaluated in the context of a possible structure collapse. If the circular dam was constructed with a basin higher than the surround water level, a dam break scenario poses a high risk to the environment near the dam. However, a lower basin far offshore built in relative shallow water could also be of potential hazard. It is therefore necessary to assess the wave field in the surrounding area and close to shore after a potential failure of such a dam structure.

In order to evaluate the risk, we assume a total collapse of the entire dam structure, i.e. the circular wall, which constitutes the dam structure is collapsing instantaneously. Of course, different height and radius of the structure will effect the impact of the dam break, but for simplicity and to select a scenario, we will consider the dimensions shown in Figure 1.



a) Circular lower basin



b) Cross-section of a circular lower basin

Figure 1 - The initial dimensions of a circular lower basin a) and a corresponding cross-section b)

Considering a simultaneous collapse, the water will flow into the lower basin towards the center and collide before a wave front starts to move outward in the opposite direction. For estimation of this scenario, two mathematical models are used, one hydrostatic model based on the shallow water equations and one phase-resolving Boussinesq-type model where the dispersive effects are included.

In Figure 2, the wave propagation given by these two models are shown. In a) the wave front has travelled about 2500 m away from the dam structure. By zooming in on the wave front as in b), the two solutions give different wave shapes where the hydrostatic solution describes a sudden bore front and the dispersive solution shows oscillations due to dispersive effects. In c) a closer look at the same dispersive solution is shown to study the wavelength, wave height, and wave steepness.

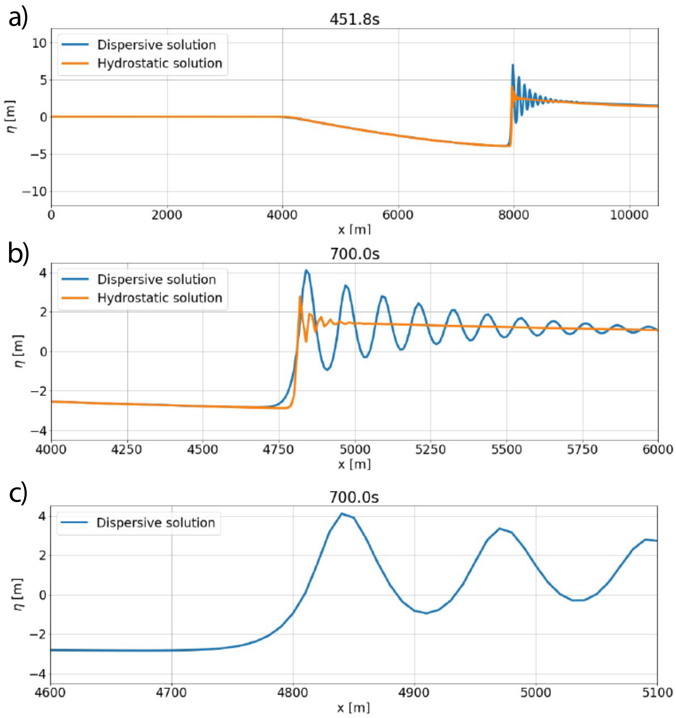


Figure 2 - Shows a dispersive solution and a hydrostatic solution of the wave front travelling away from the dam structure after a instantaneous collapse

The surrounding water depth and the effects of the bathymetry are other factors that will change the outcome from a extreme collapse of the entire structure. Using real bathymetry from Basque Coast, South-west France, the effect of bathymetry can be evaluated.

Placing a lower basin with circular construction in the upper left corner in Figure 3, the dispersive solution provides a clearer picture of how the wave shape changes when the waves propagate over a real bathymetry. In a) and b) the wave height and wavelength are changing due to the decrease in depth as the waves are propagating towards shore. The wave front has travelled closer to shore in c) and the whole wave field has been affected by the bathymetry.

Thus, the water depth and bathymetry are factors that are necessary to include in the evaluation of the dam break risk scenario.

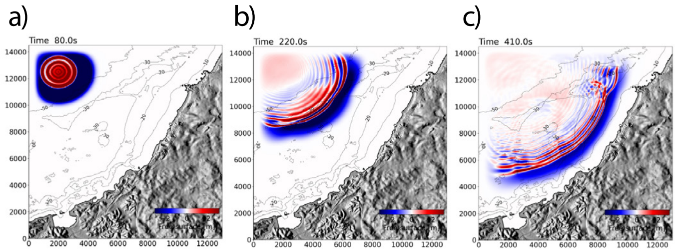


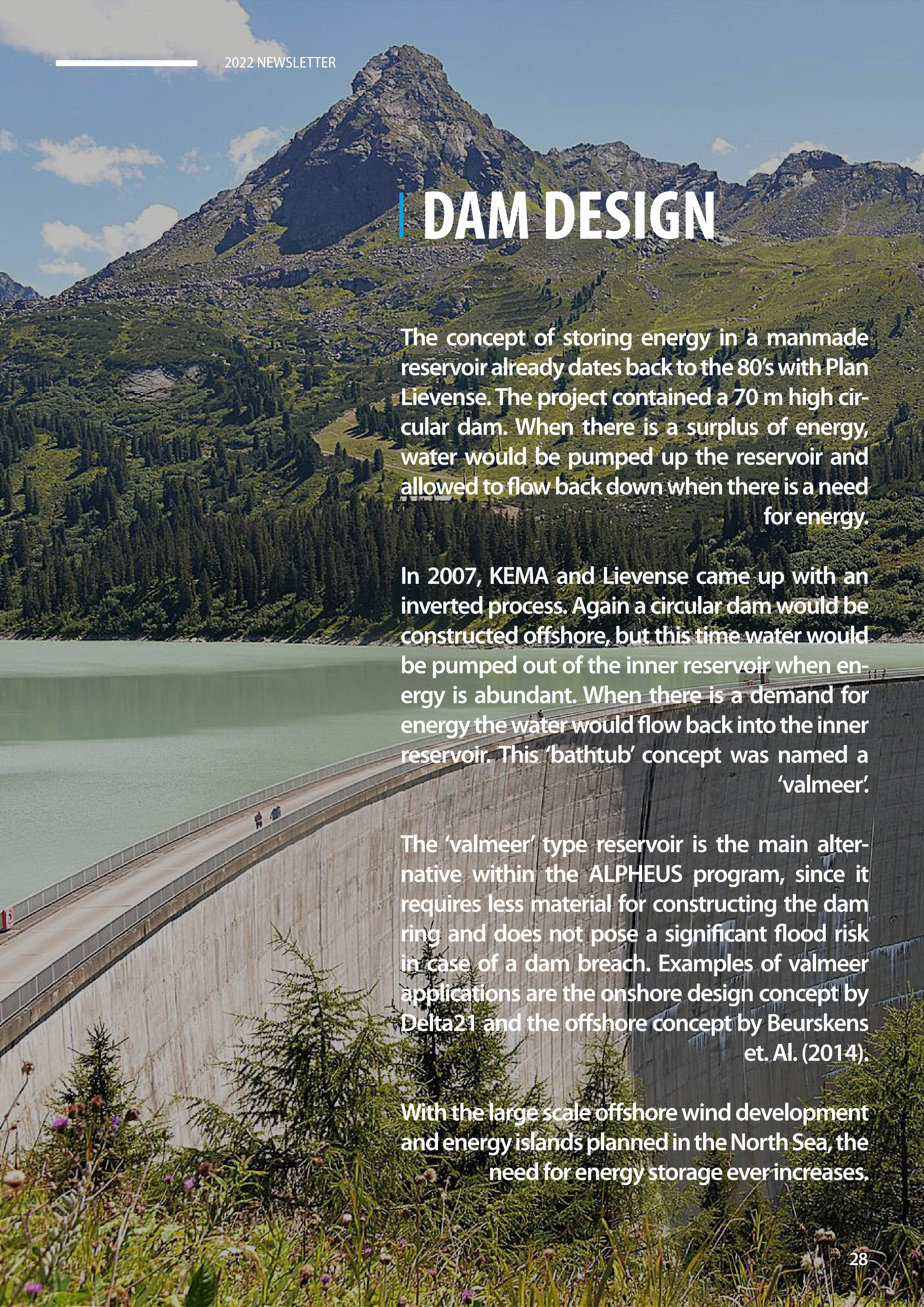
Figure 3 - A dam break scenario given over real bathymetry from Basque Coast, South-west France

ABOUT THE AUTHORS

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.

Fatima-Zahra Mihami is a PhD student at the University of Pau et Pays de l'Adour (UPPA). Her research work is deeply rooted in the E2S chair HPC-Waves and plays a key role in one of the two chair axes, which is numerical development with an emphasis on practical applications. The thesis aims to develop a new phase-resolving nearshore wave model for high-resolution, real-time forecasting of coastal hazards.

Maria Bjørnestad is a postdoctoral researcher and part of E2S chaire "Coastal Waves and High Performance Computing" at Université de Pau et des Pays de l'Adour, France. She has a PhD degree from Department of Mathematics, University of Bergen, in Applied and Computational Mathematics. For ALPHEUS, the Chair HPC-Waves is planning to help to identify and assess potential sites in the North Sea and Atlantic for the construction of low-head pumped hydro storage facilities.



DAM DESIGN

The concept of storing energy in a manmade reservoir already dates back to the 80's with Plan Lievense. The project contained a 70 m high circular dam. When there is a surplus of energy, water would be pumped up the reservoir and allowed to flow back down when there is a need for energy.

In 2007, KEMA and Lievense came up with an inverted process. Again a circular dam would be constructed offshore, but this time water would be pumped out of the inner reservoir when energy is abundant. When there is a demand for energy the water would flow back into the inner reservoir. This 'bathtub' concept was named a 'valmeer'.

The 'valmeer' type reservoir is the main alternative within the ALPHEUS program, since it requires less material for constructing the dam ring and does not pose a significant flood risk in case of a dam breach. Examples of valmeer applications are the onshore design concept by Delta21 and the offshore concept by Beurskens et. Al. (2014).

With the large scale offshore wind development and energy islands planned in the North Sea, the need for energy storage ever increases.

Figure 1 - Artist impression of Delta21 next to the port of Rotterdam by Van Eeden (2021)

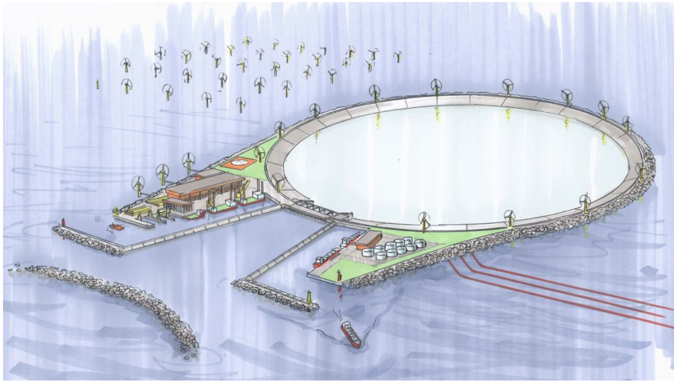


Figure 2 - Artist impression offshore valmeer by Beurskens et. al. (2014)

Adding storage to these future energy hubs has a large economic potential since investments in the transmission network can be reduced and energy can be traded with multiple interconnected countries. Therefore the research focusses on offshore applications of PHS. The large economic opportunities for offshore energy storage combine with a more challenging natural environment. The harsh wave conditions put the infrastructure to the test and hamper the construction works. To limit damage during construction and withstand the rough conditions during operation a caisson dam is proposed, as shown below. Since the exact location is unknown, a parametric design of the caisson dam has been made for varying boundary conditions

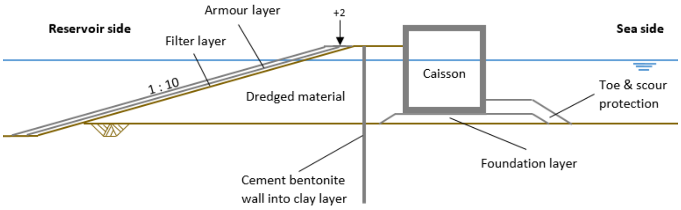


Figure 3 - Dam design concept

like the water depth, wave height and soil properties. The caisson is dimensioned for floating stability during transport and resistance against sliding, overturning, bearing capacity failure and overtopping during construction and operation. Manufacturing the large number of caissons is foreseen by using the gantry slipform method, which can either take place on land or by using a floating dock. Transportation from the construction site to the project location can be done per single caisson by tugboats or per multiple caissons by a semi-submersible vessel. The choice for the fabrication and transportation of the caissons depend on the project location and nearby port facilities. The future research will fine-tune the dam design concept and develop feasibility studies for a few specific locations in the North Sea.

ABOUT THE AUTHORS

Lucas de Vilder is a researcher within the department of Civil Engineering at the Delft University of Technology. His research is part of ALPHEUS's WP5 and focuses on the dam structure. Questions he likes to answer are: what should a dam in the middle of the North Sea look like? And how can we possibly construct it considering the harsh wave conditions? With his personal experience with dyke strengthening projects in the Netherlands and knowledge drawn from the industry about offshore construction he looks to find the critical solutions.

THANK YOU