HydroCen

NORWEGIAN RESEARCH CENTRE
FOR HYDROPOWER TECHNOLOGY

OVERVIEW OF MSC - PHD - POST DOC. **2018**

HydroCen Report nr.3

Publisher: HydroCen
Editor in chief: Hege Brende
Editor: Kari Haugan

ISBN: 978-82-93602-02-6

Photo credits:
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Layout: NTNU Grafisk senter
Print: Skipnes

Content

HydroCen

Norwegian Research Centre for Hydropower Technology

Energy demand is increasing, and hydropower is to a large extent regarded as an essential key in the transition into a fully renewable energy system.

Our research areas include hydropower structures, turbine and generator, market and services and environmental design.

The Norwegian University of Science and Technology (NTNU) is the host institution, and main research partner together with SINTEF Energy and the Norwegian Institute for Nature Research (NINA).

HydroCen has about 50 national and international partners from industry, R&D institutes and universities.

The annual budget is NOK 48 million per year, totalling NOK 384 million over eight years. HydroCen is a Centre for Environment-friendly Energy Research (FME).

The FME scheme is established by the Norwegian Research Council, and the objective is to establish time-limited centres, which conduct concentrated, focused and long-term research of high international standards to solve specific challenges within its field.

The Norwegian hydropower system:

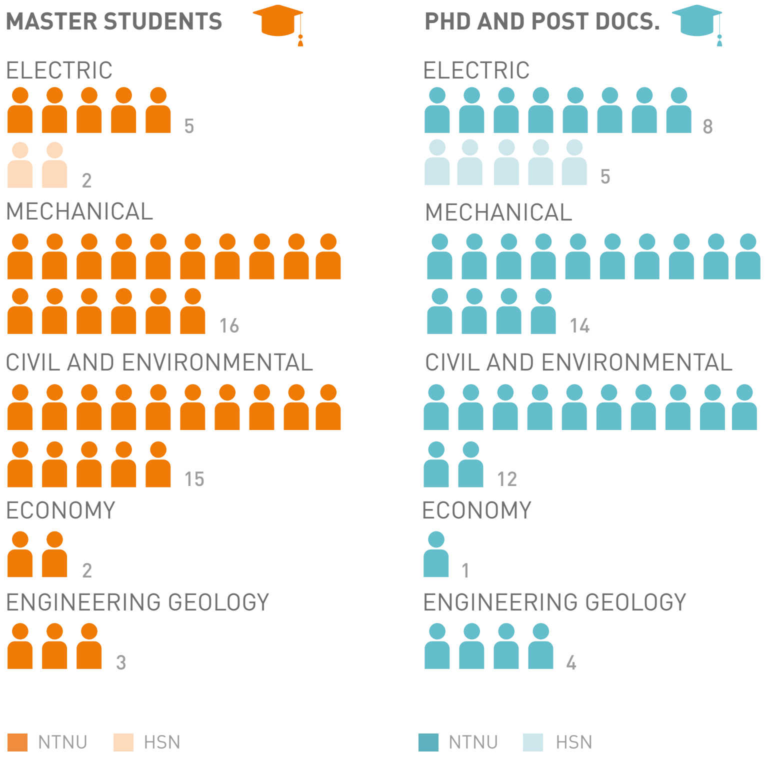
- *Norway is the sixth largest hydropower producer in the world*
- *Norwegian reservoirs represent ~50% of Europe´s storage capacity*
- *Hydropower supplies over 95% of the national electricity production*
- *The system generates an average annual production of 130 TWh*
- *It has an installed capacity of 31 000 MW*
- *It generates a production value of ~35 billion annually*

Partner overview

Overview of students and research fellows

Overview of the number of master students, PhD and Post Docs. connected to NTNU and HSN in spring 2018.

The candidates are sorted within the respective fields; Electric, Mechanical, Economy, Civil and Environmental and Engineering Geology.



PhD and Post doc. in HydroCen, funded by HydroCen

PhD and Post doc. in HydroCen, employed in 2017-2018			
Name	PhD Post doc.	Period	Topic
Andreas Kleiven	PhD	2017-2021	Investment Decisions in Upgrading and Refurbishment of Hydropower Plants
Bibek Neopane	PhD	2017-2021	Long-term impact on unlined tunnels of hydropower projects due to frequent start stop sequences
Celine Faudot	Post doc.	2017-2019	Fatigue Loads on Turbines attached to a Conduit System
Ganesh Hiriyanna Rao Ravindra	PhD	2017-2020	Embankment dam safety under extreme loading conditions
Helene Njølstad Dagsvik	PhD	2017-2020	Reversible Pump-Turbines in Existing Power Plants
Henki Ødegaard	PhD	2017-2021	Rock stress and pressure tunnel design
Håkon Sundt	PhD	2017-2020	Environmental design for multiple interests under future flexible hydropower operation
Igor Iliev	PhD	2016-2019	Design of a high-head Francis turbine for variable speed configurations
Kristian Forfot Sagmo	PhD	2017-2020	Flow manipulation for improved operation of hydraulic turbines
Lena Selen	PhD	2017-2021	Effects of swelling rock and swelling clay in water tunnels
Livia Pitorac	PhD	2017-2020	Upgrade of hydropower plant capacity influences the behavior of hydraulic transients in waterways and surge tanks
Ola Haugen Havrevoll	PhD	2017-2021	Rock traps in pumped storage and peaking power plants
Raghbendra Tiwari	PhD	2018-2020	Frequency converter solutions and control methods for variable speed operation of pump storage plant
Tor Inge Reigstad	PhD	2018-2020	Grid integration of variable speed hydro power plant
Shohreh Monshizadeh	PhD	2018-2021	The Flexible Hydro Power Unit

Department of Civil and Environmental Engineering

MASTER THESIS

Maren Benjaminsen

Department of Civil and Environmental Engineering

Spring 2018

UAV-based method for collection of data for river engineering

Supervisor: Nils Rüther
In cooperation with: FIThydro

NTNU

Background

Unmanned Aerial Vehicles (UAVs) are increasingly used in the field of engineering surveys. In river engineering, or in general water resources engineering, UAV based measurements have a huge potential. For instance, indirect measurements of the flow discharge using e.g. large-scale particle image velocimetry (LSPIV), particle tracking velocimetry (PTV), space-time image velocimetry (STIV) or radars have become a real alternative for direct flow measurements.

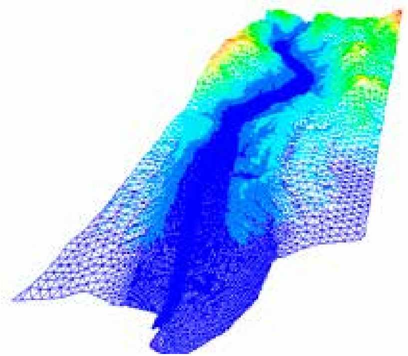
Within this thesis, two methods for the detection of the surface velocity will be compared. Based on the project work where the efficiency of different tracers have been tested, several test cases will be investigated. The goal of the thesis is to define the application range of such a method and to investigate further potential of this technique. The thesis is coupled to several projects where this technique can be a useful source of data collection. Test cases of the ongoing EU-project FIThydro will be investigated. FIThydro is about the enhancement of fish population in regulated rivers and surface water velocities are central data input for such investigations.

Digital Elevation Model in VisualSFM

Background

Due to climate change, floods in small and steep catchments are likely to increase with up to 60% in near future. In rivers with small catchment areas and high river gradients, short duration torrential rain leads to a rapid rising flood. Contrary to floods in larger river systems, where floods are characterized by a gradual increase of water depth due to rainfall of longer duration, increased discharge is followed by extensive erosion, deposition and channel avulsion. These processes leads to increased hazard due to high flow velocities inside and outside the natural river channel. After several dramatic flash floods in recent past affecting small, local communities, the attention to the problem is increasing.

This project will serve as a contribution to the development of methods for detecting and assessing hazard and risk of flash floods in torrential rivers using 2D numerical models. Simulating flood events in a test catchment, the project seeks to identify the limitations and critical input parameters associated with the use of 2D models, targeting general recommendations for simulating similar catchments.



MASTER THESIS

Sondre Fossheim

Department of Civil and Environmental Engineering

Spring 2018

2D hydraulic modelling of torrential rivers

Supervisor: Oddbjørn Bruland
Co-supervisor: Knut Alfredsen

NTNU

MASTER THESIS

Amir Nasser Katirachi

Department of Civil and Environmental Engineering

Spring 2018 – Fall 2018

Evaluation of snow simulations in SHyFT

Supervisor:
Knut Alfredsen
Co-supervisor:
Oddbjørn Bruland

NTNU

Background

Snow is a very important component in the hydrological cycle in Norway and crucial for determining reservoir operation during the spring flood to ensure full reservoir and as little flood spill as possible.

The Statkraft Hydrological Forecasting Toolbox (SHyFT) is a newly developed hydrological toolbox that is used for forecasting inflow in the Statkraft system. This is a flexible system in which a model can be custom designed for various purposes.

The SHyFT toolbox currently has three different methods for simulating snow accumulation and storage, and these are not yet evaluated with snow data. The purpose of this master thesis is to evaluate the SHyFT snow routines against observed snow data from satellite images and snow measurements in the field.

Background

Changes in land use and climate are important factors that affect the runoff from small catchments. In recent years, there has been an increased focus on floods and extreme values, due to its importance for both planning and design in small catchments. The use of hydrological models is a leading tool for flood analysis and studies on local changes in such catchments. A big challenge is that small catchments usually are ungauged, which means that calibration and validation of models is impossible. Klima2050 is a Centre of Research -based Innovation (SFI), who is actively working with flood estimation from ungauged basins and the effects of both land use and climate.

Gaula river in Trøndelag county (Wikipedia)

In cooperation with Klima 2050, this thesis will use a regionalization method to simulate runoff from small catchments in Soknedal municipality, where there has been registered culvert failures along the railway between Garli and Støren. Based on the simulation results, the effects of climate change and land use is to be analyzed. The adapted DDD (Distance Distribution Dynamics) -model will be the foundation of this project.

MASTER THESIS

Bao-Thy Huynh

Department of Civil and Environmental Engineering

Spring 2018

Effects of land use and climate change on runoff from small catchments

Supervisor:
Knut Alfredsen
Co-supervisor:
Aynalem Tsegaw
In cooperation with:
Klima 2050

NTNU

MASTER THESIS

Eivind Sønnesyn Willmann

Department of Civil and Environmental Engineering

Spring 2017

Three-dimensional numerical modelling of water flow over a rough channel bed

Supervisor:
Nils Rüther
Co-supervisor:
Nils Reidar B.Olsen

NTNU

Background

A three-dimensional numerical model is used to simulate the water flowfield over a rough channel bed, utilizing the open source computational fluid dynamics toolbox OpenFOAM. The geometry of the numerical model is a replication of a physical laboratory flume experiment with a gravel bed. The roughness of the channel bed is represented in the numerical model by generating a very fine computational grid fitted to the topography of the bed, explicitly resolving the shapes of the gravel structures. Three different turbulence modelling approaches are used: Reynolds-Averaged Navier-Stokes (RANS) based k ¡² and k ¡!, and a Large-Eddy Simulation (LES). A presentation of relevant theory is given. Tests are conducted to investigate the sensitivity of the numerical model approaches to changes in grid resolution, wall treatment, numerical schemes, time steps and sizes of simulation domains. The RANS test results show a low sensitivity, whereas the LES results show a larger variation. The latter behaviour is not fully understood, but is believed to be related to effects caused by the use of cyclic boundary conditions. Final simulations are set up based on the findings of the tests. Double-averaged velocity and turbulent kinetic energy profiles are computed for the respective simulations, and compared with data from a physical laboratory experiment. Reynolds shear stresses are also computed for LES. The simulation results are generally in reasonable agreement with experiment data.

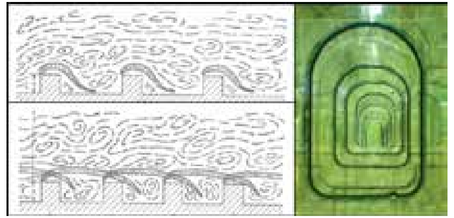
Background

The estimation of the hydraulic resistance in rough (rock-blasted) tunnels is critical in hydropower engineering. To investigate the tunnel conveyance capacity in hydropower systems, the so-called Birkeland method* has been derived at the Norwegian Hydraulic Laboratory (NTNU) to simulate the tunnel wall roughness by an equivalent strip roughness glued inside smooth tunnel models.

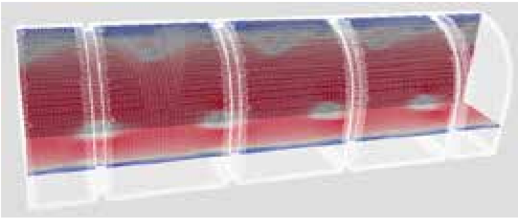
Whilst widely used in the hydraulic laboratory at NTNU, some aspects of the method are yet to be tested; such as its validity for a wider range of discharges and roughnesses, as well as the impact of the inflow conditions on the head losses and flow field between the strips of the physical model.

As a part of the investigations conducted within the Tunnel Roughness project, the validity of the Birkeland approach is tested numericaly within the OpenFOAM CFD package (RANS and RANSTT simulations), and compared to an experimental dataset acquired in 2017.

The Tunnel Roughness project is a Knowledge-building Project for Industry funded by the Norwegian Research Council and a consortium including NVE, TronderEnergi, BKK and NVKS. More information and updates can be found at www.ntnu.edu/nvks/tunnelroughness

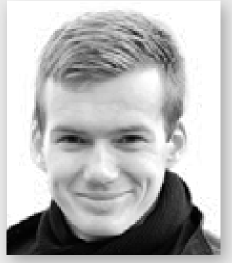


Sketch of vortex generation as described by Chow (McGraw-Hill - 1959) and example of strip roughness in a tunnel model (*Birkeland, Master thesis NTNU - 2008)



Velocity field estimations in a strip roughness tunnel model – E. Mølmann

Erik Mølmann



Department of Civil and Environmental Engineering

Spring 2018

Numerical simulation of water flow in a laboratory tunnel

Supervisor:
Nils-Reidar B. Olsen
Co-supervisor:
Pierre-Yves Henry

NTNU

MASTER THESIS

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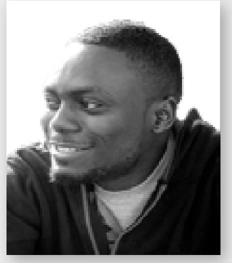
Kofi Opare



Department of Civil and Environmental Engineering

Spring 2018

Dynamic load measurements at Riprap Toe

Supervisor: Fjola Gudrun Sigtryggsdottir

NTNU

Background

Embankment dams are vulnerable to extreme flood events in turn leading to accidental overtopping of the dam core or even the dam crest as the dam is mainly made composed of pervious and erodible materials. Riprap defined as a permanent and erosion resistant ground cover of large elements such as natural rocks or artificial elements, has proven to be a cost-effective measure for erosion protection, structural stability and slope stabilization. Placed on the downstream slope of a rockfill dam, riprap can provide erosion resistance under throughflow and/or overflow conditions.

Numerous studies looking into the stability of embankment dams with steep downstream slopes (S>50%) under overtopping conditions have suggested that the probability of initiation of failure at the toe of embankment dams can be significant. This study is aimed at better understanding dynamic load generation mechanism at the toe which is one of the major factors influencing toe stability.

The existing physical model in the hydraulics laboratory, NTNU is used with slight modification to incorporate load measurement devices at the toe of the riprap as depicted in the picture below. A number of tests will be conducted and the results analyzed to arrive at a design criteria for the toe of the riprap.

Model riprap with load measurement device fixed at the toe.

Overtopping test showing highly turbulent flow at the toe of the riprap

Background

El Canada is a 47 MW hydropower plant located in Retalhuleu, Guatemala. It takes water from the Samalá river, which has a high sediment yield. An average of 50,000 m^3 of sediment are deposited annually in the regulation pond. The sediment is highly cohesive and contains garbage, debris and organic material.

During the last years, the sediment income in the regulation pond has been handled by continuous dredging. Three different dredges have been used: Conventional diesel dredge, electric powered dredge and hydrosuction dredge. The information of the daily dredging has been recollected during at least five years (since 2012), but it has not been thoroughly analyzed.

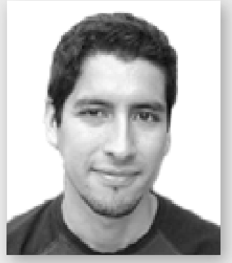
The main objective of the thesis is to assess the sediment handling strategies in the regulation pond of El Canada HPP. For this matter, the sediment yield and its potential damage to the power plant will be estimated. Besides, the current sediment handling strategies will be evaluated. A field trip will be done to recollect all the required information of the catchment, the hydropower plant and the current sediment handling strategies.

Diesel and hydrosuction dredges in the pond.

Sediment samples from a dredge discharge.

MASTER THESIS

Javier Zamora



Department of Civil and Environmental Engineering

Spring 2018

Assessment of sediment handling strategies in the regulation pond of El Canada HPP, Guatemala

Supervisor: Nils Rüther
Co-supervisor: Tom Jacobsen
In cooperation with: SediCon AS and ENEL Greenpower

NTNU

MASTER THESIS

Debora Bardini

Department of Civil and Environmental Engineering

Spring 2018

Direct simulation of surge tank stability

Supervisor:
Kaspar Vereide (NTNU)
Stefano Malavasi (Politecnico di Milano)
Co-supervisor:
Livia Pitorac

NTNU

Background

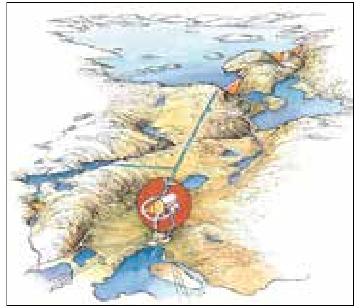
In a hydropower plant, whenever wicket gates in front of turbines are operated, pressure transients will occur. These can result in large pressures affecting the hydraulic system, particularly in the case of fast shutdown from full load. The amplitude of these transients can be reduced by installing a surge tank, which helps by reflecting incoming pressure waves. In addition, a surge tank improves quality of frequency governing. For these reasons, surge tanks should be installed in hydropower plants with long water conduits.

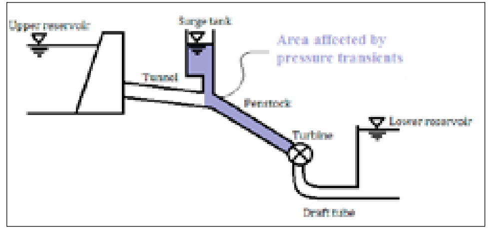
Surge tanks design is crucial in order to deal safely with mass oscillations. Thoma's equation (1910) is the standard method to select the area of a surge tank sufficient to guarantee stability. However, this method is based on simplifications.

Improvements in computational power give the chance to adopt more advanced methods, relying on complex numerical simulations. Prominent among them is the direct simulation method, consisting in a one-dimensional numerical simulation of the entire hydropower plant, without the simplifications adopted in Thoma's equation.

Objectives

The aim of this thesis is to test whether direct simulation represents a more effective and punctual alternative to Thoma's method. In order to answer this question, a one-dimensional numerical model of the Roskrepp power plant, owned by Sira-Kvina kraftselskap, is established and calibrated. The model is then used to compare results of direct simulation method with those of Thoma's method.





Background

In the past couple of years, the energy prices in the Chilean market has plummeted dramatically. This new market environment has imposed a great challenge to hydropower developers in the country. The current energy prices resulted in many projects put into stand-by as they are not economically attractive anymore.

With low energy prices in Norway, and similar climatic conditions, the Norwegian know-how on developing hydropower projects under these conditions can be relevant for the Chilean developers to refloat their projects.

In this regard, the main goal of this thesis work is to study the potential for developing a hydropower project in a glacial river basin in the Chilean Andes using hydrological models, simulating the effects of climate change and applying other practices and criterions traditionally used in Norway.

Rodrigo Suarez Barrera

Department of Civil and Environmental Engineering

Spring 2018

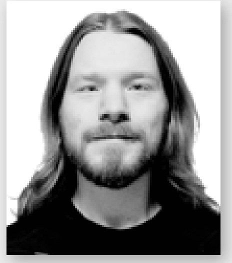
Prefeasibility study of Piedras Negras hydropower plant

Supervisor:
Oddbjørn Bruland
Co-supervisor:
Brian Glover
In cooperation with:
Anpac Energía

NTNU

MASTER THESIS

Menno Kemp



Department of Civil and Environmental Engineering

Spring 2018

Modernised GUI and automated optimizing of hydropower schemes for nMag

Supervisor:
Oddbjørn Bruland
Co-supervisor:
Knut Alfredsen

NTNU

Background

Computer programs have been steadily improving and projects are nowadays almost unthinkable without them.

nMag is a hydropower and reservoir operation simulation program. It has been used by both students and researchers at NTNU for decades to better study the effects of regulation, environmental flow release and other changes done to a water course.

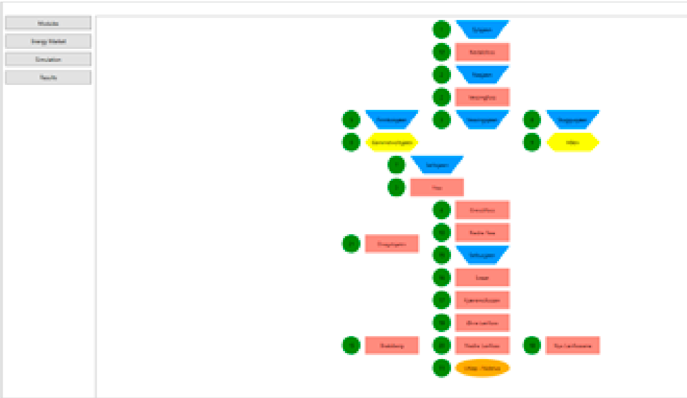
A simple user interface makes it possible to set up all kinds of systems, but by now it has become outdated and user-unfriendly.

Objective

By developing a new UI, the program will be easier to use and can be better integrated in the curriculum. Most of the changes will improve the features that already exist, for example:

- Visual overview / interaction with the modules.
- Less complicated data entry.
- Automatic result handling.

The update will also add the tools to run automatic optimization; to increase production, reduce spill or to satisfy other conditions.



A screenshot of an early version of the new GUI. Different types of modules can be seen in this hydropower scheme.

Background

Freshwater reservoirs are used to regulate flow for water supply, irrigation, navigation and hydropower.The surface areas of these water bodies and several flux rate measurements indicate the the emission of carbondioxide and methane are relevant to the inventories of the greenhouse gas fluxes, but there is insuffcient information and tools to support sound decisions about existing and new reservoirs and the possible mitigation measures.

To quantify the net greenhouse gas (GHG) emission from a reservoir, it is necessary to study emissions before and after the construction of the reservoir, as well as emission due to unrelated anthropogenic sources(UAS). The difference between pre- and post- reservoir emission from the the whole river basin, subtracting the UAS, will be the true net GHG emission.

Method

The pre- and post-impoundment emission of GHG from hydropower measured by SINTEF Energi in reservoirs in (Follsjøen) Norway, (Banje) Albania and (Nam Gnouang) Laos was analysed using G-Res Tool developed by IHA. Also, GHG emissions from Norwegian Reservoirs their average, mean, median and maximum values was calculated and compared with other sources of energy.

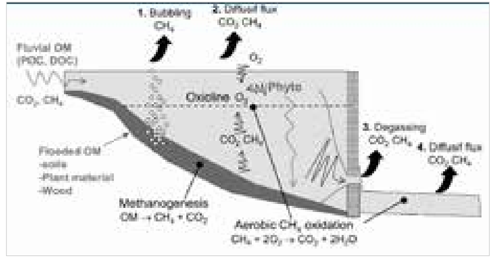
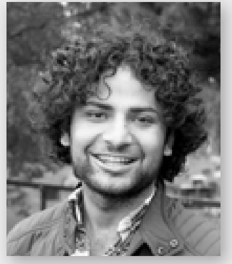


Fig. Green house gas fluxes
From Frederic Guerin

Pranab Raj Dhakal



Department of Civil and Environmental Engineering

Spring 2018

Greenhouse gas emissions from freshwater reservoirs

Supervisor: Oddbjørn Bruland
Co-supervisor: Atle Harby
In cooperation with: SINTEF

NTNU

MASTER THESIS

Lensa Etefa Jotte

Department of Civil and Environmental Engineering

Spring 2018

Water resource management for integrated use of riversand reservoirs in rural areas of developing countries: Gundar River Basin

Supervisor: Oddbjørn Bruland
Co-supervisor:
Tor Haakon Bakken

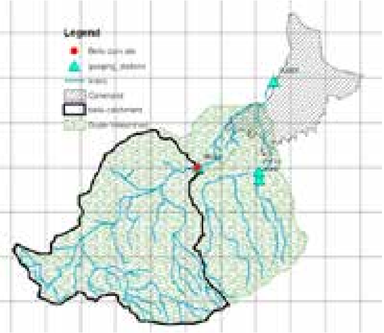
NTNU

Background

Ethiopia, with its aim of becoming the «water tower» of Africa through hydropower production, needs to fully take advantage of the country's 10% of untapped small scale hydro power potential. What is often overlooked in the prefeasibility study of not only small, but indeed, large scale hydro-power plants is the upstream competition for the use of freshwater for irrigation, water supply purposes and impact of land use on the amount of water available for energy production downstream. The consequence of such oversights is more severe on small scale hydro plants than the large scale ones.

The objective of the thesis is to examine if the Bello catchment located in the Guder River Basin (GRB) in Ethiopia, has the capacity to produce the same amount of power by mid and end of the century as it does now. The scenario analysis on the catchment is conducted by first studying the trend of temperature, precipitation, and runoff of the GRB and then level of impact on runoff due to upstream activities and evaporation was forecasted by using Water Evaluation and Planning Tool (WEAP).

Currently a similar project is in the process of development for the Central Rift Valley Lakes (CRVL) located in Ethiopia by NTNU partnering with the Stockholm Environment Institute (SEI) (creators of the WEAP tool).



Background

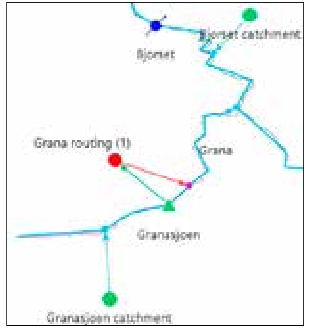
Floods are a major threat to human life and property on a global basis, Norway being no exception. However, Norway is in possession of approximately half of Europe's reservoir capacity, which provides a significant potential for flood dampening. This potential depends on factors and circumstances such as regulation capacity, initial reservoir filling, spillway capacity, rainfall location, etc.

Objective

Initially, a literature study will be carried out to establish the current situation for reservoir flood dampening research, implementation, and performance on a global and national scale, and then specific regulated catchments in Norway will be modelled. A single-reservoir system will be modelled in Excel, while the multi-reservoir Orkla catchment will be modelled in WEAP, both models with the purpose of investigating the flood dampening caused by the reservoirs, as well as the impact of initial filling (either due to seasonal variations in filling or draw-down prior to a flood event).

Using the results found in the literature study and obtained from the modelling, the possibility of creating a flood-dampening factor based on regulation capacity and other catchment characteristics will be looked into and evaluated for both single- and multi-reservoir systems.

Orkla catchment



River Grana in WEAP

MASTER THESIS

Bendik Kristoffer Torp Hansen

Department of Civil and Environmental Engineering

Spring 2018

Flood-dampening in hydropower systems

Supervisor:
Tor Haakon Bakken
Co-supervisor:
Knut Alfredsen
In cooperation with:
SINTEF

NTNU

MASTER THESIS

Alexander Anatol Ermilov

Department of Civil and Environmental Engineering

Spring 2018

Numerical simulation of sediment flushing in reservoirs

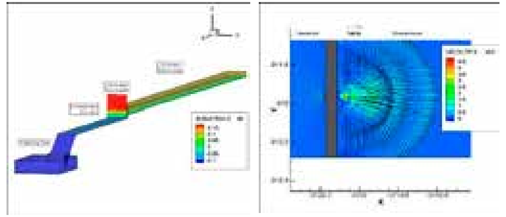
Supervisor: Dr. Nils Rüther
Co-supervisor: Dr. Sándor Baranya

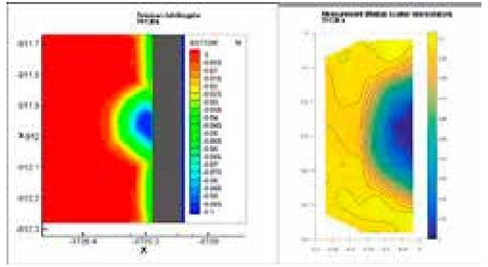
NTNU

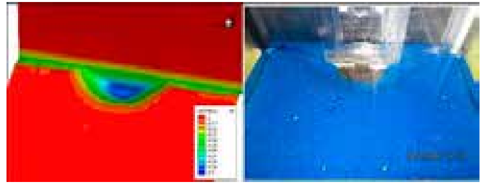
Background

In my master thesis at NTNU, my work is on a numerical model of a sediment flushing scenario of a reservoir. The flushing has been carried out in a physical model in the Department's laboratory. The goal was to build up this physical model numerically, and check if the numerical tool Telemac can be used to simulate the sediment flushing scenario or not. At the same time, in case of Telemac's applicability, to compare the forming flushing cone of the numerical and physical model.

The test flume was straight and without any bed slopes. It was separated by a sluice gate into an upstream (reservoir) and downstream part. In the upstream part, an initial light weighted, noncohesive sediment layer was placed on the bottom, up to the closed sluice gate. The test started when the sluice gate was suddenly opened to a certain height, letting through the water and the sediment towards the dry downstream. After the decrease of water level reached a certain point, the gate was closed and the final flushing cone was scanned. The size and shape of the cone, the speed of the formation was compared to the results of Telemac (Telemac-3D and Sisyphe modules). The challenge was to find out how to use the free surface flow model Telemac for this pressurized flushing scenario and model the sudden opening of the sluice gate. To solve this problem, the culvert function of Telemac was used, which was introduced quite recently. After the comparisons, the results were found to be satisfactory.







Background

In turbulent free-surface flow, the deformation of the free-surface leads to entrainment of air bubbles. To ensure safe operation of hydraulic structures, and to optimize its performance, the amount of entrained air and its mixing within the flow must be accurately predicted.

The hydraulics of aerated flows can greatly benefit from insights provided by numerical simulations. An ideal numerical model has to be fast in the definition of a macroscopic interface and at the same time be precise enough to take into account the formation of bubbles through the free surface. Due its complexity, an accurate prediction of the air entrainment process is an ambitious goal for most computational fluids dynamics tools. Some attempts have been made to capture the physical behavior of the air entrainment process into computational fluid dynamics models (CFD). Nevertheless, more research are needed to get a reliable solver for the generic air entrainment phenomena.

Objective

The objective of this study is to investigate whether a numerical model can reproduce the air-water interaction in hydraulic structures. This will be done using the open-source software, OpenFOAM, which solves the mass- and momentum equations on a three dimensional grid. The capacity of the simulation tool in predicting the air entrainment process will be investigated, with the aim of improving the relevant solver.

Silje Kreken Almeland

Department of Civil and Environmental Engineering

2016 - 2020

Numerical modeling of air entrainment in hydraulic structures

Supervisor: Nils Reidar Bøe Olsen

NTNU

PHD THESIS

Ola Haugen Havrevoll

Department of Civil and Environmental Engineering

2017 – 2021

PHD THESIS

Rock traps in pumped storage and peaking power plants

Supervisor:
Kaspar Vereide

NTNU HydroCen

Background

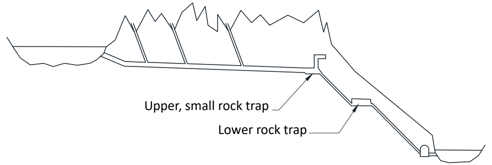
Several rock traps in Norwegian power plants are not working as expected today. Many power plants have gotten new turbine runners with higher capacity, which increases the discharge through the headrace tunnel and rock trap. The rock traps may not be dimensioned for the higher discharge, and may therefore lead more sediments through to the turbines, which causes higher erosion on the turbines. This is a problem that must be solved.

Research

Therefore, research is done to get a better understanding of the functionality and design of rock traps, and to find solutions for improving the existing rock traps without large costs. The research methods to achieve this are physical model tests and CFD modelling combined with field tests for validation.

Pumped storage and peaking power plants

This work contributes to make our power plants better suited to being used as pumped storage plants and peaking power plants. For pumped storage, we need to be sure that the rock trap will work with water flowing both ways. Maybe the reversed flow can be used as a flushing mechanism? For peaking power plants, we must prevent turbulence or free surface flow from whirling up the settled sediments.

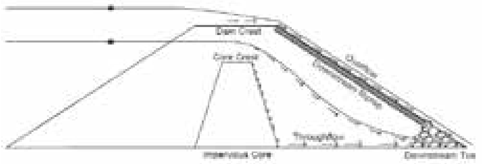


Background

Currently, there are over 185 large rockfill dams (over 15 meter high) in Norway. Many of these dams are poised to be upgraded in the near future to counteract the projected detrimental impacts of climate change on hydrology which can result in devastating floods and accidental overtopping events. Hence, from a dam safety perspective, it is of paramount importance to design efficient overtopping protection systems to protect the dams from these events.

Multitude of past research investigations conducted to study rockfill dam failure under overtopping flows have stated that the probability of initiation of failure at the dam toe is high. Hence, a research project with the working title 'Embankment dam safety under extreme loading conditions' was initiated by HydroCen to address the issue of dam toe instability under overtopping conditions. The primary objective of the project is to come up with a technically effective and economically efficient means of providing adequate stability for rockfill dam toes under overtopping flow conditions.

In order to accomplish the set objectives of the project, physical modeling investigations at the Hydraulics laboratory in NTNU, Trondheim are underway. Also, possibility of large scale field tests are also being considered.



Ganesh Hiriyanna Rao Ravindra

Department of Civil and Environmental Engineering

2017 - 2020

PHD THESIS

Embankment dam safety under extreme loading conditions

Supervisor:
Fjola Gudrun Sigtryggsdottir

NTNU HydroCen

PHD THESIS

Håkon Sundt

Department of Civil
and Environmental
Engineering

2017 – 2020

Environmental design for multiple interests under future flexible hydropower operation

Supervisor: Knut Alfredsen
Co-supervisor: Torbjørn Forseth

NTNU HydroCen

Background

Environmental design is key for combining hydropower production and river health in a sustainable way. Building on environmental design methodologies established in FME CEDREN, the PhD will look at how we can enhance and expand the methodology in question using new and available technologies.

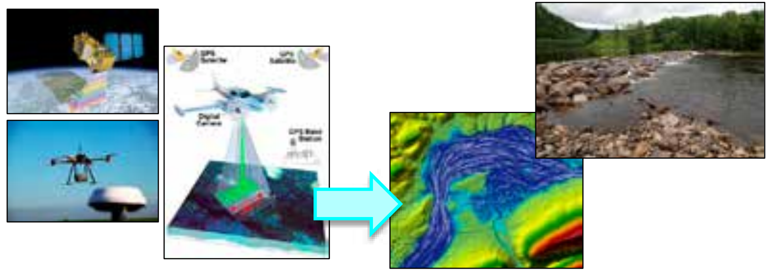
Using data from satellites, laser instruments and drones with optics, the PhD will analyse the collection and use of such data in future environmental design projects.

An example:
Green laser technology (LIDAR) makes it possible to map large river stretches in short time, obtaining high accuracy terrain data, also to a certain degree beneath the water surface. This terrain data can be put into hydraulic computer models for analysis of physical mitigation measures, water quality, biological elements, hydrology and a range of other applications.

Other issues we want to look into:

- Do the different methods for data collection give different results in our hydraulic models?
- Can we use new data collection technologies to establish a better connection between the physical environment and the biology in regulated rivers?
- How can we establish long-term surveillance of physical processes in rivers using satellite data?

With all this in mind, we still need to verify the quality of data collected using the new technology. And there is also a question of time spent on data processing, which may be the biggest challenge when using new technology.



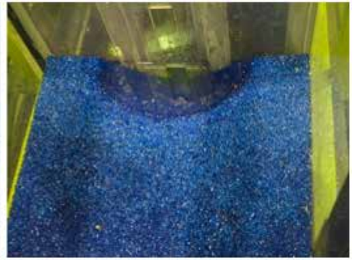
Background

The concept of lightweight models, in which lightweight materials are used as sediment, is older than six decades and is being practised by different laboratories around the world. Those laboratories have their own scaling criteria and study methodologies regarding such models. There is still a lack of common scaling criteria for designing a lightweight model and for quantitative interpretation of model results.

Objective

To assess, and develop it further if required, the existing similarity/scaling criteria for designing lightweight models for study of morphological processes with specific regards to sediments in reservoirs.

The developed scaling criteria will be tested in a case study of relevant scenario. The current work is part of the project SediPASS «Sustainable design and operation of hydro power plants exposed to high sediment yield» funded by the Research Council of Norway.



Sanat Karmacharya

Department of Civil
and Environmental
Engineering

2017 - 2019

Simulating reservoir flushing in scale models using lightweight sediments

Supervisor: Nils Ruther
Co-supervisor: Jochen Aberle
Meg B Bishwakarma
In cooperation with: Hydro Lab

NTNU

PHD THESIS

Livia Pitorac

Department of Civil and Environmental Engineering

2017 – 2020

Upgrading of hydropower plants to pumped storage plants: reconstruction and improvements of the tunnel system

Supervisors:
Leif Lia,
Kaspar Vereide

NTNU HydroCen

PHD THESIS

Background

Due to the increasing number of renewable energy power plants connected to the grid throughout the past years, the role of hydropower in energy systems is changed. The operation strategy of hydropower plants has shifted from stable operation, usually at the best efficiency point, to a more flexible operation, with frequent starts/stops, and more part-load operation. As the present design of the hydropower plants does not match the current needs, it results in lower turbine efficiency and restrictions on the power plant operation. Thus, new design concepts or improvements to the present design are needed.

The general objective of this research is to investigate various possibilities for upgrading hydropower plants to pump storage plants, focusing on possible improvements and reconstruction needs of the waterways. New layout concepts for the tunnel system, surge chambers, intakes, outlets or other tunnel system components could be investigated.

The research method is founded on field measurements, numerical simulations and physical model studies. The study is conducted starting with 1D numerical modelling, followed by research on a physical model, further validated with in-situ measurements.

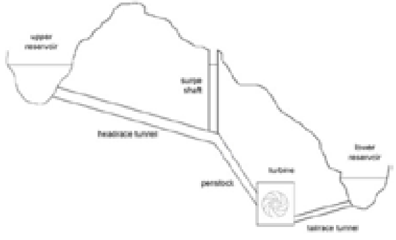


Figure 1 Pump storage plant layout

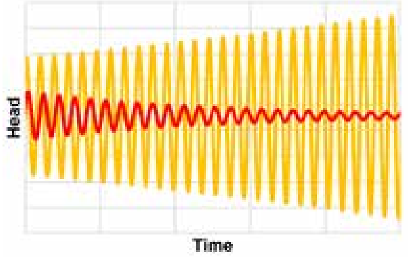


Figure 2 Stability (red) vs. instability (yellow) in surge tank

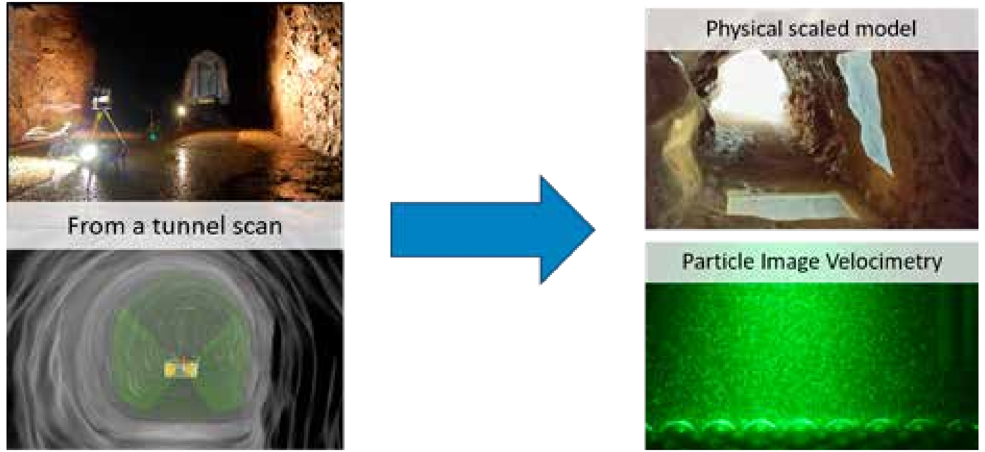
Background

This project addresses the hydraulic resistance of unlined (rough) hydropower tunnels, essential both for power production and flood control. The determination of the hydraulic capacity of such tunnels requires the knowledge of friction factors whose determination is mostly based on empirical approaches. Thus, despite their significance, friction factors are considered as an uncertain component in the design of tunnel waterways.

Methodology and outcome

- Friction losses and the flow field measured in scale model studies with miniature versions of the tunnels constructed through computer-controlled milling.
- High resolution PIV measurements as a benchmark for numerical simulations.

The Tunnel Roughness project is a Knowledge-building Project for Industry funded by the Norwegian Research Council and a consortium including NVE, TrønderEnergi, BKK and NVKS. More information and updates can be found at www.ntnu.edu/nvks/tunnelroughness



Courtesy: Kari Bråtveit & Hibbard Inshore.

Courtesy: Pierre-Yves Henry & C. Ushanth Navaratnam

Christy Ushanth Navaratnam

Department of Civil and Environmental Engineering

2016 - 2020

Hydraulics of unlined tunnels: Experimental investigations

Supervisors:
Jochen Aberle
Co-supervisor:
Nils Rüther

NTNU

PHD THESIS

Marcell Szabo-Meszaros

Department of Civil and Environmental Engineering

2015 - 2018

Safe and efficient two-way migration for salmonids and european eel past hydropower structures

Supervisor:
Knut Alfredsen
Co-supervisors:
Torbjørn Forseth
& Jochen Aberle

NTNU

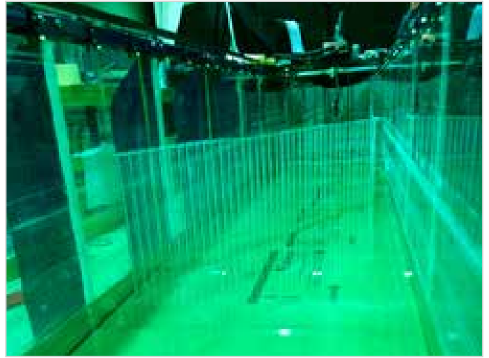
PHD THESIS

Background

The SafePass project aims to find the best solutions for fish migration in regulated rivers, from the perspectives of both the fish and the hydropower industry.

The first task will be to track fish on their way down and analyze their behavior under different conditions. The observed behavior of the fish can be combined with the data from the 3D numerical model. This will help to detect possibilities and find the most promising solutions for avoiding fish entering the intake structure. Combining this with the needs of water for hydropower production we will aim to design an operational solution that optimizes the fish passage and hydropower production.

The second task will be the examination of currently used and just developed prototypes of trash racks for power plant intakes, and will be tested in the hydraulic laboratory. The aim of these investigations is to find a formation which prevents fish from entering the intake and at the same time has acceptable energy loss and reasonable maintenance costs.



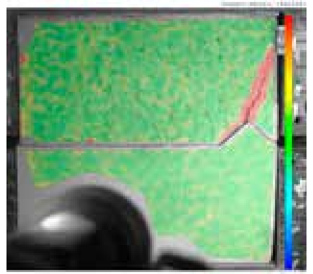
Background

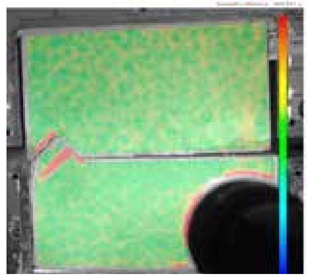
The safety evaluation of concrete gravity dams against sliding is done using the Mohr-Coulomb model. This model despite of several limitations is still in use. Several other models have been proposed to calculate the shear strength of rock joints. However, the scale and amplitude of roughness on a dam foundation is different than a rock joint. Hence, direct application of these models for dams is questionable. This knowledge gap has resulted in making the dam unsafe and upgrading has to be done to meet the current safety regulations.

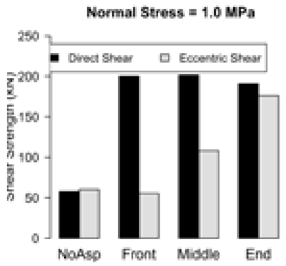
The objective of this thesis is to propose models and methodologies to reliably estimate the shear capacity and to demonstrate their use for reliable safety evaluation of a dam. This PhD is a part of "Stable dams" project at Norut, Narvik.

A series of lab tests were done in 2017 at Luleå Technical University in Sweden to investigate the effect of location of big scale asperity on shear strength. In addition, tests on scaled section of dam are planned to investigate the effect of roughness at different orders. Furthermore, other researchers on the same project are working on 3D analysis of dams and identifying semi destructive and non-destructive techniques for investigating the geometry, material properties and loads on existing dams.

The figures on the right are taken from eccentric shear tests. The two samples have different location of asperity (at the front and at the end). The figure shows that the location of asperity affects the location and mode of failure. Thus affecting the shear strength.







Dipen Bista

Department of Civil and Environmental Engineering

2016 - 2018

Sliding stability of concrete dams

Supervisor:
Leif Lia
Co-supervisor:
Fredrik Johansson

NTNU

PHD THESIS

PHD THESIS

Øyvind Pedersen

Department of Civil and Environmental Engineering

2015 - 2018

Method for reduced uncertainty in stage-discharge curves

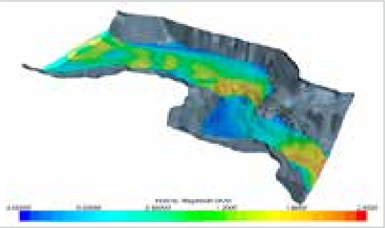
Supervisor:
Nils Rüther
Co-supervisor:
Jochen Aberle

NTNU

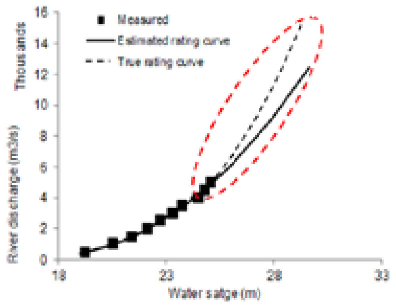
Background

Getting reliable stage-discharge data under extreme flood conditions is essential for good predictions of future flood events. At the same time, the discharge data used for prediction often have a high level of uncertainty. Getting more reliable flood predictions are potentially worth millions in saved costs for construction of dams and infrastructure, as well as in preventing damaging floods. This thesis aims to develop methodology for reducing the uncertainty in stage-discharge curves using a hybrid-modelling approach. Hybrid-modelling involves combining a physical scale-model with a numerical CFD-model. The PhD-program is part of the Flom-Q project, which goal is to create a better flood-prediction framework for Norway. The figure shows a stage-discharge curve used for calculating discharge from a measured water level at a gauging station. Measurements of the stage-discharge relations typically are done for a range of discharges from low flow to flood conditions. At larger floods, measuring discharges directly can be both difficult and dangerous, and by definition these floods are rarely occurring events. Because of this, discharge data for extreme floods often stem from stage-discharge curves extrapolated well beyond the measured range. The goal of this PhD is to develop a method to obtain better data for the extrapolation.

This figure shows a scale-model of the Eggafossen gauging station site



The above figure shows a visualization of the Eggafossen CFD-model



Source: Di Baldassarre et al. 2012

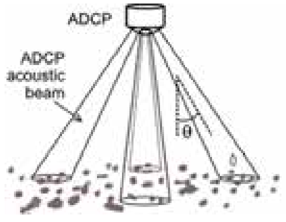
Background

The quantification of the sediment transport in fluvial environments is a notoriously difficult and labor-intensive task.

Statistically valid measurements are extremely important for the evaluation of the sediment transport masses, especially for big hydropower projects and for large navigable or heavily exploited rivers. Widespread implementation of the hydro-acoustic techniques would reduce the scarcity and statistical uncertainty of sediment data.

The main objective of this work is to develop a methodology for evaluating the bed load transport using commercial acoustic Doppler current profilers (ADCP).

The hydro acoustic measurements are relatively well explored by the scientists and engineers. The suspended load estimation has been successfully adopted by analyzing the backscattering echo and the attenuation of the acoustic signal. The bedload transport has been estimated by using the apparent velocity (vGPS- vBottomTrack), or the exploiting the bias that appears in the Bottom Tracking signal of the ADCPs. The signal reflected from the riverbed assumes complex two-phase scattering happening in the active layer of the bedload and the irregular immobile surface. It additionally complicates the results and increases the uncertainty in the sediment velocity calculation. The main focus of this study is to explore this phenomena in details and use this information for calculating the total sediment mases by developing specific methodology and models (e.g. kinematic transport model). Three laboratory experiments are performed using different ADCs and different sediments. Based on this information several field studies are planed to be conducted. The future goal is to identify the source of uncertainty and suggest new instrument parameters.



Slaven Conevski

Department of Civil and Environmental Engineering

2017 - 2019

Operation of hydropower plants exposed on high sediment yield. Non-intrusive bedload measurements

Supervisor: Nils Ruther
Co-supervisor: Massimo Guerrero. **In cooperation with**: University of Bologna

NTNU

PHD THESIS

POST DOC.

Pierre-Yves Henry

Department of Civil
and Environmental
Engineering

2016 - 2020

Hydraulics of unlined tunnels: Numerical and analytical investigations

WP leader:
Nils Reidar B. Olsen
Project leader:
Jochen Aberle

NTNU

Background

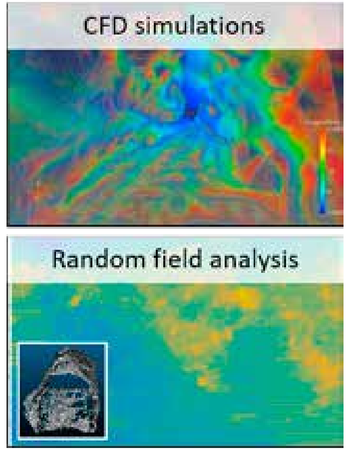
This project addresses the hydraulic resistance of unlined (rough) hydropower tunnels, essential both for power production and flood control. The determination of the hydraulic capacity of such tunnels requires the knowledge of friction factors whose determination is mostly based on empirical approaches. Thus, despite their significance, friction factors are considered as an uncertain component in the design of tunnel waterways.

Methodology and outcome

- Assessment of geometrical roughness using statistical analysis of tunnel topography and linking near-wall turbulent flow field features to tunnel roughness characteristics .
- Hi-res. 3D-numerical simulations validated by detailed PIV on the scale model data.

The Tunnel Roughness project is a Knowledge-building Project for Industry funded by the Norwegian Research Council and a consortium including NVE, TrønderEnergi, BKK and NVKS. More information and updates can be found at www.ntnu.edu/nvks/tunnelroughness

Courtesy: Kari Bråtveit & Hibbard Inshore.



Courtesy: Mari Voll & Jie Quin.

Department of Geoscience and Petroleum

MASTER THESIS

Anna Helene Mong Urdal

Department of Geoscience and Petroleum

Spring 2018

Stability assessment of the tunnel invert of Roskrepp hydropower project

Supervisor: Krishna Kanta Panthi
Co-supervisors: Bibek Neupane, Kaspar Vereide

NTNU

Background

Sira-Kvina Kraftverk is considering the opportunity to store energy through hydropower. They are interested to investigate the ability to turn Roskrepp hydropower plant into a pump-storage plant. Doing so, will cause change in water pressure in the headrace tunnel and cause potential destabilizations that can lead to destruction of the turbines.

Roskrepp headrace tunnel is an unlined tunnel with asphalt lining. The aim of the thesis is to investigate the potential engineering geological problems in relation to the asphalt lining situation that can take place in the headrace tunnel if Roskrepp hydropower plant is rebuilt into a pumped-storage plant.

Figure 1
Corase grained granite in Roskrepp that will be tested in the laboratory.

A project work carried out prior to the thesis, involved a theoretical study on hydropower plants, asphalt properties and rock engineering aspects. It also included an engineering geological investigation at site. Rock samples were collected at Roskrepp, and is going to be used on different rock mechanical tests in laboratory. The results will be used in a stability assessment of the tunnel which will include numerical analysis in RS2. A physical model of the hydraulic situation of the headrace tunnel will be carried out as well. This test will hopefully give an idea on how the asphalt lining will respond to the rapidly change of water pressure in a potential pumped-storage situation. The collected information will give an indication of possible stability problems that can be expected if Roskrepp hydropower plant is rebuilt into a pumped-storage plant.

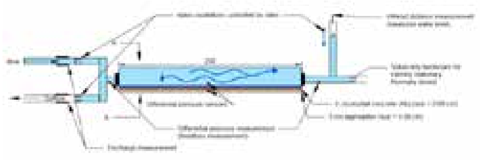
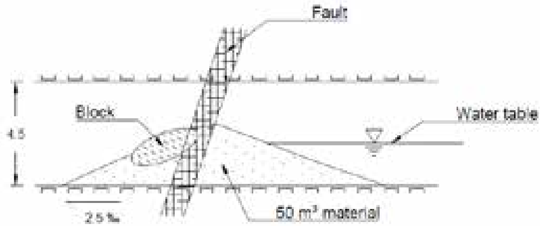


Figure 2
A sketch of the physical model that will be carried out

Background

Unlined high pressure tunnels and shafts are regarded as a Norwegian specialty in the hydropower industry. This cost saving solution has been possible due to the Norwegian support philosophy that accepts some rock fall during operation. Over the last years, the production pattern of many Norwegian hydropower plants has changed from supply driven to demand driven, which involve higher frequencies of start-and-stop cycles of the turbines. This production pattern is in use at Brattset Hydropower Project, where there has been experienced an increase in rock falls and other stability problems in the recent years.

During the project work prior to the MSc thesis, a study on the engineering geological conditions along the unlined headrace tunnel of Brattset was carried out. Four different types of instabilities were identified, relating to weakness zones, jointing and stresses in the rock mass.



The MSc thesis aims to further analyze and discuss these stability issues, and investigate the influence of hydraulic mechanisms caused by start-and-stop cycles. Stability assessment of the identified issues will be carried out, using both analytical and numerical modelling. Results from field mapping, laboratory testing of the rock mass and evaluation on gouge swelling potential will be important input data in the models. Finally the findings will be used in a discussion on the long-term stability of Norwegian unlined hydropower tunnels.

Block fall in the headrace tunnel in 2015, caused by joints and stress induced micro-cracking

Illustration of collapse of weakness zone in the headrace tunnel in 2008. The failure was caused by swelling material in the zone.

Ragna Halseth

Department of Geoscience and Petroleum

Spring 2018

Stability assessment of headrace tunnel system of Brattset hydropower project

Supervisor: Krishna K. Panthi
Co-supervisor: Bibek Neupane

NTNU

MASTER THESIS

MASTER THESIS

Snorre Anneson Ledsaak Solli

Department of Geoscience and Petroleum

Spring 2018

Evaluation of the hydraulic splitting at Bjørnstokk HPP

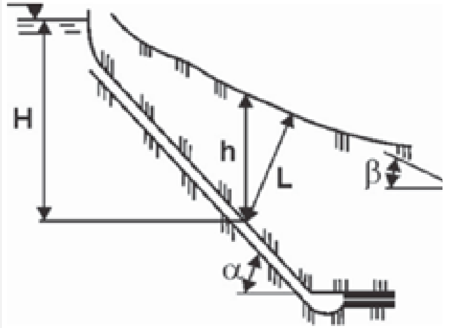
Supervisor:
Krishna K. Panthi
Co-supervisor:
Chhatra B. Basnet
In cooperation with:
Helgeland Kraft and Sweco

NTNU

Background

"Hydraulic splitting" is the initial fracture propagation in homogeneous rocks due to induced hydraulic pressure. Several failure cases, such as Byrte (1969) and Åskåra (1970), have proved that the potential for hydraulic splitting poses a challenge in the application of unlined pressure tunnels. It occurs when the water pressure exceeds the minor principal stress (3) in the surrounding rock mass.

Hydraulic splitting has occurred in the unlined tunnels at Bjørnstokk Hydropower Project (HPP). Thus it is of interest to assess the potential for hydraulic splitting.

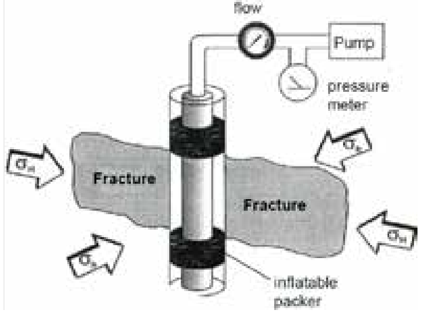


The illustration is related to the so-called Rules of thumb. The analytical stability assessment includes an assessment based on these design criteria (Panthi, 2014)

Objectives

The main objective of the Master's thesis is to carry out a stability assessment, analytically and numerically (Phase2), of the tunnel system at Bjørnstokk HPP with focus on hydraulic splitting.

- Theoretical review on in situ stresses, stress measurement techniques, and rock mechanical properties
- Review on design principles for unlined/lined pressure tunnels, as well as previous failure cases
- Carry out laboratory tests of collected samples covering mineralogy (XRD) and rock mechanical properties (UCS, tensile strength, etc.)
- Discuss case-specific engineering geological aspects



Stress measurement techniques. Hydraulic fracturing (Li, 2016)

Background

The use of unlined high pressure tunnels in a hydropower project is mainly based on the in situ stress condition among the others parameters. The state-of-the-art principle in an unlined pressure tunnel is that the minor principal stress in the rock mass should be greater than the water pressure inside the tunnel due to hydrostatic head between the tunnel location and head water level (HWL). The principle has been widely used in the Norwegian rock mass condition. The PhD research is focused on applicability of this principle in the Himalayan rock mass condition. The in-situ stress condition in the Himalaya is supposed to be different from the area of existing unlined pressure tunnels. Hence, it is necessary to analyze the stress state intensively at the location of unlined tunnels of hydropower projects in the Himalaya considering all possible factors affecting the stress.

Objectives

- Review of existing principles for unlined tunnels
- Numerical modeling of stress state and hydraulic jacking in the unlined tunnels of Norwegian as well as Himalayan hydropower projects.
- Assess the applicability of unlined / shotcrete lined tunnels in the Himalaya
- Publish the research results in journals and conferences, summarize in a PhD thesis

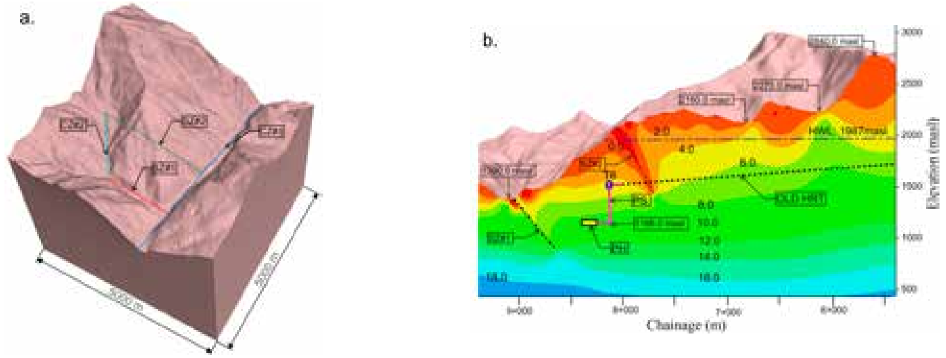


Fig. 3D modelling of in-situ stress state in Upper Tamakoshi Project, Nepal

Chhatra Bahadur Basnet

Department of Geoscience and Petroleum

2014 – 2018

Applicability of unlined/ shotcrete lined high pressure tunnels for hydropower projects in the Himalaya

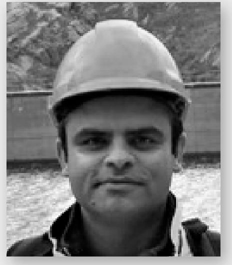
Supervisor:
Krishna K. Panthi

NTNU

PHD THESIS

PHD THESIS

Bibek Neupane



Department of Geoscience and Petroleum

2017 - 2021

Long-term impact on unlined tunnels of hydropower projects due to frequent start stop sequences

Supervisor:
Krishna K. Panthi

NTNU HydroCen

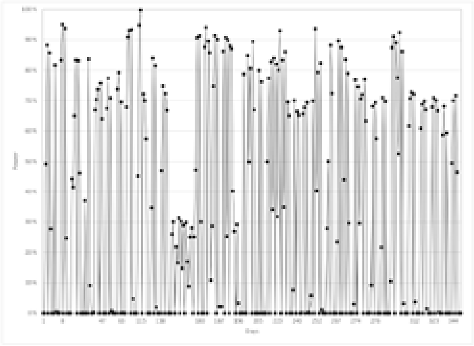
Background

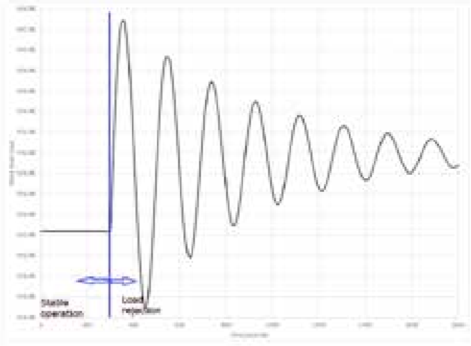
In the future, most countries in Europe will be switching to renewable energy. In this context, water reservoirs in Norway are planned to be used as a ¨battery¨ for the European power grid.

Hence, the motivation of this research comes from the fact that unlined tunnels, which have been designed and constructed for base load plants, are now operating under dynamic loading conditions in terms of water pressure since the power market deregulation in 1991. This will further be increased with increasing market demands. This research aims to focus on the effect of such dynamic pressure changes on Norwegian hydropower tunnels.

Objectives

- Understand the effect of water pressure fluctuations in the rockmass and the tunnel.
- Identification of the mechanics of failure and engineering geological factors triggering failure to occur in the tunnel.
- Analyze the functionality of the rock mass along the periphery of the tunnel alignment in the long-term.
- Investigate state-of-art safe design of unlined tunnels, which can cope with the load fluctuations resulting due to the peaking operations and catering to the need of long-term durability of underground structures.





Background

A key requirement for any unlined pressure tunnel or shaft is to ensure that there is sufficiently high rock stress to withstand the internal water pressure. Defining the location where the water enters the steel lined section of the waterway, called the cone or the transition zone, must be based on a rock stress measurements.

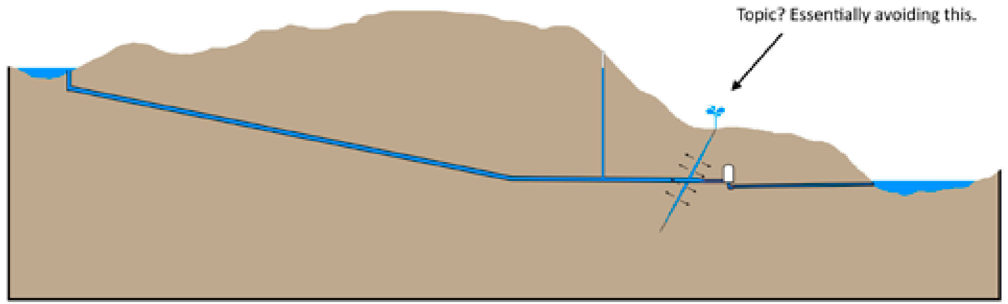
Testing is usually carried out by hydraulic fracturing or jacking tests, performed at defined locations close to the transition zone. There is good reason to advocate more frequent testing as this can reduce the uncertainty of actual stress situation and will also give early indications of stress levels.

Objectives

Contribute to an improved design philosophy for planning of pressure tunnels, with focus on stress estimation and rock stress measurements in relation to pressure tunnel layout.

Further work

- Laboratory scale hydraulic fracturing and jacking tests
- Field correlation
- Experience gained from existing projects



Henki Ødegaard

Department of Geoscience and Petroleum

2017 – 2021

Optimization of test methods and design of transition zones in unlined pressure tunnels

Supervisor:
Bjørn Nilsen

NTNU HydroCen

PHD THESIS

Lena Selen

Department of Geoscience and Petroleum

2017 – 2021

Effects of swelling rock and swelling clay in water tunnels

Supervisor: Krishna K. Panthi
Co-supervisors: Siri Stokseth(Statkraft), and Bjørn Nilsen

NTNU HydroCen

PHD THESIS

Background

The motivation for the planned research is that some hydropower projects with unlined/shotcrete-lined tunnels, domestic as well as international, have suffered from tunnel collapses causing forced outages during the operation period. Some of the collapses are believed to be related to the swelling potential of the rock itself as well as swelling clay present in the weakness zones. Degradation (slaking) of the rock material is believed to be an important contributor to the collapses.

Several methods for determining the swelling potential of clay are frequently used, whereas different configurations of oedometertests and free swelling tests. However, there are no clearly defined rules for the investigation procedures of swelling rocks, nor does it exist a standardized categorization system of the results. Additionally, the effect on stability and swelling behavior when the rocks are exposed to a cyclic exposure to water, as in hydropower water tunnels, is not sufficiently understood.

Objectives

The research aims to confront the causes of swelling behavior and the methodology to detect the critical rock parameters in an early stage.

The main objectives are:

1. Perform, discuss and analyze different laboratory methods (swelling tests, mineralogical analyses, strength tests, slake durability tests...) at both NTNU and other international institutes, to compare equipment, methodology and results, aiming to suggest an investigation procedure designated to swelling rocks.
2. Try to find a correlation between different rock parameters and between different methodologies, in regard of swelling behavior of rocks.
3. Contribute to a widening of the range of tests in operation at NTNU, by suggesting improvements on existing facilities and on the development of alternative methods. The research is performed in close cooperation with Statkraft.

Vannkraftlaboratoriet
NTNU

Department of Energy and Process Engineering

-The Waterpower Laboratory

NTNU

MASTER THESIS

Sondre Skjoldli &
Øyvind Albert

Department of Energy and Process Engineering

Spring 2018

Pump as turbine (PAT)

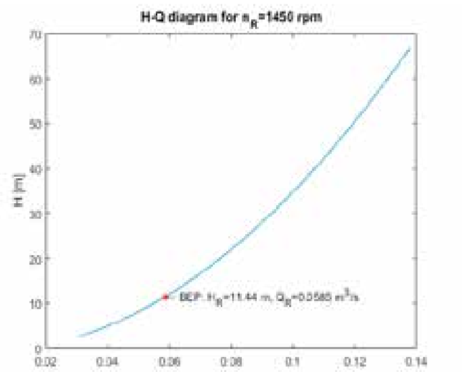
Supervisor:
Torbjørn K. Nielsen
Co-supervisor:
Mdee Ombeni, UDSM

NTNU

Background

For small hydropower plants, both in Norway and in developing countries, the issue is to reduce the turbine price as far as possible. Efficiency is not necessarily the highest priority. A centrifugal pump run in reverse is a good option. It has relatively good efficiency, it is a robust construction, and much cheaper than a turbine. The main reason for the low price is that pumps are mass produced, and there is no wicket gate. The problem is to pick the right pump for a set of head and flow conditions.

In the project work a theoretical model was established to predict the optimal operating conditions for a given pump run as a turbine. This prediction model differs from previous techniques in that it is solely based on the pump geometry. To validate the prediction model tests have to be carried out. These tests are scheduled to be conducted both at the University of Dar es Salaam, Tanzania, and at the Waterpower Laboratory at NTNU.



Predicted turbine characteristic of the pump scheduled to be tested in Dar es Salaam (UDSM)

Part of the test rig at UDSM used for model validation, with the pump used as turbine installed

Background

Investigate the relation between flexible operating patterns, mechanical loading and predict its maintenance costs.

The European electricity system is undergoing a radical change, with increasing contribution from intermittent renewable energy sources. Simultaneously there are potentially large changes in the profile of consumption. Large-scale conversion from gas and diesel engines to electrical vehicles for private transport, and subsequent conversion of short-range goods transportation and inshore marine transport may cause new significant peaks in the consumption. Smart grid solution may assist in smoothing out these peaks, but there is still large uncertainties in how efficient these demand side regulations will be. The transmission system operators and local distribution companies are thus faced with larger challenges to maintain reliable grid, with small frequency variations and good voltage stability. To meet this challenge many TSOs are considering introducing new markets for system services/ ancillary services. A common trait with many of these services are rapid response/rapid load changes. It is also probable the operation close to zero load for extended periods may be a requirement. It is a general observation in the Nordic markets that the liberalization of the energy markets in the 1990s led to changes in the operating pattern. It is inferred that this has led to increased mechanical loading and wear on the units but there exist little or no systematic documentation of this.

With stronger interconnections to continental Europe and UK and stronger integration with system services markets in this regions it is hypothesized that the trend of more dynamic operating pattern will continue. For a power plant owner wanting to operate in such market it is important to know both what will be the price in the market as well as the cost in terms of increased maintenance cost. As a starting point, it is of interest to understand how various operations increase the mechanical loading of the units.

MASTER THESIS

Andreas N. Skorpen

Department of Energy and Process Engineering

Spring 2018

Impact from Flexible Operations on High Head Francis Turbines

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Bjarne Børresen
In cooperation with:
Multiconsult

NTNU

MASTER THESIS

Vetle Frydenlund

Department of Energy and Process Engineering

Spring 2018

Design and test of a micro turbine in the water power laboratory

Supervisor:
Ole Gunnar Dalhaug
Co-supervisor:
Bjørn Winther Solemslie
In cooperation with:
Deep River and MEW

NTNU

Background

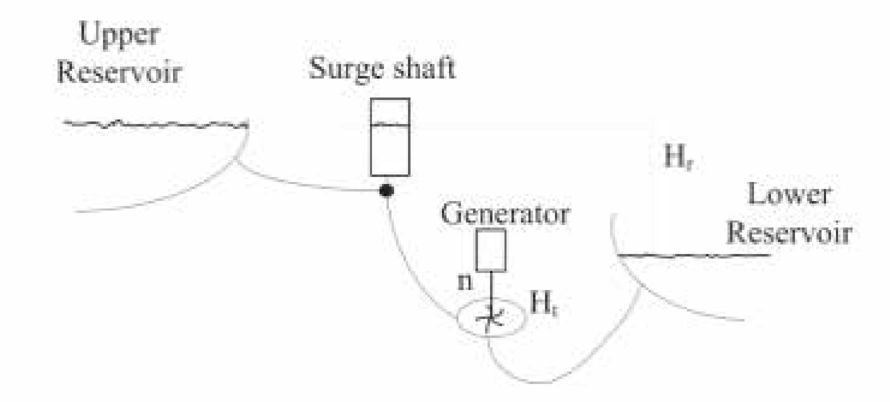
This project is in cooperation with Deep River, a company that is active in research and development of small hydropower units. The project focuses on the testing and design of a small propeller turbine, with a head between 2 and 5 meter. The turbine will be a part of a product called «Drop and Go», a portable, simple and efficient way of producing electricity from small waterfalls.

The runner consists of four adjustable blades, and for each of the runner blade angles, several tests will be preformed. By measuring the mechanical power from the turbine and hydraulic energy in the water, it is possible to calculate the hydraulic efficiency of the turbine at different operational points. The purpose of the testing is to find the best efficiency point. Using the information from the test results, a new runner that is suitable for one specific head will be designed and tested.

Background and objective

Reversible pump turbines (RPTs) are hydraulic machines that can operate both as pumps and as turbines, thus being able to switch between storing and delivering energy like a rechargeable battery. Today this change of operation is mainly done on a seasonal basis. In the future power marked, RPTs are expected to play an increasingly important role because of the ability to balance the energy production, and a rapid transition from one mode of operation to another constitutes a crucial field of investigation.

The objective of this master thesis is to establish a simulation model of Tevla power plant in Meråker and the RPT at the Waterpower Laboratory at NTNU, and to analyse the dynamic behaviour of the systems when the RPT goes directly from pump mode to turbine mode of operation. The simulations are carried out in Matlab, and will be verified by experimental measurements.



Carl Andreas Veie

Department of Energy and Process Engineering

Spring 2018

Dynamic analysis of a system with RPT

Supervisor:
Torbjørn Nielsen
Co-supervisor:
Magni Fjørtoft Svarstad

NTNU

MASTER THESIS

MASTER THESIS

Daniel Sannes

Department of Energy and Process Engineering

Spring 2018

Pressure pulsations in a Francis turbine

Supervisor:
Ole Gunnar Dahlhaug

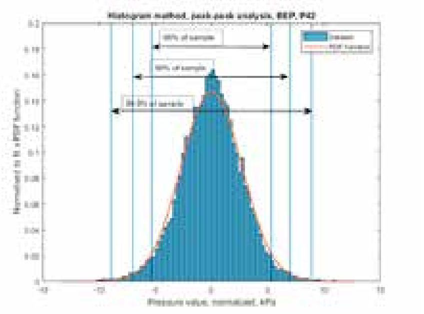
NTNU

Background and objective

The average age of a Norwegian hydropower plant is 45 years, and many show sign of fatigue and need to be constantly maintained or refurbished. Additionally, some power plants in Norway have experienced failure on new Francis runners. The main problem is the formation of cracks in the turbine runner. Today, new technologies enables us to operate the turbine at variable speed, which gives the possibility to operate the turbine were pressure pulsations are lowest. This can in theory prevent fatigue damage, and prolong the lifetime of the turbine runner.

The objective of this master thesis is to find the operating range for the Francis-99 turbine with variable speed that gives the lowest material stresses in the turbine runner. This will be done by measurements of pressure pulsations in the Francis rig and structural analysis in ANSYS. The results will further be used in fatigue analysis.

Francis rig at the Waterpower Laboratory at NTNU. Picture was taken during measurements.



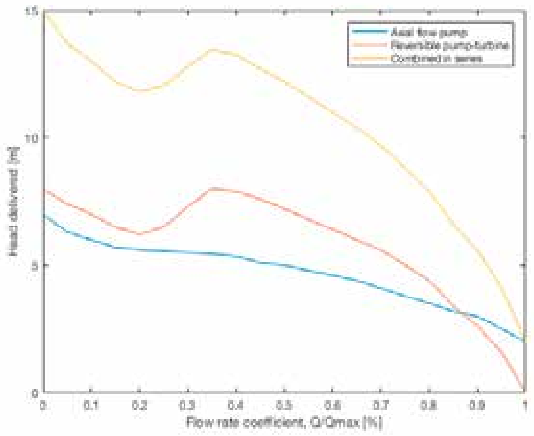
Pressure data is analyzed by using the histogram method.

Background

The purpose of this masters thesis is to investigate the possibility of introducing a booster pump in forefront of a reversible pump turbine to avoid cavitation when installing a pump turbine. With a rim-driven thruster as the booster pump. If successful, the necessary high cost procedure of lowering the waterpower plant when installing a reversible pump turbine, can be avoided.

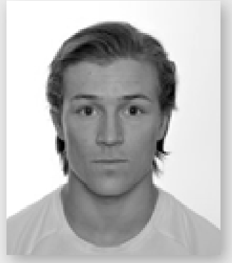
The method of the master thesis is a theoretical approach, implementing and simulating the combined operation between the two pumps, using matlab.To implement the pump characteristics two approaches are tried. Firstly, an approach using suter characteristic curves, and secondly an approach implementing dynamic models of the pumps developed at the Waterpower Laboratory at NTNU.

This picture shows a rim-driven thruster developed by Brunvoll



This picture shows the combined characteristics of a reversible pump turbine and a axial flow pump

John Valstad



Department of Energy and Process Engineering

Spring 2018

Simulation of a booster pump and a reversible pump turbine in series

Supervisor:
Pål-Tore Storli
Co-supervisor:
Helene Dagsvik,
Magni Fjørtoft Svarstad

NTNU

MASTER THESIS

MASTER THESIS

Anders Thorstad Bø

Department of Energy and Process Engineering

Spring 2018

Fluid structure interaction in a pipe

Supervisor:
Bjørnar Svingen

NTNU

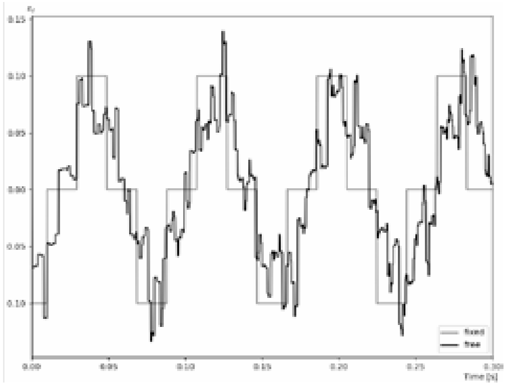
Background

Sudden changes in steady state conditions in piping systems, such as valve closure and component load rejection, may lead to extreme changes in pressure forces acting on the pipe. To accurately predict these forces and resulting stresses and strains on the pipe wall, coupled fluid-structure interaction investigations are needed.

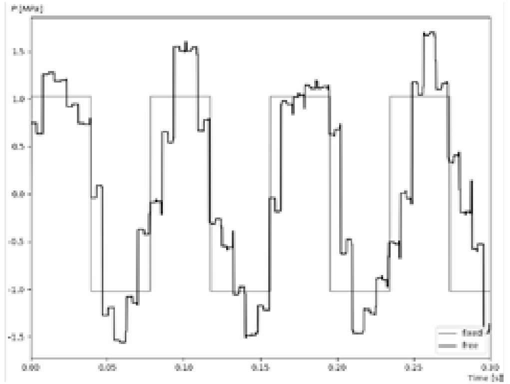
The purpose of this thesis is the experimental and numerical investigation of the waterhammer event due to rapid valve closure.

A straight pipe test rig in the Waterpower Laboratory are to be used to verify predictions from a computer program which solves the extended waterhammer equations using the method of characteristics.

To do this sufficiently, measurements of the pressure and strain, as well as acceleration of the rig, will be conducted, analyzed and compared to the numerical predictions for the computer program.



Simulated strain development at pipe center after instantaneous valve closure

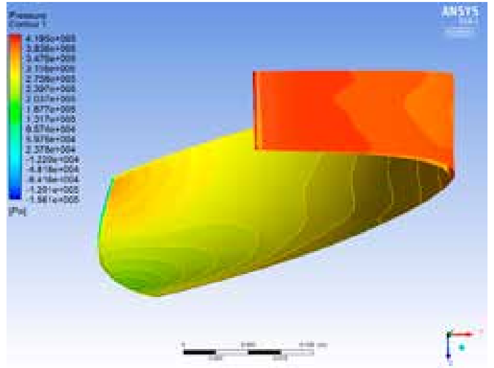


Simulated pressure development at valve after instantaneous valve closure

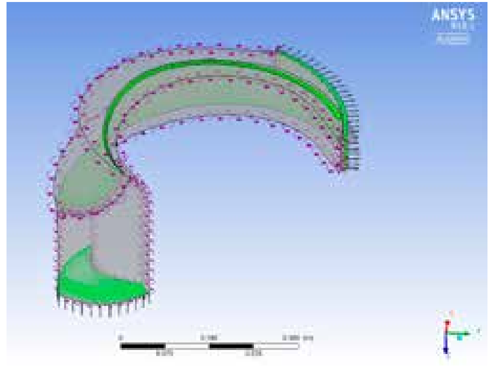
Background and objective

A limiting factor for operation of a reversible pump turbine (RPT) is cavitation. To avoid cavitation the units must be submerged, which is an expensive action. Adding a rotation to the flow before it enters the inlet of the runner (pre-rotation) might be an effective countermeasure for cavitation, reducing the necessary submergence. Pre-rotation might also change the pump characteristic curves, indicating that it can be used to control the operation of the pump.

The objective of this thesis is to conduct an investigation of the effect of pre-rotation with respect to characteristics and cavitation, and conclude whether pre-rotation has the desired effect or not for an actual model of an RPT runner. The simulations are carried out in ANSYS CFX.



Contour plot of the pressure across the runner of an RPT for a flow with no pre-rotation at the inlet.



Visualization of the flow direction and the runner inside the simulation domain.

MASTER THESIS

Kristin Morvik Torød

Department of Energy and Process Engineering

Spring 2018

Simulation of pre-rotation in the flow at the inlet of a reversible pump turbine

Supervisor:
Pål-Tore Storli
Co-supervisor:
Jan Tore Billdal
In cooperation with:
Rainpower

NTNU

MASTER THESIS

Steinar Straume

Department of Energy and Process Engineering

Spring 2018

PIV measurement of the flow in the vaneless space of a Francis turbine

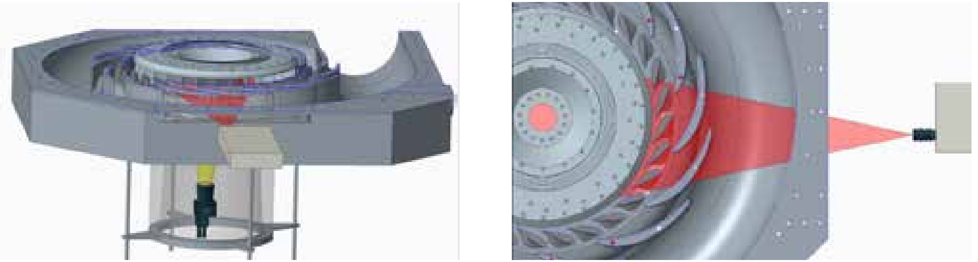
Supervisor:
Pål-Tore Selbo Storli
Co-supervisor:
Kristian Sagmo

NTNU

Background and objective

The vaneless space in a Francis turbine is a narrow region between the guide vanes and turbine blades. Experimental analysis using pressure gauges has previously been conducted. However, the data provided by gauges is not sufficient to analyse pressure distribution in an area. It is hypothesized that the pressure pulsations in this region is root cause of several undesired dynamic phenomena in Francis runners.

The goal for this thesis is to provide a deeper understanding of the velocity field, and thus also the pressure, in the vaneless space of a Francis turbine. This is to be done with the help of Particle Induced Velocimetry (PIV). PIV is a non-intrusive measuring technique, utilizing camera, laser and tracer particles to give an overview of a velocity field. The Francis test rig has to be modified to allow for PIV measurements and a measurement campaign is to be developed.



Side and top view of the suggested PIV setup for the Francis test rig.

Background

Local patches of high and low energy exists, but the mix of energy is better further away from the turbine. The energy consists of velocity and temperature. This non-homogenous mixture can result in errors when doing thermodynamic efficiency measurements. When doing thermodynamic efficiency measurements IEC 60041:1991 is used as a standard. IEC 41 specifies that for measuring sections with free surface a distance of 4 to 10 runner diameters is found to be satisfactory for Pelton turbines.

The objective of this thesis is to see how the energy in a cross section changes with distance from the turbine. If it is possible to do energy measurements closer to the turbine then what the IEC 41 recommends. Field measurements shall be done in the outlet of Ylja power plant (Eidsiva) . Temperature measurements will be done with a frame that can be moved up/down and back/forth. Propeller current measurements are to be taken simultaneously. Data from the measurements will be analyzed with respect to flow, temperature and error analysis for thermodynamic efficiency measurements.

Entrance to Ylja power plant

From project thesis: Propeller current measurements in the free surface loop at the Water power Laboratory at NTNU.

Trine Brath

Department of Energy and Process Engineering

Spring 2018

Energy measurements in the field

Supervisor:
Bjørnar Svingen

NTNU

MASTER THESIS

MASTER THESIS

Johannes Kverno

Department of Energy and Process Engineering

Spring 2018

Pressure pulsations at Smeland power plant

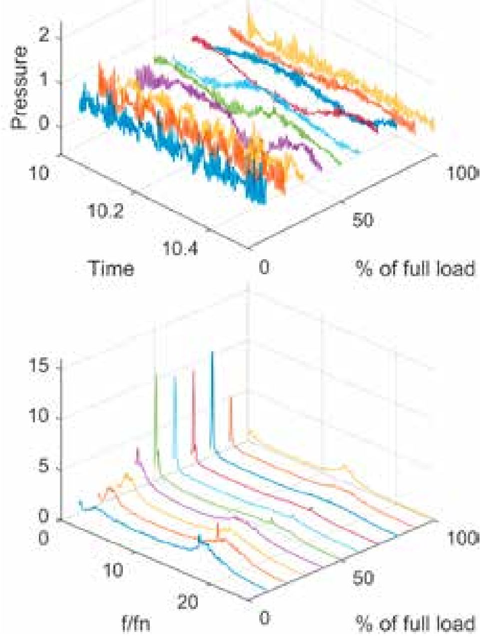
Supervisor:
Ole G. Dahlhaug
Co-supervisor:
Torbjørn Nielsen
In cooperation with:
Agder Energi

Background

In recent years Agder Energi have been struggling with pressure pulsations in the Francis turbine at Smeland power plant. The pulsations appear above BEP, and seems to be in the 1 Hz order of magnitude. The purpose of this thesis is to perform pressure measurements and evaluate the results in order to identify the root cause and severity of the problem.

A crane used as a fixed reference to demonstrate the vibrations during a visit in October 2017

Through measurements done on the turbine at the inlet, draft tube and the leakage pipe, the dominating frequency can be identified through spectral analysis in MATLAB.

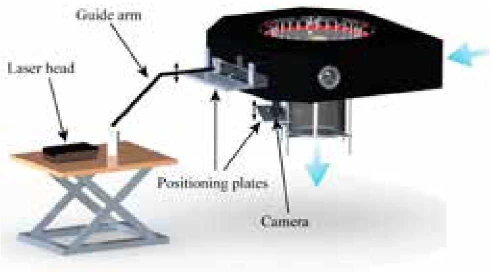


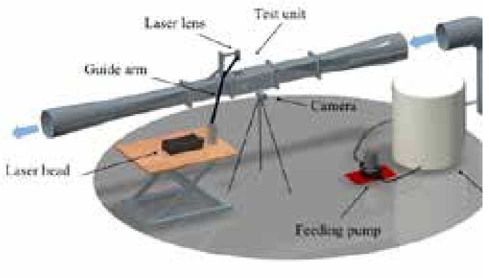
Results from a spectral analysis of measurements done at Santa Rosa II in late November 2017

Background

Vortex shedding is a dominant feature occurring for almost any bluff geometry exposed for fluid flow. In a hydropower context, this phenomenon has been found to generate high frequency fatigue damage and noise, potentially causing structural failures in components such as turbine runners.

Vortex shedding from a hydrofoil





The figures presents the PIV-setups to be utilised for the Francis turbine (above) and hydrofoil investigations (right).

Objective

In this work, the main objective is to investigate the vortex shedding phenomenon using particle image velocimetry (PIV) on two experimental setups. Measurements will be performed in the downstream region of a hydrofoil resembling a typical Francis runner blade, and in the vaneless space of a Francis turbine. Simultaneous measurements of structural vibrations will be performed to analyse the fluid-structure interaction (FSI) in the corresponding setups. The experimental data will be used as a comparative basis for simulations, and to evaluate if the undesired effects of vortex shedding may be mitigated by means of alternative structural designs.

Magne Tveit Bolstad

Department of Energy and Process Engineering

Fall 2017

Experimental investigation and mitigation of vortex shedding

Supervisor:
Pål-Tore Storli
Co-supervisor:
Kristian Sagmo

MASTER THESIS

MASTER THESIS

Madeleine J. Selvig

Department of Energy and Process Engineering

Spring 2018

Pressure pulsations in high head Francis turbines

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Chirag Trivedi

NTNU

Background

As energy demand is growing along with the quest for green energy, the operating range for hydropower is being pushed into non-favourable conditions. The unsteady flow regimes at these conditions lead to transient phenomena's like pressure oscillations that can propagate through the whole turbine, threatening the reliability of the turbine. It is therefore important to identify these pressure pulsations to ensure safe operation.

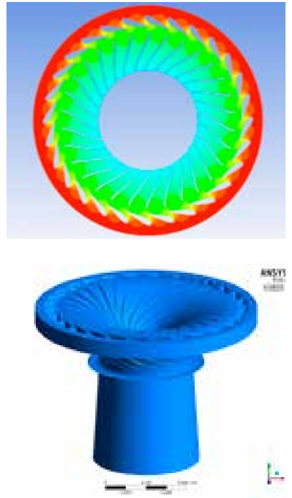


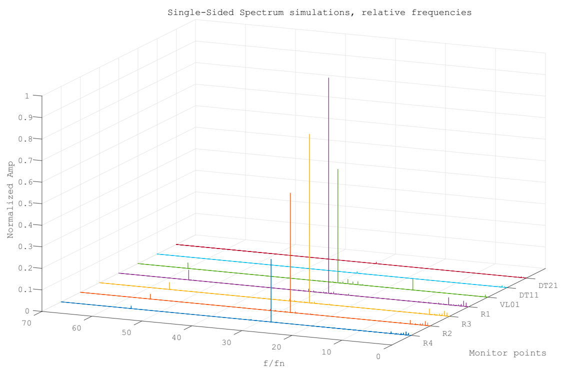
Fig. 1: Computational domain (left) and pressure contour (right).

Method

A transient simulation of the Francis model turbine at NTNU is to be performed for several guide vane openings ranging from a 4 degree opening to 14 degrees opening. The simulations are performed in ANSYS CFX using the SST turbulence model. The primary focus is on rotor-stator interactions (RSI).

Further work

Because pressure pulsations also arise from other phenomenas than RSI, simulations of the whole waterway is necessary. Simulations at different rotational speeds is also vital in order to obtain a hill diagram.



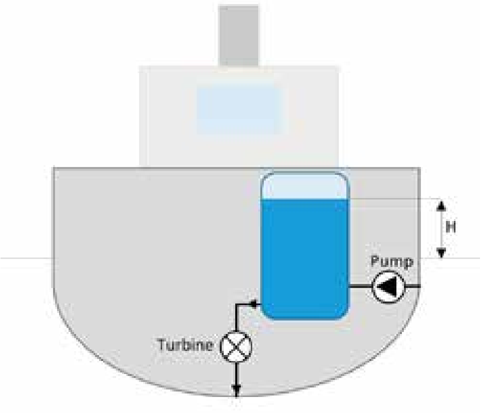
Background

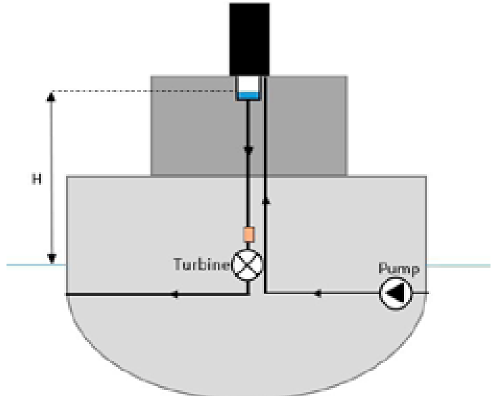
This thesis considers an axial turbine provided by QRRNT, which is a company that are developing turbines to recover kinetic energy in ship's systems to save fuel and reduce emissions.

One of QRRNT's ideas is to utilize a hydro turbine in well boats, which have huge fish tanks that continuously have to circulate the water flow due to the fish. This specific prototype was designed for installation at the outlet of a fishing tank on a well boat (see illustration below to the left).

The main goal has been to measure the prototype turbine's efficiency by laboratory testing and do modifications to increase the efficiency. This was done by setting up a test rig in the Waterpower Laboratory and replicating the conditions on the ship and mapping the turbine performance.

Future work will be to create new custom design for different boats and estimate their performance by CFD-simulations. This thesis include designing a new turbine to be utilized in the scrubber system of large ships (see illustration below to the right).





Christoffer Meek

Department of Energy and Process Engineering

Spring 2018

Design of a turbine which utilizes the spill water of large ships

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisors:
Bjørn Solemslie and Chirag Trivedi
In cooperation with:
QRRNT AS

NTNU

MASTER THESIS

MASTER THESIS

Vegard Ulvan

Department of Energy and Process Engineering

Spring 2018

Thermodynamic efficiency measurements at Smeland power plant

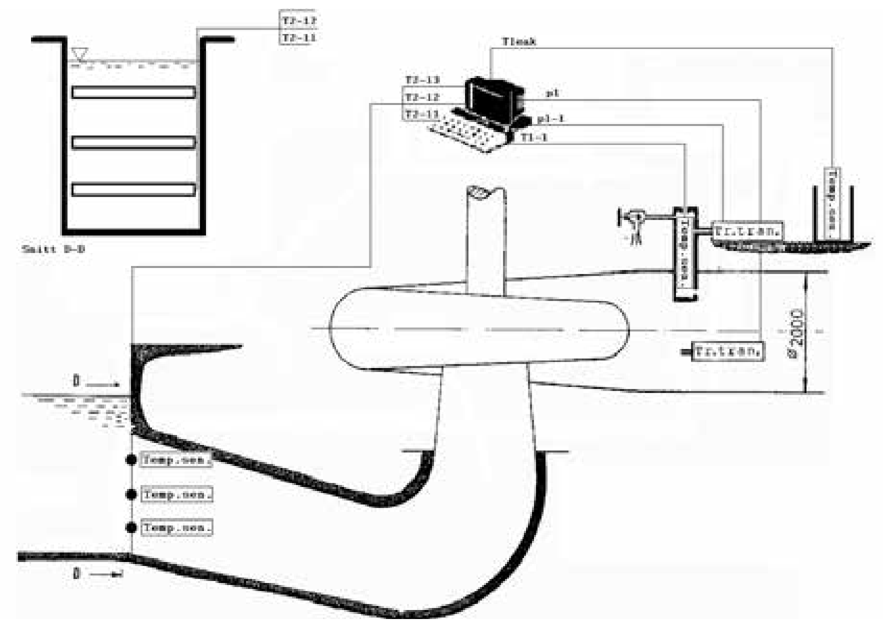
Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Bjørn Winther Solemslie
In cooperation with:
Agder Energi

NTNU

Background

In a water turbine hydraulic energy is converted into mechanical energy. However, not all of the energy is converted, i.e. there are losses through the turbine. The thermodynamic method builds on the principle that all of the losses turns into heat in the flow itself, and by measuring the change of temperature one can with little other data find the turbine's hydraulic efficiency.

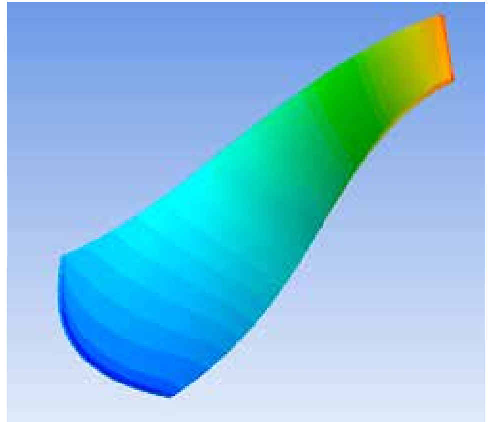
The objective of this master thesis is to perform such a thermodynamic efficiency measurement at power plant in Vest-Agder, on a 30 year old Francis turbine, currently experiencing pressure pulsations at full load. In the picture below is a drawing of the measurement set-up that will be used.

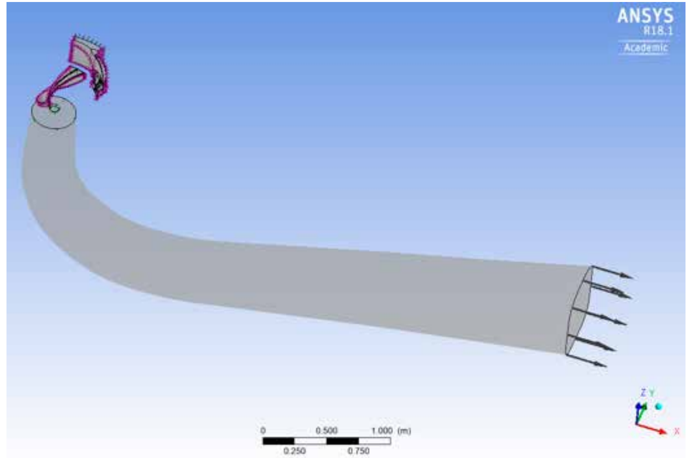


Background

A more diversified energy market leads to a desire of extending the operational range of hydraulic turbines. At off-design conditions cavitation can be a limiting factor.

The objective of this master thesis is to perform numerical simulations on a model of a Francis runner at full load in order to investigate if full load trailing edge cavitation can be predicted. Additionally, numerical simulations shall be performed at deep part load to see if inter-blade vortex cavitation can be predicted. The simulations will be done using ANSYS CFX.





Andreas Slagstad

Department of Energy and Process Engineering

Spring 2018

Investigation of on-set of trailing edge cavitation in a Francis runner

Supervisor:
Pål-Tore Storli
Co-supervisor:
Petter Østby
In cooperation with:
Rainpower

NTNU

MASTER THESIS

PHD THESIS

Helene Njølstad Dagsvik

Department of Energy and Process Engineering

2017 – 2020

Reversible pump-turbines in existing power plants

Supervisor:
Pål-Tore Selbo Storli

NTNU HydroCen

Background

When reconstructing existing power plants into pumped storage plants, new turbine solutions are required when replacing the existing runner. Since a reversible pump-turbine (RPT) must be designed considerably larger to ensure a sufficient pressure head, in addition to demand further immerse, there is a need of a simpler and more cost-effective alternative.

Objective

The aim of this PhD research is to examine if a booster pump installed in the draft tube can replace the need of increasing the runner dimensions and avoid the immersion requirement. The pressure contribution from the booster pump should feed the RPT sufficiently and also ensure that no cavitation occurs in the inlet areas of the runner.

By using a contra-rotating axial pump as a booster, the rotation between the pump and runner can be controlled and manipulate the pump characteristics of the RPT. This could possibly change the necessity of designing the RPT similar to a pump and avoid the runner from running in turbine mode outside best point.

The research work will consist of laboratory work, field measurements, cooperation with pump and turbine manufacturers, literature review and numerical simulations. By the end of the PhD work, a booster pump design should be completed and further be tested in Roskrepp power plant, Sira-Kvina.

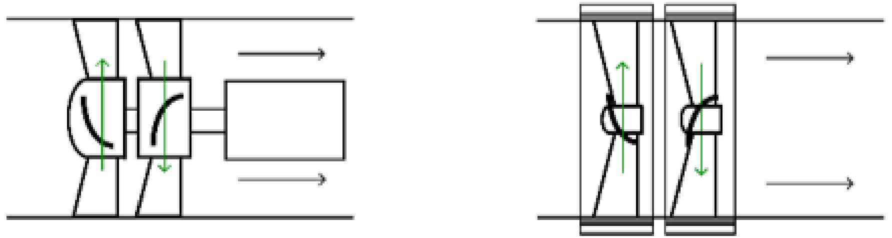


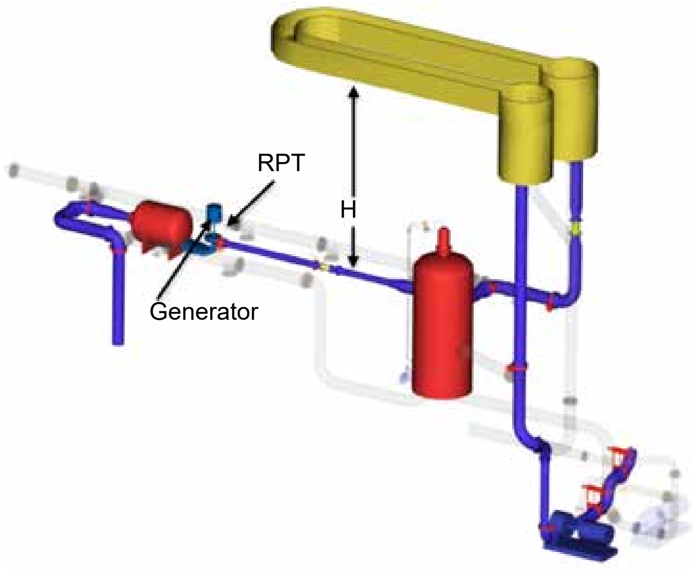
Figure 1: Possible booster pump solutions:
1) Generator installed inside draft tube. 2) Rim-driven generator.

Background

In the Norwegian power market, reversible pump turbines (RPT) for the most part change from pump to turbine mode of operation on a seasonal basis. In the future power market, the RPT are often given the role of balancing the power production.

This will require more frequent and faster changes between the operational modes. The machines experience higher loads in off-design and start and stop operations.

Through laboratory experiments, the objective of this work is to investigate the rapid change from pump to turbine mode of operation. And especially look at the characteristics, loads and stability concerns in this fast change from pump to turbine.



Magni Fjørtoft Svarstad

Department of Energy and Process Engineering

2014 - 2018

Dynamics and stability in reversible pump turbines

Supervisor:
Torbjørn K. Nielsen

NTNU

PHD THESIS

Einar Agnalt

Department of Energy and Process Engineering

2016 - 2019

High head Francis turbines

Supervisor:
Ole Gunnar Dahlhaug

PHD THESIS

NTNU

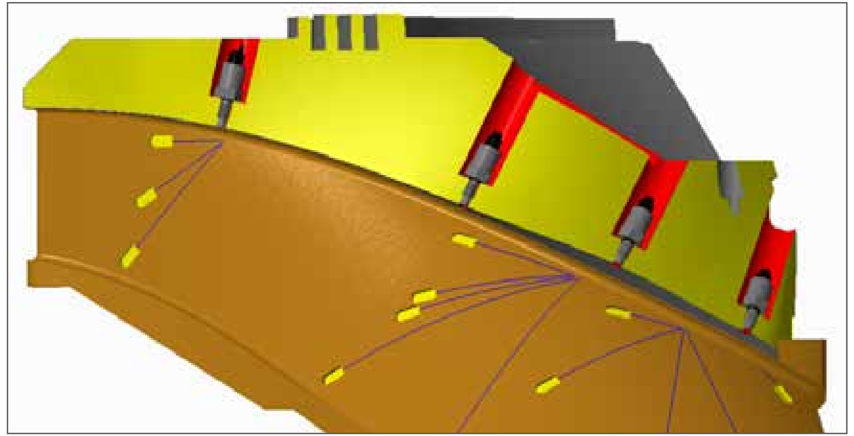
Background

Today, Francis runners are designed and verified by means of numerical methods. The challenge is to get reliable results for pressure oscillations in the fluid and the natural frequency of the runner. To be able to verify and improve calculated and simulated values, experiments must be performed.

Objective and method

The objective of this thesis is to investigate the fluid structure interaction in a Francis turbine runner. To get a better understanding of the physics, measurements will be performed to find the fluid influence on the runner, and the runners response to this influence. Quantities measured include pressure and velocity of the fluid, and acceleration, strain and displacement of the runner. The measurements will be compared with numerical results.

In addition, the relation between a stiff and a softer runner will be investigated to see the effect of runner movement closer to the resonance condition.

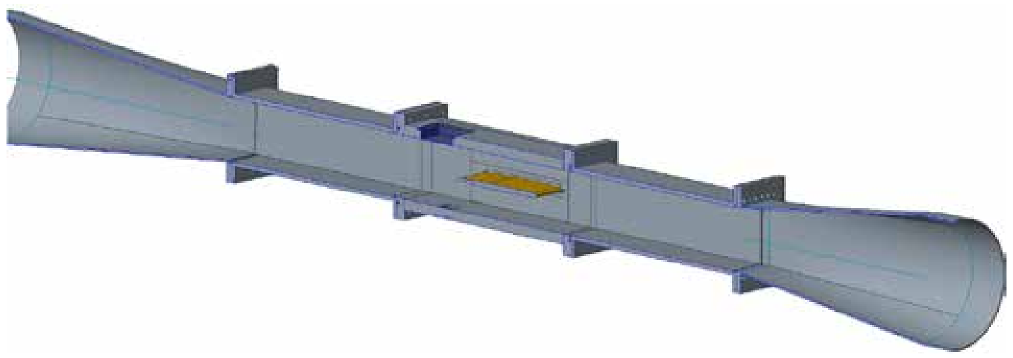


Pressure sensors in the hub of Francis99 model runner

Background

The blades of high head Francis turbines are exposed to high frequency fatigue loads due to Rotor-Stator interactions. Modern runner blades are made to be thin, increasing the efficiency, but making the runner suseptible to vibration.

The aim of this thesis is to better understand how the runner blades behave when subject to vibration, and how it affects the runner's lifetime. The thesis will also investigate how the dynamic properties of a simplified runner blade change with changing water velocity.



Carl Bergan

Department of Energy and Process Engineering

2014 - 2018

Dynamic response of Francis turbine blades

Supervisor:
Ole Gunnar Dahlhaug

PHD THESIS

NTNU

PHD THESIS

Igor Iliev

Department of Energy and Process Engineering

2016 - 2019

Design of a high-head Francis turbine for variable speed configurations

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Chirag Trivedi

NTNU HydroCen

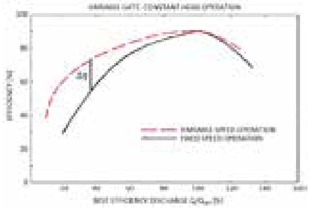
Background

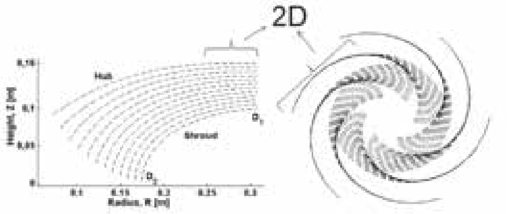
Traditionally speaking, the runners of hydraulic turbines have always been designed to operate at synchronous speed. This is governed by the fact that the generator has a certain number of poles and it has to rotate at a certain synchronous speed to produce the required grid frequency. This is crucial for uninterrupted electricity production.

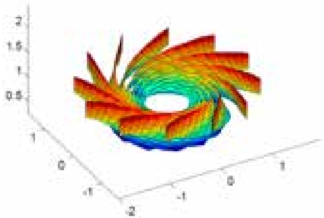
On the other hand, synchronous speed turbines have certain challenges when they are operated at off-design load. Nowadays, turbines are indeed required to operate at either part-load or full-load much more frequently than before. Despite the decreased efficiency at these operating points, there is a higher dynamical load present on the runner as well, which can lead to severe material cracks, expensive repairs and decreased power plant reliability in general. Therefore, it's considered that variable speed operation can improve efficiency and stability of the turbine.

The idea of using variable speed generators is relatively old but opens future prospects only because the price of such generators are getting lower nowadays. But, as reported in previous research, not all turbine runners can gain benefit from operating at variable speeds.

Both the idea and objective of this research is to develop new tools and methodology for designing a turbine that will operate at variable speeds almost exclusively. A better understanding of the design philosophy is then required in order to sustain the parametric study needed. Finally, a model runner will be produced and tested in order to compare the performance against the existing Francis-99 runner.







Background

The problems of sediment erosion and secondary (unwanted) flow in Francis turbines is simultaneous in nature. Depending upon the type of flow phenomena in particular regions and operating conditions, the sediment particles having certain geometric and material properties create distinct erosion patterns in those regions. The erosion on the other hand, deteriorates the surface morphology, aggravating the flow. The combined effect of these two problems contributes to more losses, vibrations, fatigue problems and failure of the turbine. This PhD deals with the regions around guide vanes (GV), where the flow is highly unsteady due to leakages through the clearance gap, horseshoe vortices, rotor-stator-interaction and turbulence supported by high velocity and acceleration. A small clearance is present between guide vane and cover plates to adjust the angle corresponding to the certain operating condition. When the sediment particles carried by the flow passes through this gap as a leakage from the pressure side to the suction side of the vane, the facing walls are heavily eroded. This erosion increases the gap size and eventually, aggravates the flow. This PhD is a part of a project called SEDIPASS which is being coordinated by NTNU. Moreover, it is a joint PhD program between Kathmandu University (KU) and NTNU.

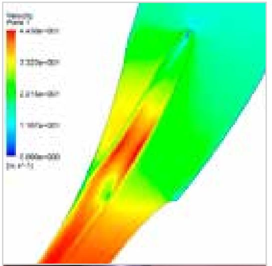
Objectives

a)Numerical and experimental investigation of the leakage flow through the clearance gap of guide vanes in high head Francis turbines

I. Numerical and PIV experiment of existing 1 GV cascade rig including clearance gaps

II: Design and development of 3 GV cascade rig for TTL in Kathmandu University and conduct the PIV experiments in that rig

b)Guide vane design optimization to reduce the secondary flow and its consequent effects on turbine erosion in sediment laden hydropower projects.



Flow through a clearance gap of GV cascade rig

Erosion in GV of Jhimruk HP, Nepal

Sailesh Chitrakar

Department of Energy and Process Engineering

2015 - 2018

Secondary flow and sediment erosion in Francis turbines

Supervisor:
Ole G. Dahlhaug
Co-supervisor:
Hari P. Neopane

NTNU

PHD THESIS

PHD THESIS

Kristian Sagmo

Department of Energy and Process Engineering

2017 – 2020

Flow manipulation for improved operation of hydraulic turbines

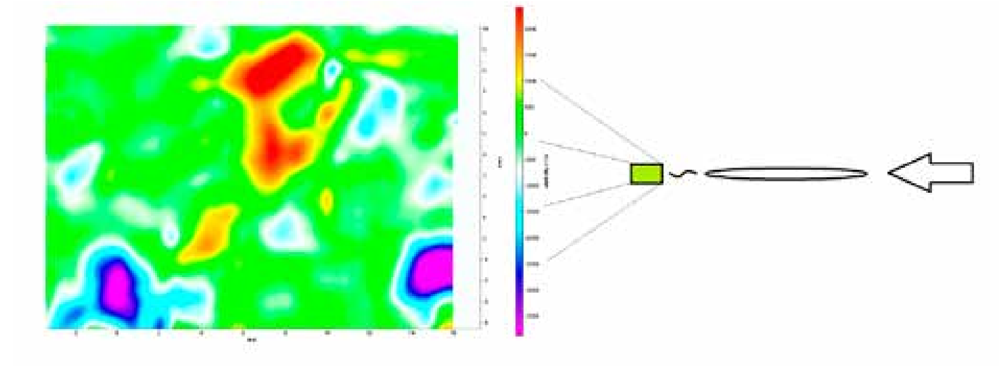
Supervisor:
Pål-Tore S. Storli

Background

In Francis turbines, modern industrial designs and installations are pushing the material costs to a minimum. This increases risk of turbine component failure, and recent failures in new hydropower installments point towards gaps in the understading of the complex fluid-structure interactions (FSI) present in the turbine. This work will focus on modifications to guide-vane design, in order to mitigate lock-in effects and provide insight to the rotor stator interaction in Francis turbines.

Particle image velocimetry (PIV) measurements will be utilized in order to study the wake of hydrofoils, coupled with vibration measurements of the structure. New guide vane designs, developed using computational fluid dynamics analysis will also be tested in situ on the Francis model test rig at the Waterpower Laboratory.

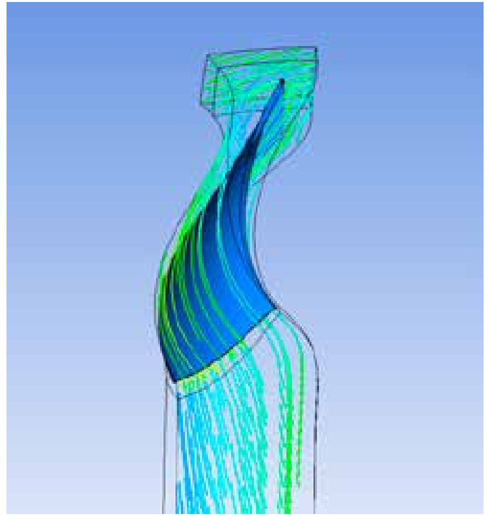
Once a functional protoype has been put forth, the foundation is laid for further optimization and life-time analysis of the design versus conventional designs.



PIV measurement of the wake of a hydrofoil taken in the Waterpower Laboratory at NTNU. Image is colored according to vorticity about the axis perpendicular to the imageplane, showing the vortices of alternating rotation in a turbulent Von Karman vortex street.

Background

About 30% of all High Head Francis turbines installed worldwide are located in Norway. The average age of a Norwegian hydropower plant is 45 years, and many show sign of fatigue and needs to be refurbished. A serious concern is that some newly refurbished high head power plants have experienced failures after having new and modern Francis runners installed. The main problem is that the turbine runner develops cracks in the blades due to cyclic loads.



Objective

The objective of this project is to establish a correct modeling approach with respect to High Head Francis turbines. A stepwise fluid-structure coupling will be used to handle the interaction in the runner. Reduction of the simulation time by means of model order reduction will be investigated.

The primary output of the project will be a recommended practice and toolkit for FSI simulations on High Head Francis turbines.

This is an industrial PhD project with EDR-Medeso, supported by The Research Council of Norway.

Erik Tengs

Department of Energy and Process Engineering

2016 - 2019

FSI simulation of steady and transient operation of a high head Francis turbine

Supervisor:
Pål-Tore Storli

INDUSTRIAL PHD

INDUSTRIAL PHD

Ingrid K. Vilberg

Department of Energy and Process Engineering

2015 - 2018

Consequence and active use of free gas in hydro power

Supervisor:
Torbjørn K. Nielsen
Co-supervisor:
Morten Kjeldsen

NTNU

Background

This project is motivated by challenges in the hydropower industry, where the demand for more flexible power control of each machine can cause wear and unscheduled shutdowns. This may result from cavitation, vibration and pressure pulsations due to resonances in the water conduit system.

With focus on water quality and gas content, this study will investigate the effect of free gas and cavitation. It will also include flow control solutions with free gas to achieve more favorable operating conditions.

A draft tube water injection system is installed on the unit, in addition to an original air suction system. The visual investigation will be carried out in combination with cavitation intensity measurements. At the same time, the effects of the water injection system and the air system will also be examined, both with regard to cavitation and pressure pulsations in the draft tube.
This is an industrial PhD project with Flow Design Bureau (FDB), supported by The Research Council of Norway.

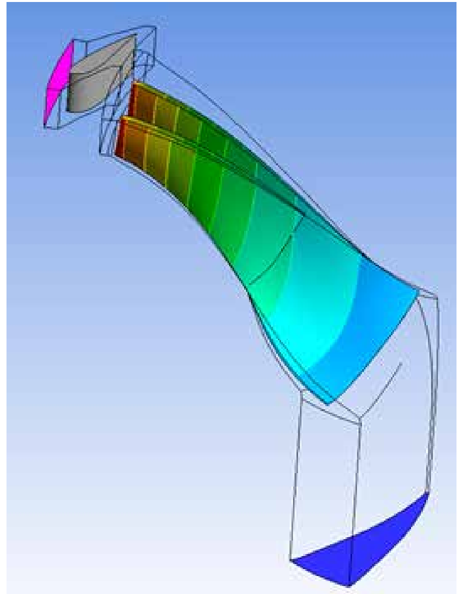
Plexiglass windows are installed on the draft tube of Svorka power plant (25 MW), operated by Statkraft

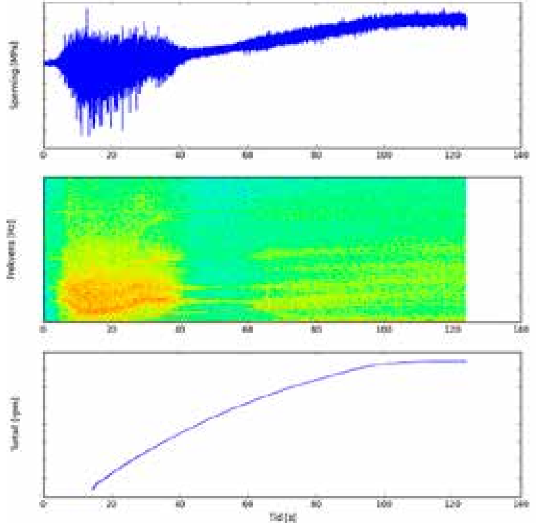
Background

Due to recent failures of high head Francis turbines, there is a need to improve the understanding of the physics related to dynamic stresses in high head Francis turbines.

Objective

Evaluate and possibly improve the current methods for calculating stresses in Francis turbines. This is an industrial PhD project with Rainpower, supported by The Research Council of Norway.





Petter T. K. Østby

Department of Energy and Process Engineering

(Associated)
2015 - 2019

Dynamic stresses in high head Francis turbines

Supervisor:
Bjørn Haugen
Co-supervisor:
Ole Gunnar Dahlhaug

NTNU

INDUSTRIAL PHD

INDUSTRIAL PHD

Eirik Volent

Department of Energy and Process Engineering

2016 - 2019

Solid particle erosion in control valves

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Nils Braaten

NTNU

Background

Subsea Chokes International is a company which is developing erosion resistant control valves and nozzles for applications such as Pelton turbine systems.

Erosion is a challenge in many industries where fluid is transferred through pipe- and valve systems. Erosion can occur in a diversity of systems and is often related to the presence of solid particles in the fluid flow. Erosive wear can cause a vast variety of damage ranging from manageable wear to component failure.

The objective of this industrial PhD is to study particle trajectories and erosion in a laboratory environment, and compare with numerical models. The aim is to develop a method for designing relevant valve geometries and predicting erosion in control valves and nozzles.

This is an industrial PhD project with Subsea Chokes International, supported by The Research Council of Norway.

POST DOC.

Celine Faudot

Department of Energy and Process Engineering

2017 – 2019

Fatigue loads on turbines attached to a conduit system

Supervisor:
Torbjørn K. Nielsen

NTNU HydroCen

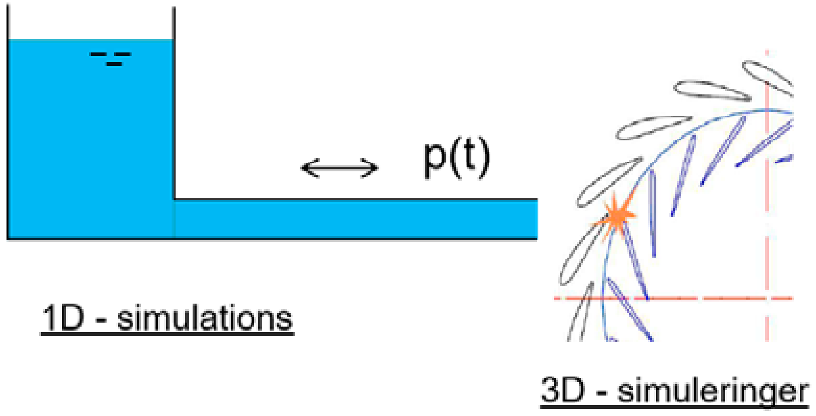
Background

Dynamic loads on hydro turbines during transient operation is highly dependent on the conduit system, i.e penstock, tunnels and surge shafts, in which the turbine is installed. During steady state operation, the pressure fluctuation inflicted by the turbine will propagate into the system and reflect. During start-stop, the retardation forces and elastic waves will give additional stress in the turbine.

Full 3D-CFD simulation of the whole system is naturally out of the question due to the time consume of such simulations. The system dynamic simulations are more effectively done by 1D. The 1D simulations can be implemented as input to the 3D simulations.

By this method, it should be possible to find the correlation or dependency between the internal dynamic flow in the turbine and the attached system.

The dynamic load simulations should be analyzed with respect to crack propagation and fatigue. Both low and high cycle fatigue should be addressed.



POSST DOC.

Chirag Trivedi

Department of Energy and Process Engineering

2014 - 2017

Fluid structure analysis of a model Francis turbine

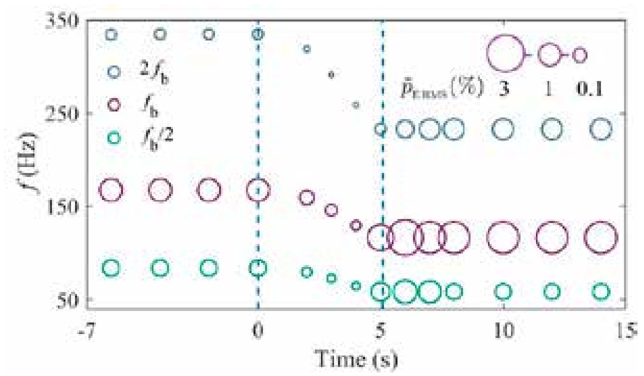
Supervisor:
Ole Gunnar Dahlhaug

Background

Although hydraulic turbines are expected to operate seamlessly during steep ramping, the resulting pressure amplitudes are so significant that they take a toll on a machine's operating life. Objective of the present study is to design and develop a Francis turbine that enables flexible operation and accommodate steep-ramping with several start-stop cycles per day.

I am responsible for specific research tasks in three R&D projects, i.e., #HiFrancis, #HydroCen and #HydroFlex. I am also responsible to manage #Francis-99 workshop series, which allows hydropower researchers and gives the possibility to explore their capabilities and enhance their skills.

- Verification and validation of numerical models
- Fluids structure interaction
- Unsteady pressure and velocity measurements in Francis turbine
- Design of a variable-speed Francis turbine
- Lifetime estimation of a Francis Turbine subject to heavy ramping-rate
- Sediment erosion and determining wear characteristics of a Francis turbine



$$\tilde{p}_E = \frac{p(t) - \bar{p}(t)}{(\rho E)_{BEP}}$$

$$\tilde{p}_{E\,rms} = \frac{\tilde{p}_E}{\sqrt{2}}$$

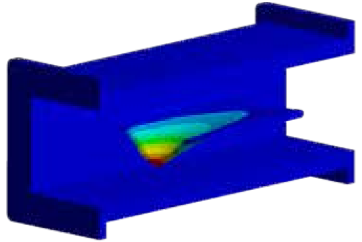
Background

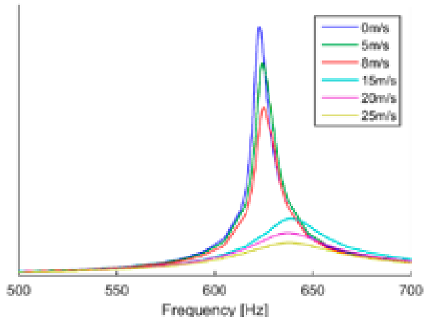
In the last two decades several high head Francis turbines have failed due to rotor-stator interaction (RSI) and resonance issues.

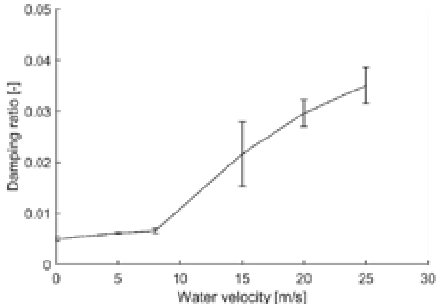
Some have failed after a few hours, others have lasted months, or years, before failing. To prevent such failures, it is important to understand the physics behind these failures.

Every harmonic oscillating system consists of a natural frequency and a damping. In order to predict the frequency response of such a system, both the natural frequency and damping must be known. Since resonance plays an important role in many of the failures, the effect flowing water has on the natural frequency and damping is considered a natural starting point in this research.

There is currently no research openly available for all turbine manufacturers to validate their numerical tools with respect to damping and natural frequency. This experiment aims to improve the knowledge on the fluid structure interaction (FSI) between flowing water and oscillating structures, while at the same time providing an open platform to validate numerical tools.







Bjørn Winther Solemslie

Department of Energy and Process Engineering

2016 - 2018

Pressure pulsations and fatigue in high head francis turbines

Supervisor:
Ole Gunnar Dahlhaug

POST DOC.

Department of Electric Power Engineering

MASTER THESIS

Vegard Paulsen Særen

Department of Electric Power Engineering

Spring 2018

Academic version of a fundamental market model

Supervisor:
Hossein Farahmand
Co-supervisor:
Martin N. Hjelmeland

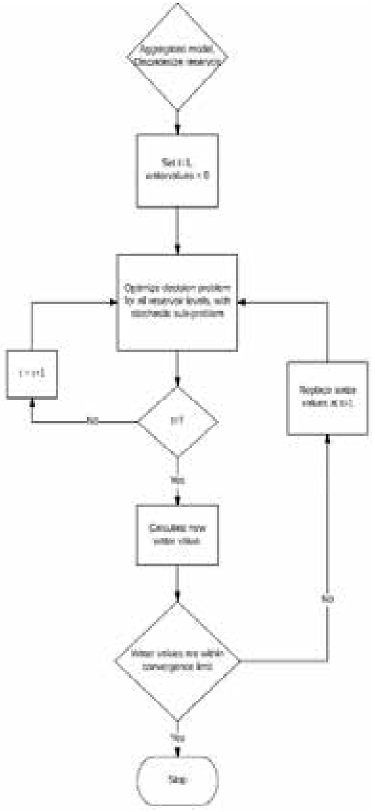
NTNU

Background

The European power market is in transition, both in terms of technologies used for power generation and market structures. Binding targets exist for renewable power generation towards 2020, as well as decisions to decommission nuclear generation capacity. Thus, the overall share of variable renewable energy sources is expected to continue growing, and consequently, the need for flexibility and controlability both in production and demand will increase.

Technologies

- Python and Pyomo
- Stochastic dynamic programming

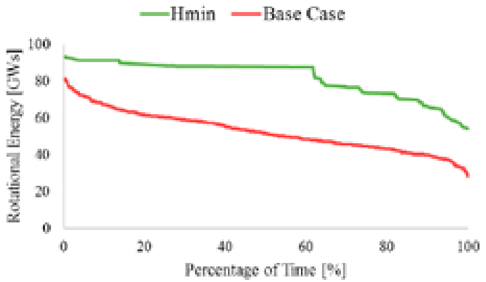


Watervalue calculation algorithm

Background

Having a stable system frequency is vital for safe operations of a power system. A small change in frequency is adjusted for by the system inertia. The system inertia has the important ability that it helps maintain a stable frequency. The consequence of an unstable frequency can in the worst case be a blackout.

The Nordic power system is changing, and it is expected that these changes will lead to more occurrences of low inertia situations. Low inertia situations must be avoided as they lead to a more unstable frequency. To avoid low-inertia situations it is necessary to introduce measures to increase the inertia in the Nordic power system.



Objective

The objective of the masters thesis is to find a cost-effective strategy to ensure sufficient inertia in the Norwegian power system. Three strategies will be evaluated based on their socioeconomic costs and their effectiveness in providing sufficient inertia. To analyze the effect of the strategies, a market model of the Northern European power system, implemented in GAMS, was used.

The first strategy is to define a minimum production level for the hydro generators and extend it to only apply on days with low inertia. The second is to reduce the capacity on an HVDC link, and the third strategy is load reduction by disconnecting the pumps for hydro storage.

Duration curve of the rotational energy in the Norwegtian power system when the first strategy (Hmin) is implemented, compared to the original data set (Base Case).

Astrid Sølna

Department of Electric Power Engineering

Fall 2017

Strategies to ensure sufficient inertia in the norwegian power system

Supervisor:
Magnus Korpås
Co-supervisor:
Markus Löschenbrand

NTNU

MASTER THESIS

MASTER THESIS

Andreas Blix Møller

Department of Electric Power Engineering

Spring 2018

On-line condition monitoring and fault detection in hydropower generators

supervisor:
Arne Nysveen
Co-supervisor:
Mostafa Valavi
In cooperation with:
Statkraft

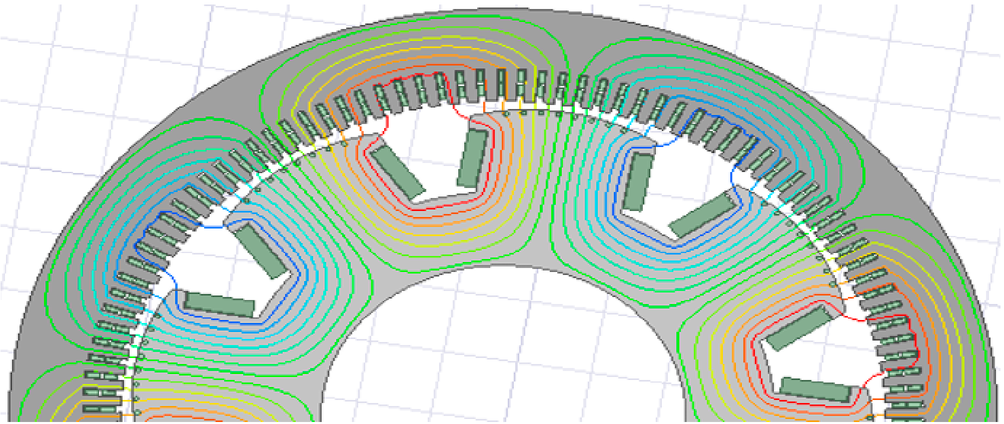
NTNU

Background

The hydropower generator is a vital component in hydropower powerplants, and it's critical failures are associated with high repair and outage costs. Therefore hydropower producers utilize preventive maintaince on the generators to avoid failures. The advancement of technology creates new opportunities to improve the maintance of the generators by the use of On-Line monitoring systems, increasing reliablity of the generator in a cost-effective manner.

This thesis will study eccentricity faults. Eccentricity is the condition when the center of the rotor and center of stator is not the same. This results in an asymmetrical airgap, which leads to the occurrence of an unbalanced magnetic pull(UMP). Excess UMP will lead to mechanical degradation of the generator.

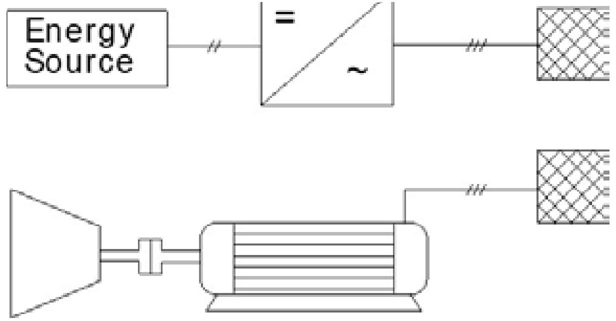
The objective of the master thesis is to develop a monitoring technique for eccentricity faults, which will be able to distinguish between the types of eccentricity, and other UMP conditions. The fault conditions are to be simulated with the FEM software Ansys Maxwell, and then analyzed.

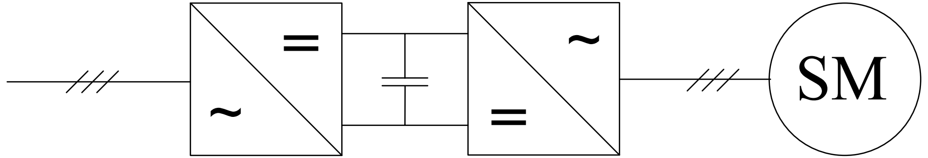


Background

Increasing integration of renewable energy sources in the electric power system raises the demand for balancing technologies to compensate for fluctuation in production. Of all the balancing technologies available, pumped hydropower is by far the most mature technology. In recent years, the interest for adjustable speed drives has increased due to the ability to adjust power consumption in pumping mode of hydro-electric power plants. However, decoupling generators from the grid using power electronics reduces the total inertia of the system. In grids with high penetration of power electronic controlled production, this can reduce the overall system stability.

This work will further develop a simulation model made in the specialization project during fall 2017. The system consists of a converter-fed synchronous machine connected to a weak grid. In the project work, inertia control strategies were developed and tested during a system disturbance. This master's thesis will aim to further developed these control strategies using principle of virtual synchronous machine, and other possible implementations discussed in the project work. If time and resources permits, this should also be tested in a laboratory set up.





MASTER THESIS

Mathias Gallefoss

Department of Electric Power Engineering

Spring 2018

Synthetic inertia from a converter-fed synchronous machine in a hydro-electric power plant

Supervisor:
Trond Toftevaag

NTNU

MASTER THESIS

Arne Moen Lid

Department of Electric Power Engineering

Spring 2018

Analysis of magnetic field and losses at end-region of directly water-cooled hydropower generators

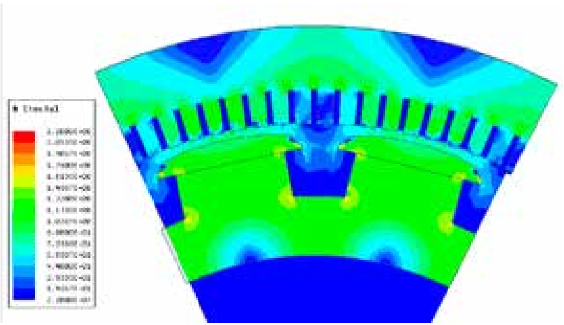
Supervisor: Arne Nysveen
Co-supervisor: Mostafa Valavi
In cooperation with: Statkraft AS

NTNU

Background

During a hurricane in January 2006 one of Statkraft AS synchronous generator at Svartisen experienced huge amount of stresses because of several short-circuits in the main grid of the Norwegian power system. With this followed a breakdown of the generator in August same year, and a new one in October. This lead to a outage of several months. The reason for this breakdown was due to overheating in the end-part of the stator.

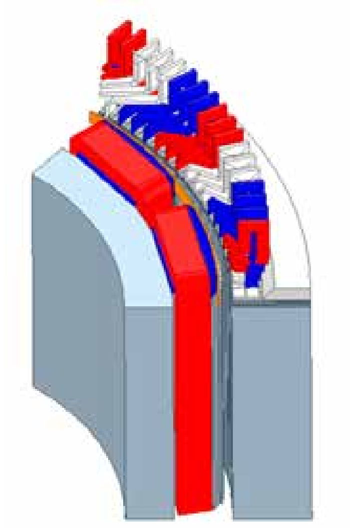
This was the first and only time Statkraft AS experienced such a breakdown and they became more interested in this topic.



Objective

A 3D-model based on data from one of Statkraft AS synchronous generator with directly water-cooled stator has been made in FEM-software ANSYS Maxwell.

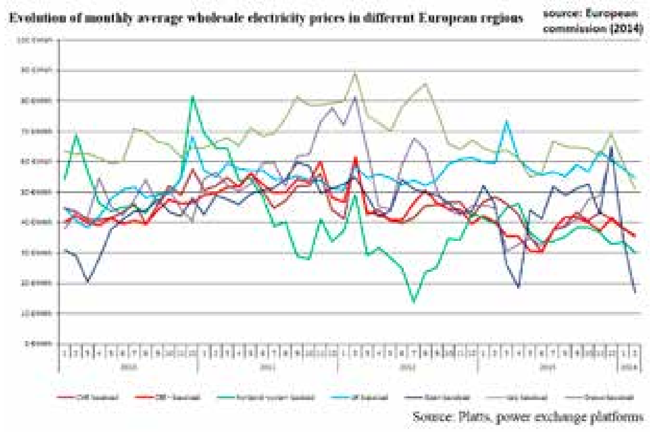
The objective is to get a deeper understading on how the magnetic field at end-region in the stator varies at different loading situations with simulations of the 3D-model. Eddy-current losses will be analyzed.



Background

Ongoing integration of continental European system and traditionally and physically less integrated (island) systems such as Great Britain into the Nordic system adds several additional factors to be considered. Strong focus has to be put on stability and sustainability of the system, especially considering that services to reach that goal differ vastly throughout the different countries.

Those ancillary services are the current topic of the ongoing research in this PhD project. The current questions consist of – how do the different services interact; what potential and risk exists for prospective future services; how do market participants realize their goals through offering or calling such services?



Methods

The pool of methods includes a range of modelling concepts from the fields of (stochastic) optimization and economic analysis, such as scheduling models, game theory, agent based simulation, etc.

Current topics are:

- development of a river run aggregation algorithm
- pricing of inertial response as an ancillary service
- balancing market arbitrage through hydropower

Markus Löschenbrand

Department of Electric Power Engineering

2015 - 2019

Multi market short term bidding of hydropower

Supervisor: Magnus Korpås
Co-supervisor: Marte Fodstad

NTNU

PHD THESIS

Tor Inge Reigstad

Department of Electric Power Engineering

2018 – 2020

Grid integration of variable speed hydro power plant

Supervisor:
Kjetil Uhlen

PHD THESIS

NTNU HydroCen

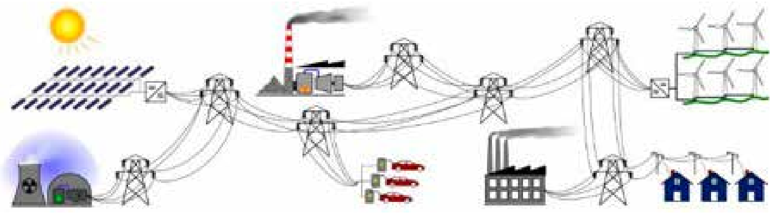
Background

As the share of wind and solar energy production increases, more flexible production and loads are required to control the balance of the grid. A potential use of Variable Speed Hydro Power (VSHP) is to provide this flexibility and compensates the production of variable renewables. The hypothesis is that VSHP can offer additional ancillary services, contributing to the frequency regulation and improving the grid stability, allowing for higher penetration of renewables in the grid.

The advantages compare to conventional pumped-storage hydro power with constant rotational speed is better utilization of the rotation energy in the turbine and generator and improved power control in pumping mode. The efficiency and operating range of variable speed hydro power will also be higher and they can contribute in frequency control both in production and pumping mode.

The focus of the PhD work will be to investigate the interactions between the VSHP plant and the grid, and how variable speed operation can benefit the security and flexibility of the power system operation. The main research task will be to explore the control possibilities from a system perspective while considering the limitations given by the water/turbine system. This comprise development of non-linear time domain simulation models with limitations for water flows in the tunnel, turbine, governor, generator with magnetizing system, generator-side converter and grid-side converter, and a representatively test grid.

Different methods for virtual inertia control methods will be investigated for damping of power fluctuation. Also new control schemes for coordinated control of governor, synchronous generator and grid converter considering limitations given by the water and turbine system and will be developed and optimized for a system perspective.



Background

Every day power is traded based on the estimated consumption, and the scheduled production on the Nord Pool Spot power exchange. On this exchange, power produced from different sources is bought and sold and is ready for delivery the next day. This is called the Day-ahead market.

Even though the marked is planned to be in balance, the system is continuously influenced by factors that could lead to imbalances. This could be changes in consumption as result of colder weather or unplanned outage in a Power Station. During the last decades Statnett have introduced market solutions to ensure sufficient supply of reserves.

To manage and plan for sales in an increasing number of markets, most power producers have engaged production planners. In production planning, the power producer attempts to optimize the value of the resources in a long and short-term perspective. This is done by applying a wide range of models and commercial competence

The complexity in the planning and nomination process is increasing. The time from when information is acquired to decisions are made is getting shorter, and the degree of details modelled in the power systems, and the amount of information processed, is continuously increasing. In addition, restrictions given by local, state-dependent, concessional and environmental conditions tend to introduce additional requirements to models that are applied in the planning process.

The objective of this project is to develop new methods for applied decision support for hydro- and windpower production planning. The long-term target is automatization of the nomination process using a combination of fundamental models, and deep reinforced learning methods.

Hans Ole Riddervold

Department of Electric Power Engineering

2017 – 2021

Automated short-term production planning for hydro- and wind power

Supervisor:
Magnus Korpås
In cooperation with Hydro

NTNU

PHD THESIS

PHD THESIS

Martin N. Hjelmeland

Department of Electric Power Engineering

2015 - 2018

Integrating balancing markets in hydropower scheduling models

Supervisor:
Magnus Korpås
Co-supervisors:
Arild Helseth and Gerard Doorman

NTNU

Background

In the EU there are ambitious targets for increasing the renewable electricity generation, especially wind- and solar-power. Due to the stochastic characteristics of the renewable generation, additional balancing is needed to secure a stable power grid. The Norwegian government recently gave concession to build two HVDC cables, 1400 MW both to Germany and UK, giving Norwegian hydro producers access to balancing markets at the European continent. My PhD will focus on methods for implementing additional markets, such as the balancing reserves markets, in hydropower scheduling models.

Due to the underlying uncertainty of inflow and power prices, hydropower scheduling for long-term models are considerably difficult to solve. The amount of potential stochastic outcomes explode over time, potentially diminishing the computational tractability. In order to cope with this issue the method of Stochastic Dual Dynamic Programming (SDDP) has proven beneficial for solving these types of problems. The method is, however, based on Linear Programming (LP), such that to model the added complexity provided by balancing reserve markets, e.g. integer bids and minimum production limits, is cumbersome.

The main purpose of the PhD is to investigate and potentially develop methods for incorporating multi-market hydropower scheduling.

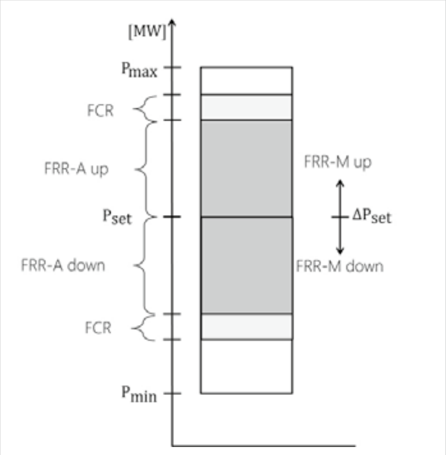


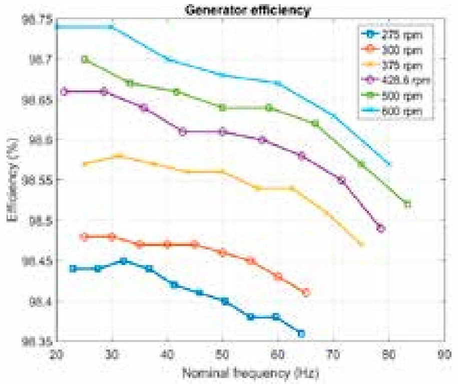
Illustration of different balancing reserves that could be provided from a hydropower station. FCR, FRR-A and FRR-M respectively refers to primary, secondary and tertiary balancing reserves

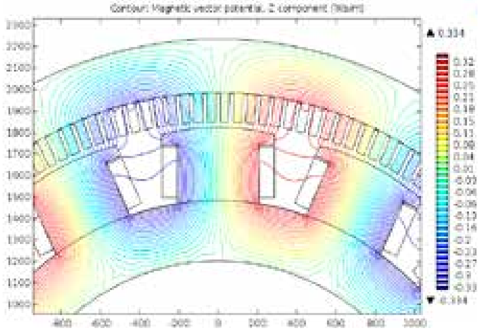
Background

The power system is experiencing an increasing share of electric power production that comes from intermittent power sources like wind and solar. Increased pressure is put on controllable power sources like hydropower to deal with fluctuations in the output of electric power production.

Generators used in hydropower plants today are not designed and optimized for frequent changes in active power production. The main purpose of this work is to develop optimum synchronous generator designs where the speed of rotation and electrical frequency is allowed to vary within given intervals.

Results indicates that the highest efficiency is achieved at low nominal frequencies, while generator weight is reduced substantially at higher nominal frequencies. Cost optimization where both losses and use of materials are taken into account indicates that a nominal frequency around 50 Hz will achieve the lowest total cost. There are also cost benefits associated with increasing the maximum values of the synchronous reactance, but this does also cause several possible design issues that will have to be resolved.





Erlend L. Engevik

Department of Electric Power Engineering

2014 - 2018

Design of variable speed generators for hydropower applications

Supervisor:
Arne Nysveen
Co-supervisor:
Robert Nilssen

NTNU

PHD THESIS

Raghbendra Tiwari

Department of Electric
Power Engineering

2017 – 2020

Frequency converter solutions and control methods for variable speed operation of pump storage plant

Supervisor: Roy Nilsen

PHD THESIS

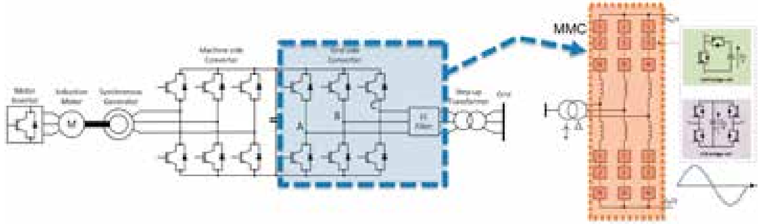
NTNU HydroCen

Background

At present, the pump storage hydropower plants are realized with at a ternary set of turbine, AC machine (generator/motor) and pump connected on the same shaft. The combination of turbine and AC machine (as generator) are active in power generation mode whereas the AC machine (as motor) and pump set are active in pumping mode. As the AC machines are directly connected to the large AC network, the ternary set of machines run at almost constant speed depending upon the frequency of the grid regardless of the amount of water flow into the turbine/pump. However, it is a well-proven theory that the turbine/pump operates at optimal efficiency only if its speed is varied according the variation in the water flow. This optimal efficiency operation of hydraulic machines can be achieved only by decoupling the turbine/generator sets from the AC grid using a full power back-to-back converter between the AC machine and the grid.

The research within this PhD will involve a lab setup of 100 kW capacity with 2-level back-to-back converter connected between the grid and the synchronous machine. The prime mover of the synchronous machine will be an induction machine and the variable speed operation of turbine to track the maximum efficiency will be simulated using a motor inverter connected to the induction machine. As the converters decouple the physical inertia of the machine, emulating virtual inertia and damping in the control system will be also be one of the major requirement. The decoupling will also limit the influence of grid dynamics on the hydraulic and civil structures.

To avoid the additional passive filter components or to make it very small, Multi-Modular Converter (MMC) topologies will also be tested.



Lab set-up (future extension in orange color)

Background

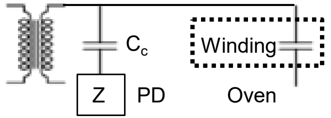
The majority of the Norwegian hydropower generators was installed between 1960 and 1990, and many of these will soon reach the expected lifetime and need refurbishment. One main root cause for failure in hydro generators is generally located to the groundwall insulation. It is therefore important to have reliable diagnostic methods to assess the groundwall insulation. This reduces the risk of unexpected breakdown and also too early winding replacement.

The objective of this PhD work is to correlate insulation defects and non-destructive measured quantities.

The method to be used is to first measure on single generator windings with different history, both spare windings and in-service aged windings from both high and low voltage locations. This will create a connection between the pristine system and the aged system to quantify measurable differences. Then, the faults will be localized by acoustic or high frequency techniques before a smaller area containing the fault, as well as a non-fault area, will be measured again by the same techniques. Next step is to reproduce the faults artificially in a model system and prove that the correlations found in the real system is originating from the proposed defects.

Relevant measurement techniques for condition assessment are dielectric spectroscopy, partial discharges, acoustic measurement and dissection. These methods will characterize the condition of the hydropower generator winding.

Laboratory test setup for partial discharge (PD) testing at 50 Hz. Transformer in front, connected to a coupling capacitor and the generator winding in back. An oven is surrounding the winding and enables measurements at different temperatures



Torstein Grav Aakre

Department of Electric
Power Engineering

2016 - 2019

Condition assessment of generator insulation

Supervisor:
Erling Ildstad
Co-supervisors:
Sverre Hvidsten,
Arne Nysveen

NTNU

PHD THESIS

POST DOC.

Mostafa Valavi

Department of Electric Power Engineering

2014 - 2017

Variable speed operation of hydro power plants/ vibration analysis of hydro generators

Supervisor:
Arne Nysveen

NTNU

Background: Variable Speed Operation

In conventional pumped-storage power plants, synchronous motor/generators are directly connected to the grid and operate at a constant speed.

Variable-speed operation of the hydro motor/ generators could increase the flexibility of hydro power plants and enable optimal hydraulic operation in both pumping and generating modes. In this system, the rotational speed of the motor/generator and pump/turbine does not need to be constant and can be varied to improve the hydraulic performance and reduce the stresses. A variable-speed pumped-storage power plant can also effectively contribute to the grid stability.

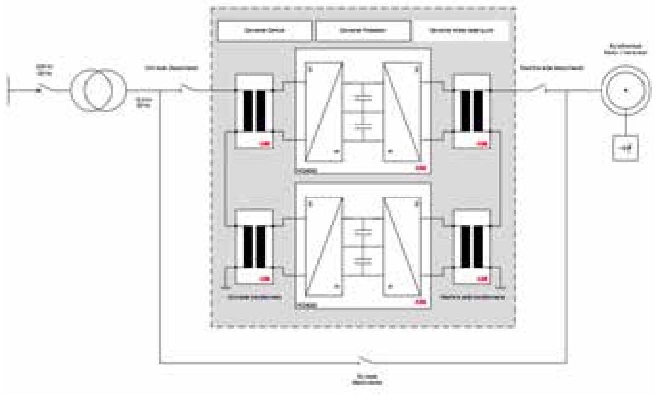
There are two energy conversion systems to realize the variable-speed operation of the hydro power plant: converter-fed synchronous machine (CFSM) and doubly-fed induction machine (DFIM). The focus of this research work is on the CFSM with full-rated converter which offers a higher degree of flexibility and superior performance.

Background: Vibration Analysis

In the operation of the hydro generators, radial magnetic forces are produced, causing vibration in the stator.

The objective of this research work is to investigate magnetic forces and vibration and to identify the main factors affecting vibration characteristics. The focus is on the fractional-slot synchronous generators.

CFSM installed at a pumped-storage power plant in Switzerland by ABB



Department of Industrial Economics and Technology Management

NTNU

MASTER THESIS

Sunniva Reiten Bovim and
Hilde Rollefsen Næss

Department of Industrial Economics and Technology Management

Spring 2018

Analysis and optimization to provide decision support in Elbas

Supervisor:
Asgeir Thomasgard
Co-Supervisors:
Stein-Erik Fleten and
Ellen Krohn Aasgård

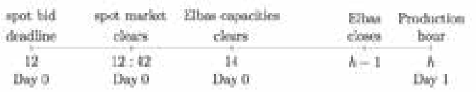
NTNU

Background and objective

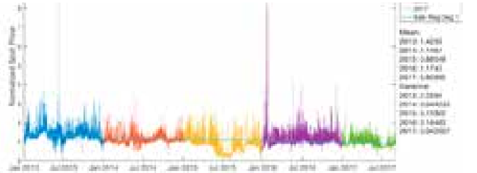
Increased proportions of renewables in the energy mix results in more uncertainties concerning production capacities the day ahead of production. As a consequence, the intraday market, Elbas, experiences increased trading volumes.

The purpose of this study is to develop an optimization model as a tool for decision support when bidding in Elbas. The model provides information about the optimal timing to place a bid, and the optimal volume to be traded at a specific price.

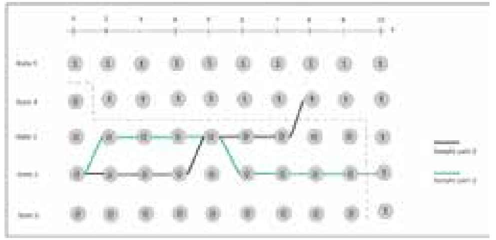
Each hour of production is regarded as a unique product that is to be traded. Optimal timing of trade to obtain a maximized profit can take place at any time from the spot market closes, until one hour prior to production. The timeline below illustrates the time of events.



A stochastic price model is developed to predict Elbas prices, based on historical data and correlation to spot prices. The data set is plotted as a timeseries below.

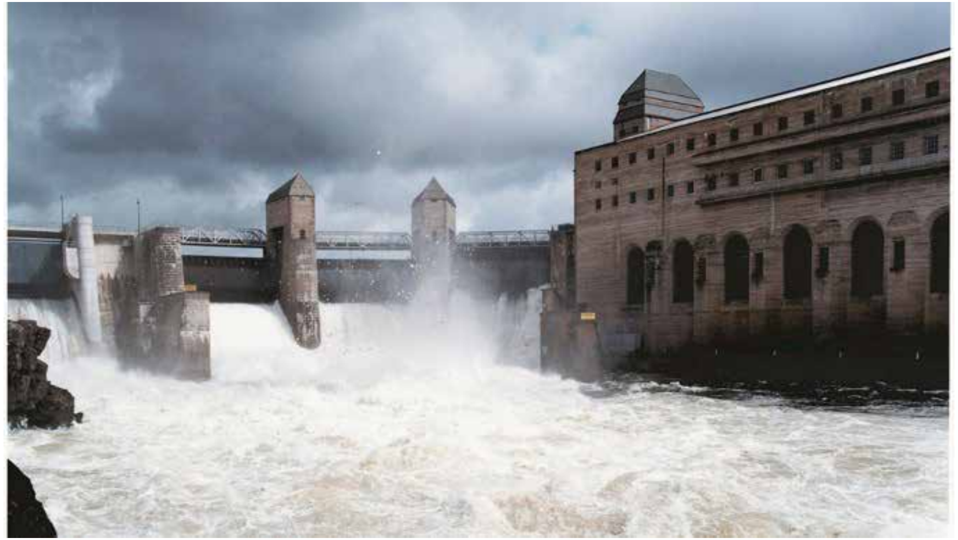


The contingency plan below is an example of how decision support can take place in a simplified modelling context. The green and black lines illustrate two possible price paths up until a specific production hour. The numbers 1 and 0 indicate whether to bid or not at time t.



Background

The project will impart knowledge about cost-effective, safe and sustainable upgrading and refurbishment of hydropower plants. Such plants are subject to operational and value changes as a result of changes in operating requirements, coming mainly from environmental concerns and market changes that ultimately stem from a transition to a more sustainable power system. Major choices involved in upgrading and expansion of hydropower plants include timing of commencement, size/scale, and technology changes, such as new tunnels, a reduction or expansion in the number of power stations or different turbine/generator configurations. The main objective in this project is to develop models and methods for calculation of future revenues for hydropower and to support decisions regarding optimal investments in upgrading and expansion projects.



Solbergfoss kraftverk

Andreas Kleiven

Department of Industrial Economics and Technology Management

2017 – 2021

Investment decisions in upgrading and refurbishment of hydropower plants

Supervisor:
Stein-Erik Fleten

NTNU HydroCen

PHD THESIS

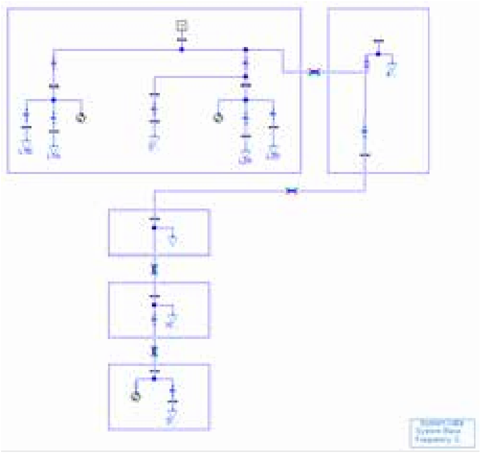
HSN University College of Southeast Norway

Background

Power system modelling and simulation is crucial to achieve a successful operation and management of electricity networks. It creates an offline working platform for engineers to perform test and scenarios to verify if the operation of the network is safe and reliable. Therefore, to meet this demand, a new modelling and simulation environment, Dymola, which is based on Modelica language will be utilised in this thesis. A power system from another simulation environment, DIgSILENT PowerFactory, will be implemented in Dymola using a power system library called OpenIPSL. OpenIPSL started as a fork of the iPSL from the iTesla project in 2016, and is now actively developing by ALSETLab (formerly SmarTS lab). Two simulation environments, PowerFactory and Dymola, will be compared to check if the physical behaviour of models can give the same response and results.

The power system located in the North of Iceland is planning to upgrade the geothermal powerplant Bjarnarflag to 5 MW. In the light of this upgrade a new opportunity for the delivery of energy has opened. A new delivery point is added at Bjarnarflag and need to be investigated. The figure below shows the distribution between the new line, new user and upgraded Bjarnarflag with a new transformer (a screenshot from Dymola).

In addition to the turbine upgrade of 5 MW in Bjarnarflag, the power station is being connected to a new 220 kV subsystem in Krafla. Krafla is a 2x30 MW geothermal power station close to Bjarnarflag. A new line, Reykjarhlíðarlina (B), will be connecting Bjarnarflag to this new 220 kV substation. The investigation is therefore to see much power delivery can be guaranteed for the new user and how reliable is the system. The power flow solution from Dymola will then be compared to the simulation results made by in PowerFactory.



MASTER THESIS

Tien Thanh Nguyen

Department of Process, Energy and Environmental Technology

2016 – 2018

Modelling and simulation of a new power delivery in the north of Iceland

Supervisor: Dietmar Winkler

HSN University College of Southeast Norway

MASTER THESIS

Erik Boye Abrahamsen

Department of Process, Energy and Environmental Technology

2016 – 2018

Machine learning with application to weather forecast

Supervisor:
Bernt Lie
Co-supervisor:
Ole Magnus Brastein

University College of Southeast Norway

Background and objectives

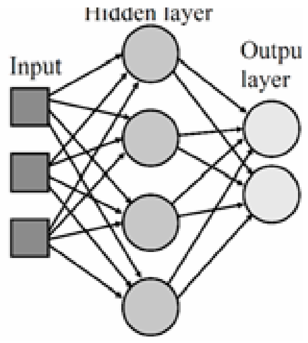
Forecasting weather conditions such as precipitation is important for hydropower operation and flood management. Mechanistic meteorology prediction based on Navier Stokes equation (3D CFD) is extremely demanding w.r.t. computing power: generating a 14 day weather forecast can easily take 12 hours on super computers.

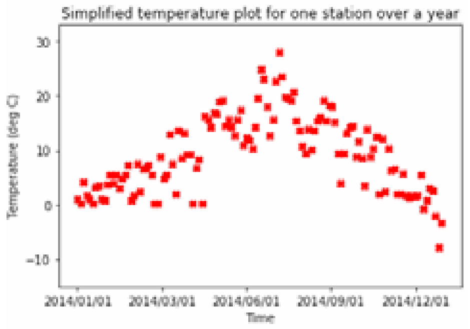
Today, a large amount of weather data (temperature, pressure, humidity, precipitation) is readily available, e.g., from the Norwegian Meteorological Institute (MET), from Netatmo weather stations, etc. An interesting question is whether a large amount of data in combination with machine learning can give decent forecasting quality with low computational power.

In this thesis, Python APIs are developed for reading public weather data. A deep neural network model is built and trained to predict the weather in Porsgrunn based on data from carefully chosen geographic locations throughout Eastern Norway and beyond.

Scenarios to investigate

- Assuming a correlation between recent past and near future weather conditions, thus predicting the weather at a single location using the model and historical data at point of interest
- Predict the future weather at point of interest using real time data at geographical points in the region surrounding the point of interest.





The flexible hydropower unit – Power system analysis and balancing control impacts

Adaption of Optimal Power Flow (OPF) in day-to-day operation of a Hydroelectric dominated power system as in Norway.

Motivation: The possibility to optimize production of reactive power to minimize transmission network losses.

The study work will be executed on offline network models to show how OPF will affect transmission losses.

The study will contain:

- A description / study of what adaption has to be included in Control Centre software system to operate OPF.
- An evaluation of the control chain from Control Centre to the HPUs.
- Evaluations on requirement about an increased flexibility / utilization of the HPU in balancing of the power system including dispatch of reactive power from OPF.

Guidelines for the further development of the control chain for the Flexible HPU should then be proposed.

Shohreh Monshizadeh

Department of Process, Energy and Environmental Technology

2018 – 2021

The Flexible Hydro Power Unit

Supervisor:
Gunne John Hegglid

University College of Southeast Norway

HydroCen

PHD THESIS

PHD THESIS

Liubomyr Vytvytskyi

Process, Energy and Automation Engineering

2016 – 2019

Dynamics and control of integrated energy systems

Supervisor:
Bernt Lie
Co-supervisor:
Roshan Sharma

University College of Southeast Norway

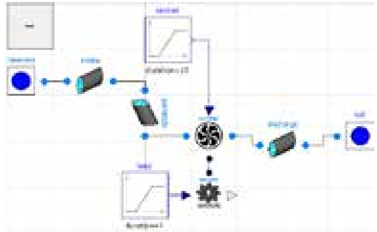
Background and objectives

A transition towards more renewable energy sources is currently happening in Europe and all over the world. This leads to an increase in the use of flexible hydropower plants to compensate the highly changing production from intermittent energy sources such as wind and solar energy. In the study of dynamics and control of integrated energy systems, the research focus will be within hydropower systems, but in such a way that the developed methods and tools are relevant for other energy systems, too.

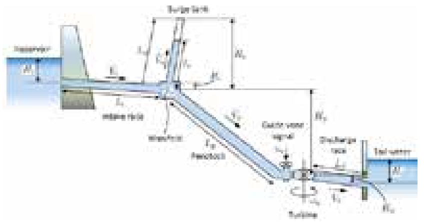
The study aims at developing a set of models relevant for hydropower production from precipitation, via transport through the catchment to dams or rivers (hydrology) , as well as flow in rivers and/or pressure shafts to the turbine, including turbine, various pressure shock damping devices, and possibly including generator. The models will be encoded in a Modelica library (using OpenModelica as an open-source Modelica-based modelling and simulation environment), and should be able to interact with other libraries "downstream" from the generator, e.g., including transmission, and consumption.

Different methods for efficient analysis of the models, such as decomposition into different time scales, decoupling into subsystems and others are the aims of study. The developed methods should be implemented as tools in Python (powerful open source programming language), which can be interfaced to Open Modelica via a Python API under development.

Other methods for energy analysis and synthesis of control systems exist, e.g., the Power flow method, which attempts to integrate modelling and control of the system. These methods are designed for the overall power system network, consisting of an interconnection of the various components.



Screen dump of the library components combined in the hydro power system



Schematic of a hydro power system

Background and objectives

Within the EU/EEA-area in Europe, work is in progress to standardize the requirements of generating units. The objective is to increase the operational security of the power system.

In the Nordic power system, the hydroelectric generation is widely spread throughout the transmission grid. Single short circuit events in such a system will have impact on a number of nearby units. These short circuit events imply heavy strain to the generating equipment.

The capability of hydroelectric generating units to stay in synchronism through short circuit events in the connected power network is investigated.

The impact of the electric relaying system on the dynamic properties of generating units which are interconnected in a comprehensive grid system is also investigated.

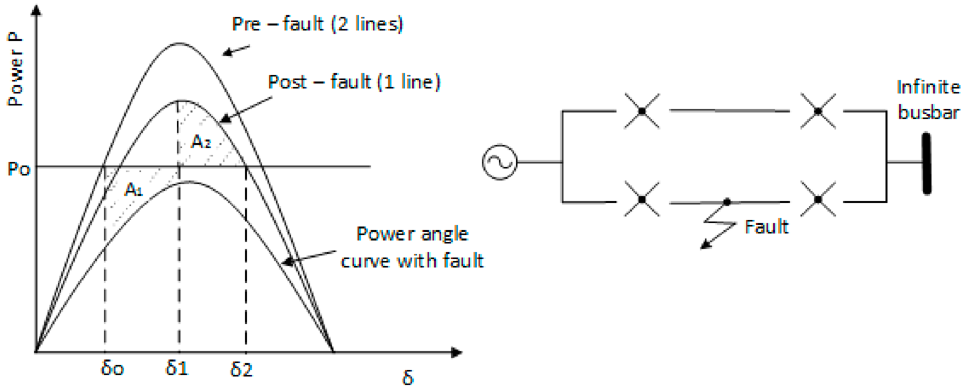


Figure: Fault on oneline of two lines i parallel. Equal-area criterion. Resistance neglected. 1 is critical clearing angle for input power Po (Reference: B. M. Weedy, B. J. Cory, N. Jenkins, J. B. Ekanayeka, G. Strbac, Electrical Power Systems, Fifth edition, 2012, page 289)

Manjula Edirisinghe

Process, Energy and Automation Engineering

2016 – 2020

Transient stability in high voltage power systems

Supervisor:
Gunne Hegglid
Co-supervisor:
Svein Thore Hagen

University College of Southeast Norway

PHD THESIS

PHD THESIS

Jonas Kristiansen Nøland

Department of Microsystems

2014 – 2018

Remote controlled fast-response brushless rotating exciters for improved performance of hydrogenerators

Supervisor:
Urban Lundin

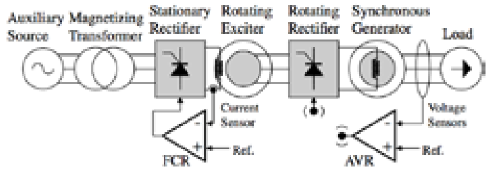
HSN University College of Southeast Norway

Background

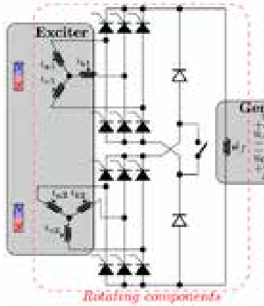
The grid code, FIKS, from the Norwegian Transmission System Operator (TSO), Statnett, states that synchronous generators ≥ 25 MVA, must have a static excitation system. However, an improved brushless excitation system is in operation on some commercial power plants (36MVA, 93.75rpm & 52 MVA, 167.67rpm) with grid-assisting performance beyond the conventional static system.

Preliminary outcomes of the project

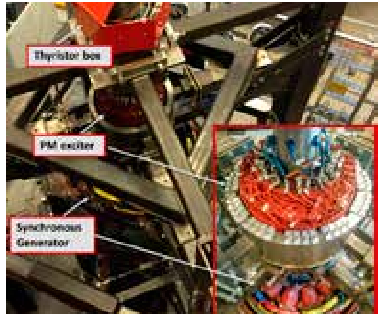
- A new era for large brushless hydro-generators is expected. If remote control is not allowed, a control signal through brushes should be employed instead.
- A six-phase exciter design with a hybrid-mode thyristor interface leads to improved redundancy, better controllability, minimized torque pulsations and reduced armature currents for the exciter.
- Proposed brushless system leads to reduced regular maintenance due to lack of slip rings and reduced unscheduled maintenance due to redundancy; both causing a reduced cost-of-energy.
- Permanent magnets on test rig is equivalent to constant field current control (FCR) of exciter in the commercial system.
- Excitation boosting (EB) is included in the brushless system without additional components or circuitry, leading to improved FRT-capability and PSS-actions.



Schematics of commercial brushless system (Voith)



Proposed hydbrid-mode thyristor based interface



State-of-the-art experimental test rig (Uppsala)

Future work

Extensive measurements and verification of the system on large-scale power plants.

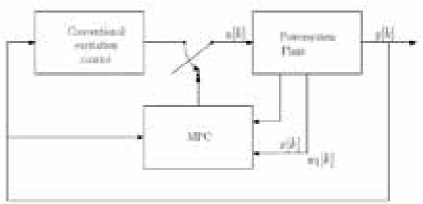
Background and objectives

The Norwegian Network Code FIKS from the Norwegian Transmission System Operator (TSO) Statnett, states that synchronous generators ≥ 1 MVA must connect to the grid with a cos ≤0.85 capacitive and ≤ 0.95 inductive. Reactive power can be used to compensate for voltage drops in a power system, but must be provided closer to the demands than real power needs due to transportation limitations of reactive power through the grid.

Flexible power factor control on large synchronous generators located close to points of high demand could enhance the voltage stability of a power system.

Model Predictive Control for voltage control through field excitation of hydroelectric generating units is investigated.

Typical objective criterion:

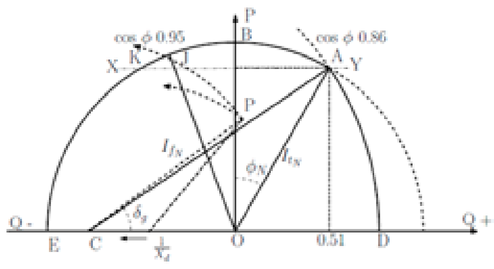


Structure of plant and controller. Here, MPC is a Single Input, Multiple Output (SIMO) controller

An attractive feature of MPC is its capability to handle Multiple Input, Multiple Output (MIMO) systems and nonlinear systems taking constraints into account.

With increased provision of reactive power, the generating unit will be more mechanically stressed. Due to these stresses an investigation of thermal performance of the generating unit by varying the ratio of active/reactive power provision will be done

An optimal utilization of thermal capacity and cooling mechanisms of hydroelectric synchronous generators should be found and compared with design and standards. Thanks to Statkraft for funding the study.



Capabillity diagram of a synchronous generator

Thomas Øyvang

Process, Energy and Automation Engineering

2014 - 2018

Improved functionality of power systems using model predictive control

Supervisor:
Bernt Lie
Co-supervisor:
Gunne Hegglid

HSN University College of Southeast Norway

PHD THESIS

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