HydroCen

NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

OVERVIEW OF MSC - PHD - POST DOC. **2019**

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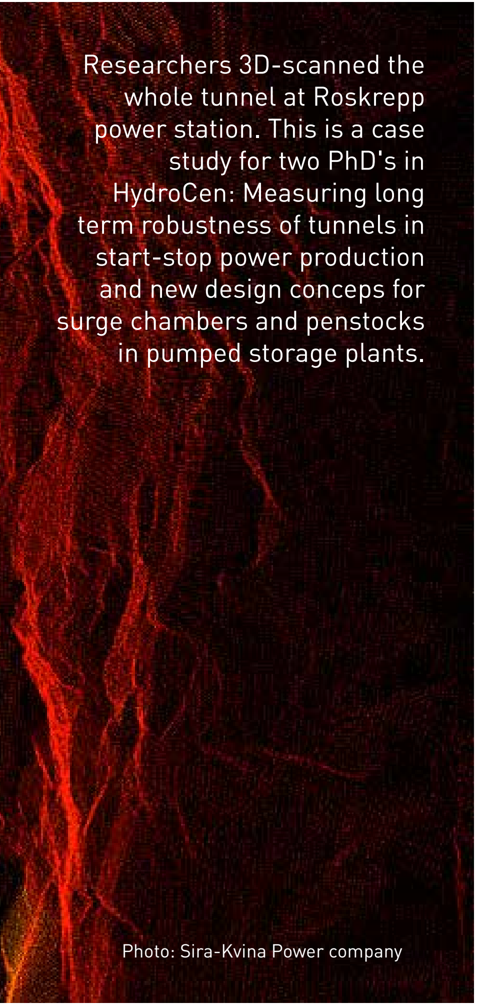
Content



Researchers 3D-scanned the whole tunnel at Roskrepp power station. This is a case study for two PhD's in HydroCen: Measuring long term robustness of tunnels in start-stop power production and new design conceps for surge chambers and penstocks in pumped storage plants.

Photo: Sira-Kvina Power company

HydroCen

Norwegian Research Centre for Hydropower Technology

I am very proud to present our suite of excellent master students, PhD and Post doc. in HydroCen! Their willingness to engage, be creative, challenge and work together with industry partners ensure that we deliver on our mission to define and enable the new role of hydropower in the clean energy system.

The education and research in HydroCen investigate how hydropower will operate in the future energy system. The future is uncertain in regards to climate change and sustainable growth, where clean energy for all is one of the major, and critical, challenges of our time. Globally, hydropower generates ~62 percent of the renewable electricity share. In Europe hydropower amounts to ~50 percent, and in Norway this is ~96 percent.
In short, hydropower is the major supplier of renewable energy in the world. In this respect, hydropower competence, new solutions and new knowledge are keys to meet UNs sustainable development goals and accelerate the transition to a clean energy system.

Hydropower has some unique capabilities for flexibility and regulation. This can be demonstrated across time, scale and characteristics. A hydropower unit with a turbine, generator and converter can be optimized to deliver and absorb energy in order to regulate grid frequencies down to milliseconds. A hydro tunnel can be designed to handle large and frequent fluctuations in the flow in order to start and stop the machines whenever needed to optimize operation and take advantage of new markets. A large hydropower reservoir scheme can store energy for weeks, months and even seasons. New methods for fish migration and operations of reservoirs and watercourses mitigate and avoid environmental impacts. New models for hydro scheduling and market design secure profitability and future investments in renewable hydropower. Innovative solutions for sediment handling and water management secures that future development of hydropower is sustainable.

Hege Brende, Executive Director, HydroCen

HydroCen is a Centre for Environment-friendly Energy Research (FME). The FME scheme is established by the Research Council of Norway 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 students and research fellows in HydroCen are graduated from The Norwegian University of Science and (NTNU) and from The University of South-Eastern Norway (USN)

Partner overview

NTNU
SINTEF
NINA Norwegian Institute for Nature Research

University of South-Eastern Norway
NGI
NTNU Technology Transfer as

The Research Council of Norway

NVKS Norsk Vannkraftsenter

agder energi · BKK · ECO · Eidsiva · EnergiNorge
GLITRE ENERGI · HELGELAND KRAFT · Hydro · Lyse · NTE · SFE
Sira-Kvina KRAFTSELSKAP · Skagerak Energi · SKL · SKS · Sognekraft
Statkraft · SUNNFJORD ENERGI · TrønderEnergi · TUSSA · ØSTFOLD ENERGI

ABB · ANDRITZ Hydro · GE Renewable Energy · RAINPOWER · VOITH HYDRO POWER GENERATION

DR. TECHN. OLAV OLSEN · Multiconsult · Norconsult · SWECO

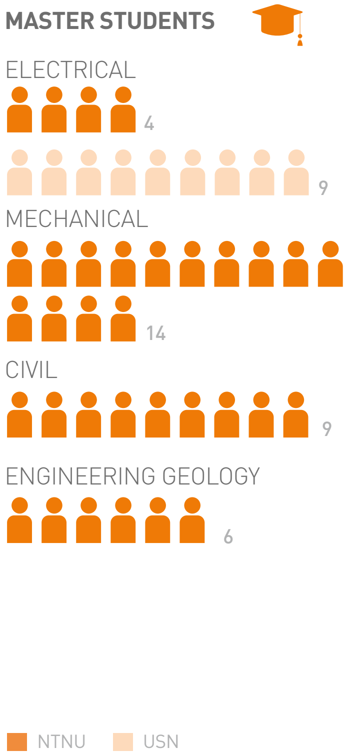
DYNAVEC AS · EDR MEDESO · FDB · SediCon · NVE

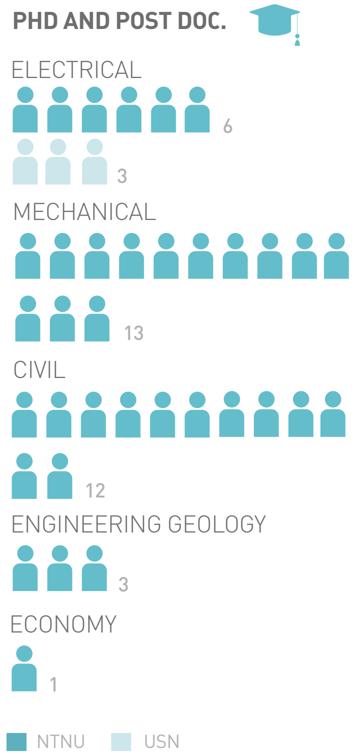
HydroCen

Overview of students and research fellows

Overview of the number of master students, PhD and Post Doc connected to NTNU and USN in Spring 2019.

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





Vortexes, louvers and bubble-walls were some of the suggestions put forward when HydroCen researchers discussed possible new solutions to prevent fish from entering power stations and embarking on the often-fatal turbine passage.

Previous research has shown that scaring fish is an inefficient way of influencing fish behaviour, so now experts from several diciplines pool their resources to guide fish away from turbines.

Photo: Marcell Szabo-Meszaros / Geir Mogen, NTNU

Hydropower Development Program (HPD)

The Department of Civil and Environmental Engineering at the Norwegian University of Science and Technology (NTNU) is engaged in research and scientific services in determining how to develop hydropower resources while considering technological, environmental and economic conditions in a balanced way. The Hydropower Development program was evaluated by external referees in 2005 and was found to be "international state of the art and possibly superior product".

The program consistently incorporates international experience and hydropower development practice outside Norway. The teaching staff has relevant international experience and include professors from NTNU as well as experts from the hydropower industry.

PhD and Post doc. in HydroCen, employed in 2018-2019

MSc students spring 2019	Title master thesis	Supervisor
Abbas Ashimiyu Lawal		
Andrew Mabula	Chiriqui Viejo Watershed Optimization	Oddbjørn Bruland/Knut Alfredsen
Beyene Feye Fulasa	Investigation on different shapes of broad-crested weirs by means of CFD	Nils Rüther
Charles Mwase	Cascade Power Plants Optimization, UEGCL, Using Nmag and/or Vannsimtap	Oddbjørn Bruland/Knut Alfredsen
Dipesh Nepal	3D CFD simulation of flow and bed load in Binga HHP reservoir	Nils Rüther
Erik Kleiven Rynning	Snow measurements using Drone	Oddbjørn Bruland
Jana Daxnerova	Hydraulic scale modelling of diffusers for hydropower sand traps	Kaspar Vereide
Jeevan Maharjan	Planning, optimization and analysis of waterway system and stability assessment of settling basin caverns for KHIMTI II HPP in Nepal	Krishna Panthi
Kamrun Naher	Climate change assessment in Gaula catchment	Knut Alfredsen
Kh Rahat Usman	Identification of critical points in rivers by using GIS and HEC	Oddbjørn Bruland
Medhin Shiferaw Assaminew	Sediment handling at Paso Ancho HPP in Panama	Nils Rüther
Parash Mani Mishra	Assessment on the partial use of shotcrete lined headrace tunnel with underground powerhouse cavern at Solu Dudhkosi Project, Nepal	Krishna Panthi
Pia Rønne	Vurdering av minstevassføringsslepp i Årdalselva	Knut Alfredsen
Prashant Bhatta	Stepped large scale spillways in unlined rock	Elena Pummer
Pratik Bijukchhe	Numerical modelling of sediment deposition at Paso Ancho HPP in Panama	Nils Rüther
Sanjoy Kumar Saha	Feasibility Study of Kuli Pumped Storage Project	Kaspar Vereide
Sudhir Man Shrestha	Physical modeling of pressurized flushing of lightweight material	Nils Rüther
Tom Erik Berg	Bruk av driftstunnel som magasin for kraftproduksjon (Using water conveyance tunnel as storage for power production)	Leif Lia
Ujjwal Shrestha	Structure from Motion applied to movable bed scale models	Nils Rüther
Wolfgang Szentkereszty	Multi beam echosounding in river engineering	Nils Rüther
Wondwosen Dejenne Amsalu	Numerical modelling of flow and bed load transport in residual flow reach at Schiffmühle HPP	Nils Rüther /Fjola Sigtryggsdottir

Department of Civil and Environmental Engineering

NTNU

MASTER THESIS

Malin Fossum Asbølmo

Department of Civil and Environmental Engineering

Spring 2019

Significance of toe on placed riprap stability

Supervisor:
Fjóla Guðrún Sigtryggsdóttir
Co-supervisor:
Ganesh H.R. Ravindra

NTNU

Background

Rockfill dams are of much importance to Norwegian hydropower schemes, and many of these dams needs to be refurbished in the near future to meet dam safety regulations. The upgrading process often includes expensive upgrading of the overtopping protection system for the dams, such as the riprap and the dam toe.

Several past studies of rockfill dam failure under overtopping flow conditions, have suggested that the initiation of failure at the toe is probable.

Method

A field survey aimed at measuring riprap- and toe features of 9 different Norwegian rockfill dams was undertaken in the autumn of 2018, and is illustrated in the left picture. In his thesis the measurements will be analysed and compared to the Norwegian regulations and guidelines. The field study showed that most rockfill dams are built with no toe support.

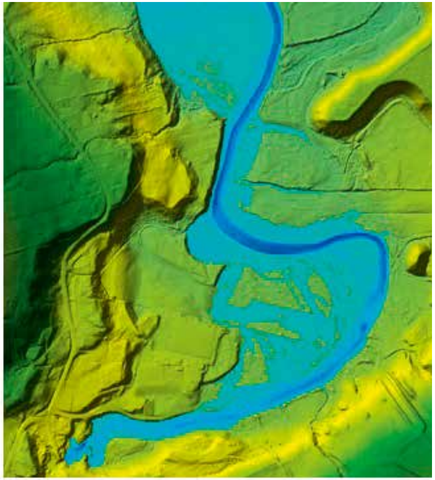
The significance of the downstream toe on placed riprap stability is investigated by physical modelling investigations as depicted in the right picture. And the model dams are built with no toe support, as observed in the field survey.

Background

Manndalen in Kåfjord municipality, Troms, is often exposed to floods. The NVE plans to set up a flood protection measure in this area and needs to know the water levels of the re-occurring flood levels.

A 1D and 2D numerical model will be set up in HEC-RAS based on bathymetry data measured by handheld GPS and laser data of the terrain. In addition, the use of Unmanned Aerial Vehicles (UAV) to measure bathymetry data of shallow water bodies will be investigated.

The thesis will include a discussion on the use of 1D and 2D numerical models with regards to accuracy, and a discussion on the use of UAV based photogrammetry to measure bathymetry.
The best fit model will be used to suggest flood protection measures.



2D numerical model of Manndalen in HEC-RAS 5.0.6

From bathymetry measurements during the summer of 2018.

MASTER THESIS

Oda Alstad Førlie

Department of Civil and Environmental Engineering

Spring 2019

2D Numerical modelling of Manndalselva to ensure flood protection

Supervisor:
Nils Rüther
Co-supervisor:
Per Ludvig Bjerke
In cooperation with: NVE

NTNU

MASTER THESIS

Mari Leikvangen

Department of Civil and Environmental Engineering

Spring 2019

Optimal compaction of rockfill in embankment dams

Supervisor: Leif Lia
Co-supervisor: Andreas Fløystad, Arnfinn Emdal
In cooperation with: Sweco Norge AS

NTNU

Background

In building of rockfill dams, compaction has an important role for the stability of the dam. There is different methods for compaction of rockfill, like dumping in high lifts and flushing, but the most used method today is compaction with vibratory rollers. The Norwegian water resources and Energy directorate (NVE) have regulations for compaction of rockfill in embankment dams which is based on weight and number of passes of the roller.

These regulations were made when the vibratory rollers were smaller and lighter, but these regulations do not fit with todays heavy vibratory rollers. Also, the regulations do not take into account the characteristics of the rockfill or how the rockfill material responds to compaction. Ideally, one wants to compact as little as possible in the case of over-compaction which can lead to an impervious rockfill and also increased cost and work-time. Since most of the vibratory rollers have the ability to measure the response value under compaction, it will be more efficient to use this measure equipment for compaction and control of compaction.

Objective

The objective of this thesis is to look at the ability to use measuring devices like response meters, accelerometers and GPS to easily control the compaction of rockfill in embankment dams. A literature study will be carried out to establish the current situation in compaction methods, implementation and usability on a national and global scale.

Since there is little information on the use of response values in dam building it is necessary to look into other professions like construction of roads and airports.

In cooperation with Sweco Norge AS, test fills with vibro rollers will be carried out and the response values will be analysed and compared with settlement data. Test fills will be conducted on dam Langevatn located at Ljosland in Åseral, Vest Agder.

The area and old dam Langevatn at Ljosland.
Courtesy: Agder Energi

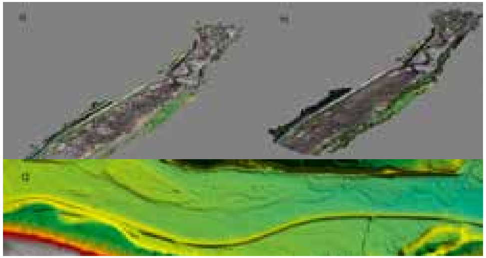
Background

Environmental design in regulated rivers aims to minimize the effect power production has on those who use – and live in the water course. Researchers at HydroCen is now looking to expand existing environmental design concepts established in FME CEDREN, by exploring various new tools for mapping and analyses of different river typologies.

Obtaining data by using innovative methods in remote sensing with available technology provides a new methodology for environmental design diagnosis and solutions. Drones with high-resolution cameras, laser measurements (LiDAR) and satellite images can be used to model how water levels in the river connects to important factors in habitat and fish-migrating conditions, such as water-covered area and river bottom conditions.

Nea is a river connecting Vessingsjøen to Selbusjøen and is heavily regulated through different power plants and magazines. In the process of regulating the river several weirs were constructed along the reach. Today, the weirs effect on hydraulic conditions in the lower part of the river system is being questioned.

The main objective of the thesis is to obtain and assess remote sensing data from green LiDAR and aerial photographs in order to model the hydraulic effects of possible measures on the weirs in Nea.



Section of Nea constructed as an artificial channel: a) point cloud b) orthophoto c) DEM

MASTER THESIS

Sebastian Moss

Department of Civil and Environmental Engineering

Spring 2019

Hydraulic Modeling of Nea

Supervisor:
Knut Alfredsen
Co-supervisor:
Håkon Sundt

NTNU

MASTER THESIS

Daniel Kevin Pace

Department of Civil and Environmental Engineering

Spring 2019

Numerical Simulation of Long Tailrace Tunnels for Hydropower Pumped Storage Plants

Supervisor:
Kaspar Vereide
Co-supervisors:
Livia Pitorac, Leif Lia

NTNU

Background

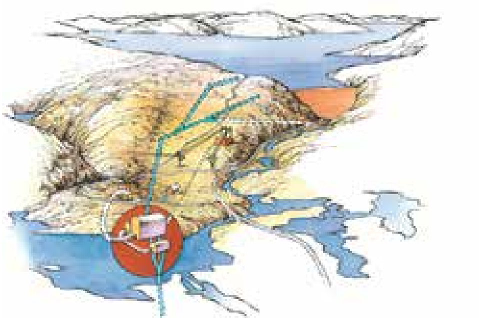
Pumped storage plants are beneficial in power systems with high intrusion of wind and solar power, owing to their high flexibility and energy storage capabilities.

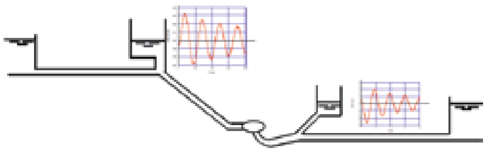
Hydraulic transients are more adverse in pumped storage plants compared to conventional hydropower plants, due to the fact that water can be moved in both directions. It is therefore necessary to study the effects on hydraulic transients as these may result in damages to the power plant or require operational restrictions to have an acceptable safety.

Many pumped storage plants have a longer tailrace tunnel instead of a longer headrace tunnel, to increase the length of the low-pressure section of the waterway. One of the reasons is that pumped storage plants have more hydraulic transients compared to conventional hydropower plants. The same design can be seen for pumping stations in drinking water systems. A long tailrace tunnel provides different challenges compared to a long headrace tunnel.

Objectives

The purpose of this master thesis is to study and optimize the design of waterways for pumped storage plants with emphasis on long tailrace tunnels. Two case studies shall be applied, the existing 200 MW Duge pumped storage plant, and the planned 500 MW Skjerka pumped storage plant. The challenge in Duge pumped storage plant is to improve the existing condition, while the challenge in Skjerka pumped storage plant is to design a new waterway.

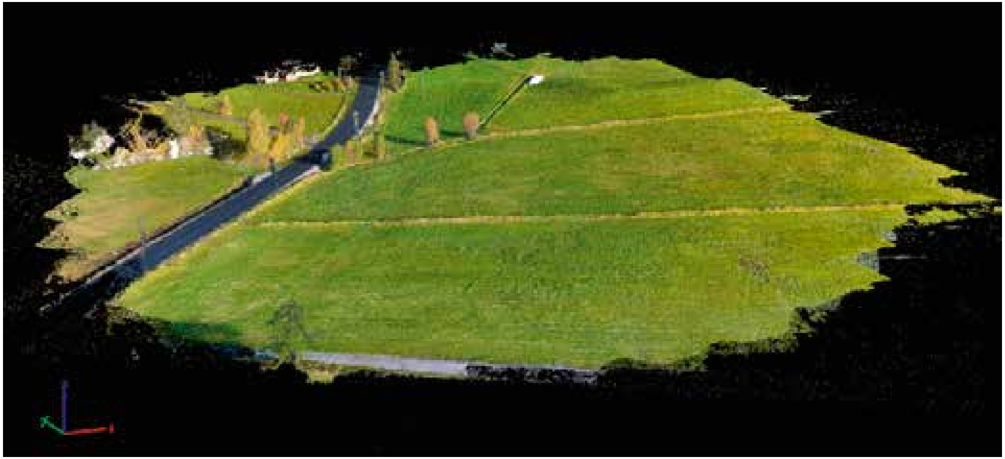




Background

Hydropower companies in Norway have a common challenge in measuring the snow reservoir during winter. The amount of snow in the catchment will have a high influence on the optimum operation of the water reservoirs. The reservoir have to be sufficiently emptied to account for the snowmelt, or large water losses may be encountered. However, if the reservoirs are emptied too much, the available head on the turbines will be reduced and it may not be possible to refill the reservoirs before winter.

In cooperation with Sira-Kvina power company, a new method for snow measurements will be tested. Drones can be used to make 3D models with photogrammetry, and this method can be used to find the snow volume. The water equivalent for the snow can be found either manually, or with theoretical models. This method might improve the existing methods for snow measurements.



MASTER THESIS

Erik Kleiven Rynning

Department of Civil and Environmental Engineering

Spring 2019

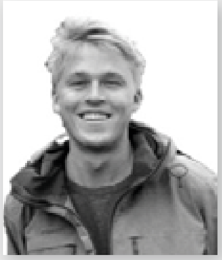
Snow measurement with drones

Supervisor:
Oddbjørn Bruland
Co-supervisor:
Kaspar Vereide
In cooperation with:
Sira-Kvina Kraftselskap

NTNU

MASTER THESIS

Sturla Dimmen Sæle



Department of Civil and Environmental Engineering

Spring 2019

Development of "snorkel" for Coanda intakes

Supervisor:
Leif Lia
Co-supervisor:
Knut Alfredsen, Halvor Kjærås

NTNU

Background

The Coanda intake is a solution for intakes to small river run-off hydro power plants. It has a very good self cleansing ability, as well as it is friendly towards fish migration through the intake area. In some coastal climates there are problems with several stops in production throughout the winter season. This is due to the freezing of the intakes trash rack, and the varying climate gives more such events throughout the winter.

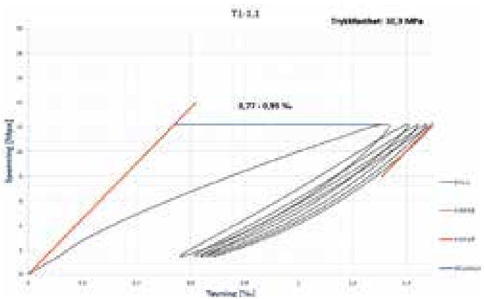
At Dyrkorn Power Station, Tafjord Kraft has installed a special snorkel-patent to solve this problem, and there is a desire to document and optimize the function of this. In the work with this master thesis there will be completed laboratory tests and field measurements at Dyrkorn.

Background

Alkali Aggregate Reactions (AAR) are chemical reactions where sodium and potassium ions in solution react with certain rock types in the concrete aggregates. The reaction forms a hygroscopic alkali-silica gel which imbibes water and swells. The swelling forces generated may be enough to disrupt aggregate particles and the surrounding concrete, causing expansions, cracking and associated deterioration. In addition, the concrete becomes softer (lower E-module), loses tensile strength and eventually also reduces the compressive strength. Problems regarding AAR in dam constructions have been known internationally since the 1960s and in Norway since the mid-80s. This means that dams built in Norway before 1990 can be affected by such reactions. The reaction is dependent on the minerals in both cement and aggregate, in addition to the speed being greatly influenced by moisture content and temperature.
Concrete dams are characterized by massive structural parts, little reinforcement and relatively low stresses. Concrete dams will therefore experience large swelling due to AAR, and in the worst cases high tension in the reinforcement. It is known that no cure has yet been found. Today's research focus is on rehabilitate (possibly reinforcing) the dam constructions so that they also in the future can fulfill their purpose.

In this thesis, 10 core samples have been drilled from Tyin dam 3, owned by Hydro Energy. The objective is to participate in the different testing procedures, interpret and evaluate the results and finally suggest measures to avoid further deterioration.

The core samples will be analyzed for AAR using different types of tests in the laboratorium. One of the cores will be sent to Canada, where there will be performed a test called Damage Rating Index (DRI). A half core is going to Denmark where there will be prepared thin and plan polished sections. After returning from Denmark these will be examined under a microscope using UV-light. Samples for Micro XRF have been put aside. PF/DCS will be performed to find out information about the concrete's inner pore structure and water content. At last the Stiffness Damage Test (SDT) and standard pressure testing will be performed to find changes in mechanical properties.



Kristen Rockland Aarethun

Department of Civil and Environmental Engineering

MASTER THESIS

Spring 2019

Necessary measures at the Tyin dams based on new assessments of alkali aggregate reactions

Supervisor: Leif Lia
Co-supervisor:
Hans Stemland, Jan Lindgård
In cooperation with:
Hydro Energy

NTNU

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

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.

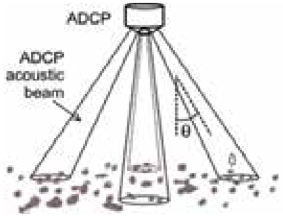
Background

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 hydro-power plants exposed on high sediment yield. Non-intrusive bedload measurements

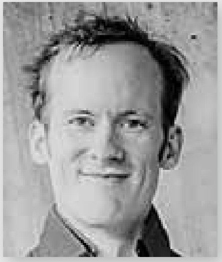
Supervisor: Nils Ruther
Co-supervisor: Massimo Guerrero.
In cooperation with: University of Bologna

NTNU

PHD THESIS

PHD THESIS

Ola Haugen Havrevoll



Department of Civil and Environmental Engineering

2017 – 2021

Rock traps in pumped storage and peaking power plants

Supervisor:
Kaspar Vereide

NTNU HydroCen

Background

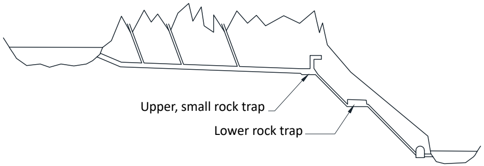
Several rock traps in Norwegian power plants are not working as expected today. Many power plants have gotten new turbine runners with higher capacity, which increases the discharge through the headrace tunnel and rock trap. The rock traps may not be dimensioned for the higher discharge, and may therefore 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.



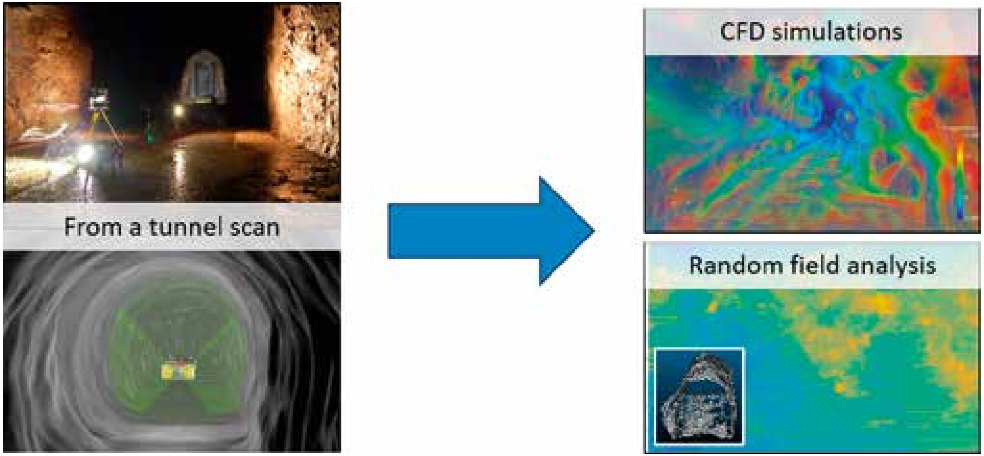
Background

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.

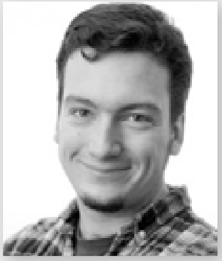
The Tunnel Roughness project is a *Knowledge-building Project for Industry* funded by the Norwegian Research Council and a consortium including NVE, TrønderEnergi, BKK and NVKS. More information and updates can be found at www.ntnu.edu/nvks/tunnelroughness



Courtesy: Kari Bråtveit & Hibbard Inshore.

Courtesy: Mari Voll & Jie Quin.

Pierre-Yves Henry



Department of Civil and Environmental Engineering

2016 - 2020

Hydraulics of unlined tunnels: Numerical and analytical investigations

Supervisor:
Nils Reidar B. Olsen
Co-supervisor:
Jochen Aberle

NTNU

POST DOC.

PHD THESIS

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

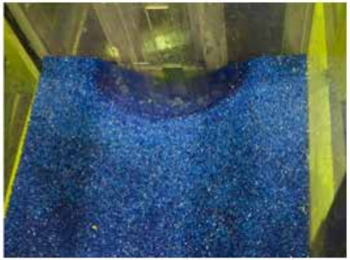
Background

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.



Background

One negative side effect of hydropower is that fish can be killed and injured in the power plants. The fish mortality of the turbines and screens varies, among other things, with the type and size of the turbine and the pressure head. In particular, the mortality depends on the type and size of the fish. The protection of fish has become a particularly important issue in the hydropower business. Without functioning fish protection systems, the acceptance of hydropower by large sections of the modern society is highly endangered.

Method

The project aims at developing a method for finding designs for intake structures and intake areas that maximize the fish bypass efficiency. The method used is a numerical model to resolve the hydraulic flow field in the intake area and couple this with telemetric data of fish movements. The movement of the fish is strongly influenced by the hydraulics, and changing the flow pattern by excavation and/or physical barriers might be an economic and practical alternative to installing finer trash racks. A good numerical model makes it possible to assess different designs in the virtual model before implementing the measures in the real world.

Halvor Kjærås

Department of Civil and Environmental Engineering

2018 – 2022

Modelling of fish guidance by floating devices

Supervisor:
Leif Lia
Co-supervisors:
Nils Reidar Bøe Olsen,
Knut Alfredsen

NTNU HydroCen

PHD THESIS

POST DOC.

Christy Ushanth Navaratnam

Department of Civil and Environmental Engineering

2018 - 2020

Hydraulics of unlined tunnels: Experimental investigations

Supervisors:
Jochen Aberle
Co-supervisor:
Nils Rüther

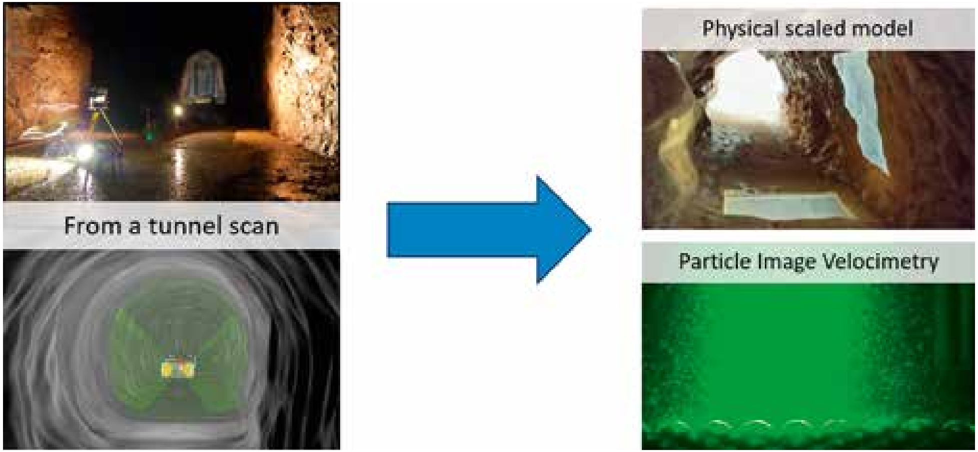
Background

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 can be 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

NTNU

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.

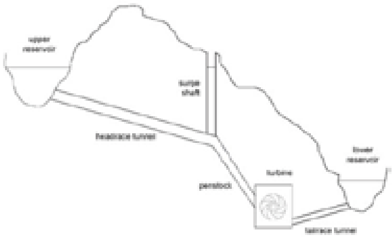


Figure 1 Pump storage plant layout

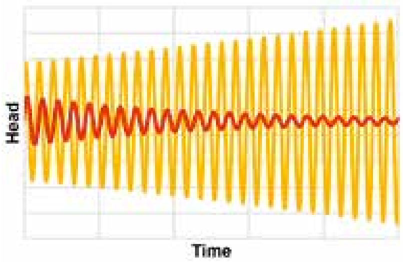


Figure 2 Stability (red) vs. instability (yellow) in surge tank

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

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

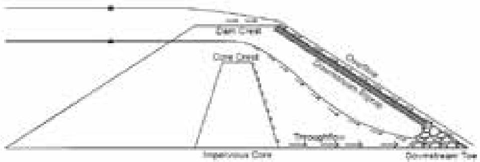
NTNU HydroCen

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.



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.

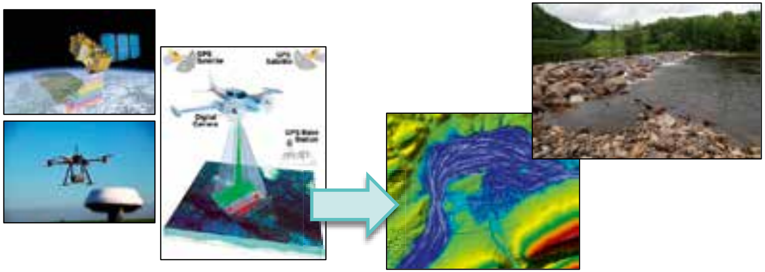
Using data from satellites, laser instruments and drones with optics, the PhD will analyse the collection and use of such data in future environmental design projects.

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.



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

PHD THESIS

Einar Rødtang

Department of Civil and Environmental Engineering

2019 - 2022

Ice conditions and ice loads on infrastructure in rivers

Supervisor:
Knut Alfredsen

NTNU

Background

During winter, ice can exert significant dynamic and static loads on structures in rivers. Predicting loads on infrastructure such as bridges and hydropower installations during ice breakup events is of particular interest.

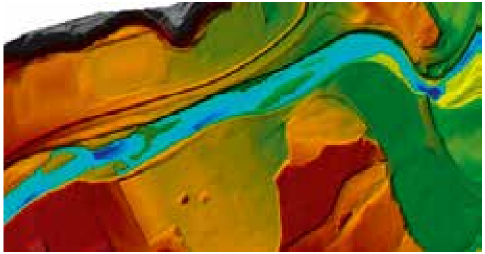
Current best practice is known to be overly conservative in general. Presently regulations use data from arctic ice drift from Canada and Siberia, since little Norwegian river ice data exists. These regulations describe crushing loads on structures assuming a sum of forces on the ice flow exceeding the crushing load against the structure. For the case of small steep rivers this assumption may not hold, current guidelines however do not provide clear recommendation on how to handle such situations.

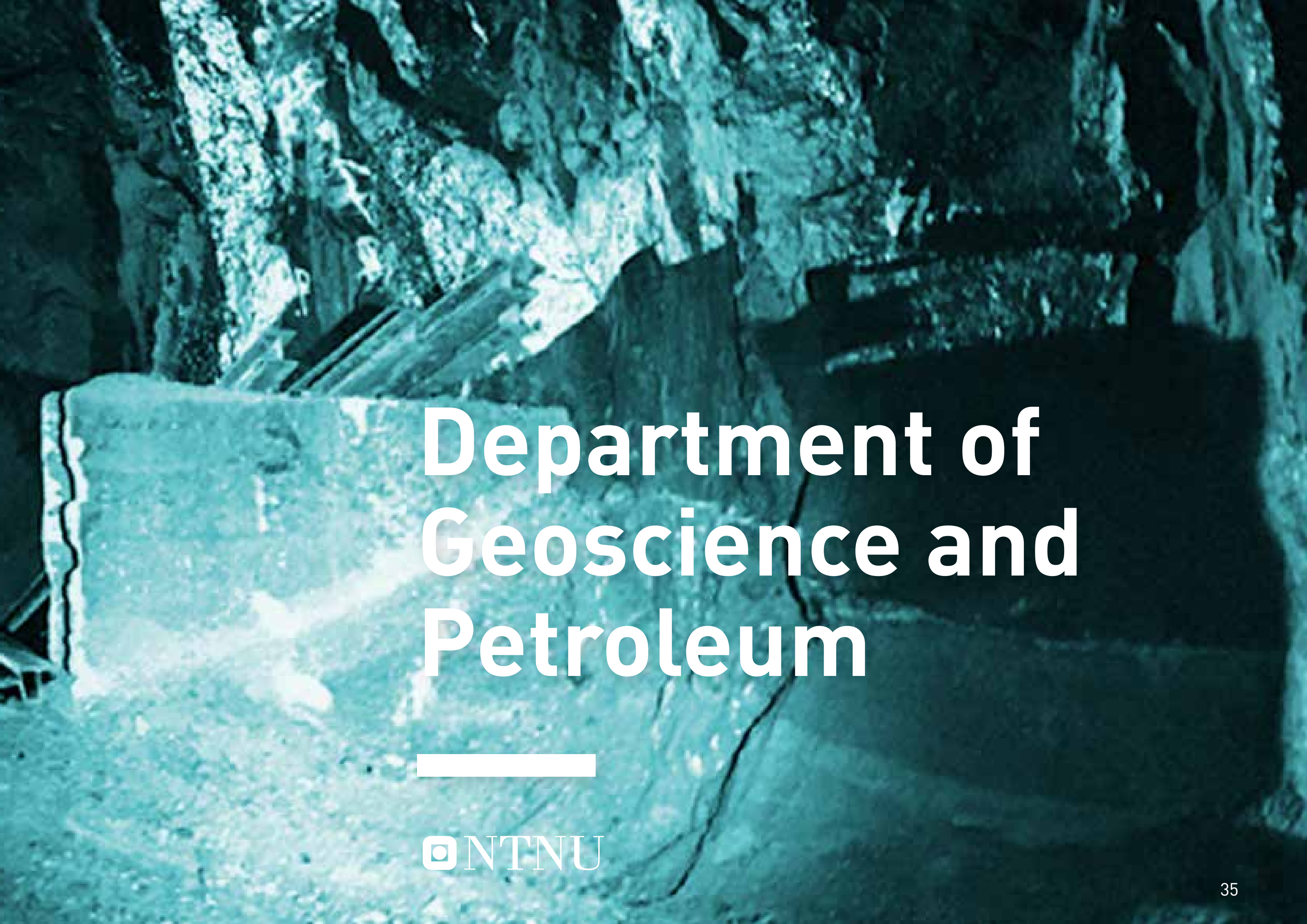
Objectives

- Developing improved methods for predicting ice breakup in small steep rivers.
- Developing improved methods for estimating ice forces on river infrastructure.
- Suggesting updates to current regulations concerning river ice.

Methods

Field measurements of river ice growth and breakup conditions will be conducted, ice core samples from representative rivers will be collected and analysed.
Field measurements of ice loads on structures will be conducted using static and dynamic force gauges attached at locations of interest on river constructions including bridges and hydropower intakes. Furthermore, software for predicting ice forces based on metrological data is being developed.





Department of Geoscience and Petroleum

MASTER THESIS

Håvard Barkved

Department of Geoscience and Petroleum

Spring 2019

The Mandal hydropower system – Optimization of tunnel system relatively to geology, rock stress conditions and costs

Supervisor: Bjørn Nilsen
Co-supervisor:
Henki Ødegaard

NTNU

Background

The Mandal hydropower system today consists of several hydropower plants. The AlternaFuture project aims to develop alternative future redesign solutions, focusing on both flexible operation and environmental conditions. The AlternaFuture project is multidisciplinary, and will focus on combining knowledge and innovations from the different disciplines involved in HydroCen.

The scope of this thesis is to evaluate the engineering geological conditions along potential traces of new tunnel systems. Topographic conditions cleary sets design limitations when the tunnel lengths exceed 40 km. The work will mainly be based on map studies, 3D terrain models and engineering geological reports from hydropower projects nearby.

Water conducting tunnel systems demands long-time operational stability. An assssment of potential stability problems is therefore of high importance. Considering this, the rock stress condtions plays an important role. Low rock stresses may for instance lead to hydraulic jacking and extensive leakage problems as a consequence.

In short, the optimum tunnel trace is rarely a straight line between A and B.

Background

Since 1991 the operating scheme of Norwegian hydropower plants has gone from supply to demand driven. This have resulted in more start-and-stop cycles of turbines, causing pressure fluctuations in the water systems. As most of the Norwegian water tunnels are unlined, these fluctuations can have a negative effect on the rock mass.

The demand driven operation scheme has also been implemented at Ulset hydropower plant. Ulset hydropower project is located in Tynset municipality north in Hedmark county. In this area there are large horizontal rock stresses, which together with unfavourable joint systems cause instability in the headrace tunnel. The instability issues were identified during the project work carried out in fall 2018, and the MSc thesis will be a continuation of the project work. It will analyse and discuss the instabilities and assess the stability of the headrace tunnel. Both analytical and numerical modelling will be used in the stability assessment, together with information gathered from field mapping and laboratory work.

Rock fall in the roof of the headrace tunnel, caused by unfavorable joint systems and stress induced fracturing.

MASTER THESIS

Linn Døvle

Department of Geoscience and Petroleum

Spring 2019

Study on the long-term stability issues of the headrace tunnel of Ulset hydropower project

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

NTNU

MASTER THESIS

Tonje Mek Eidset

Department of Geoscience and Petroleum

Spring 2019

Reservoir slope stability, Moglicë HPP

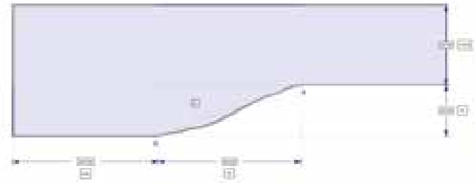
Supervisor:
Charlie Li
Co-supervisor:
Thomas Schönborn (Statkraft)

NTNU

Background

Water regulation is vital in hydropower energy generation, but also implies changes in the ground water regime of reservoir slopes. In this context, failures triggered by initial reservoir filling, rapid drawdown and possibly annual regulation, is a matter of concern. Consequences of reservoir slope failure include damage to the dam or appurtenant features such as the outlet structure, generation big displacement waves and reduced storage capacity of the reservoir, among others.

The objective of this master thesis is to assess the stability of a reservoir side slope in Statkraft's Moglicë Hydropower Project in Albania. A special attention is given the effect of repeated filling and draw-down on the reservoir slope stability. Limit equilibrium analyses are conducted for the assessment of possible failure scenarios. Input parameters are determined by means of a field observations, borehole logging, assessment of inclinometer measurements and laboratory tests.



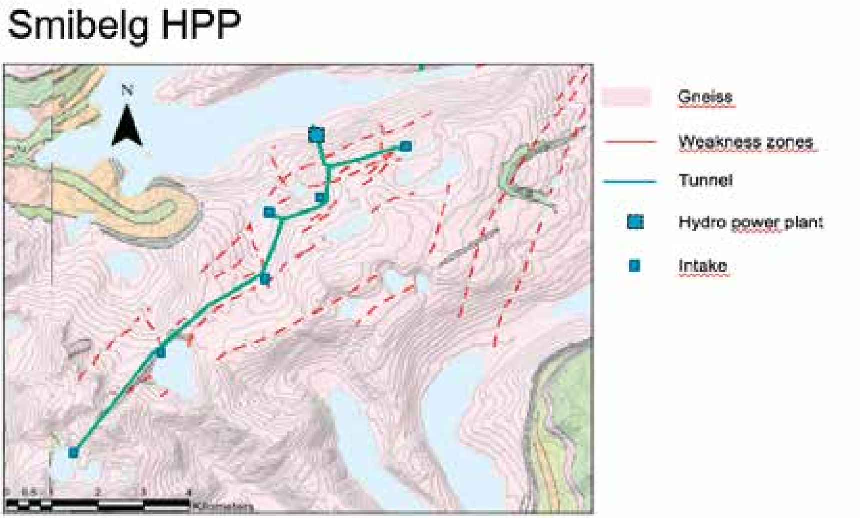
Background

The SmiSto hydropower project is a new initiative in the Norwegian hydro power industry. The project consists of two underground hydropower plants: Smibelg HPP and Storåvatn HPP near the Gjervalen fjord in Nordland, Norway. By the end of construction in 2019, these plant will have an installed capacity of 33 MW and 25 MW, respectively.

During excavation there have been challenges with respect to water inflow in the tunnels. Extensive grouting works have been performed to reduce the water inflow.

Objective

A lot of information has been gathered in sections where water inflow has been encountered. Schemes with results from tunnel mapping, tunnel face probing and performed grouting give valuable information in the problem areas. The objective of this project / thesis work is to analyze and assess the conditions along the tunnel systems with respect to the geology, topography, water sources and the mapping results in the area.



MASTER THESIS

Haakon Haugerud

Department of Geoscience and Petroleum

Spring 2019

Assessment of geological conditions and water leakages for tunnels in Gjervalen, Nordland

Supervisor:
Krishna Kanta Panthi
Co-supervisor: Magni Vestad
In cooperation with:
Multiconsult

NTNU

MASTER THESIS

Steven Sergij Salim

Department of Geoscience and Petroleum

Spring 2019

Water Loss in Unlined Pressure Tunnel – A Review of the extent, causes and consequences for selected cases

Supervisor: Bjørn Nilsen
Co-supervisor: Henki Ødegaard

NTNU

Background

In the planning of underground hydropower plants, particular emphasis is placed on locating and designing pressure tunnels in such a way that water loss is minimized. To optimize the location of pressure tunnels and ensuring successful design, hydrogeological, topographical, rock mass and rock stress considerations are key issues. Failure in properly addressing these issues during the design procedure may have severe security and financial consequences.

The main objective of this study is to review water loss in pressure tunnel system for some Norwegian hydropower plans (Roskrepp, Hatlestad, Tondstad and Tafjord V), and discuss the significance of the issue on a general basis. Alongside the main objective, this study also assess the lost of revenue from the water loss and evaluate the potential loss due to hydraulic jacking in case of marginal factor of safety against hydraulic failure.

As a final conclusion, this study will suggest best practice on how measure to reduce water loss can be incorporated in pressure tunnel design.

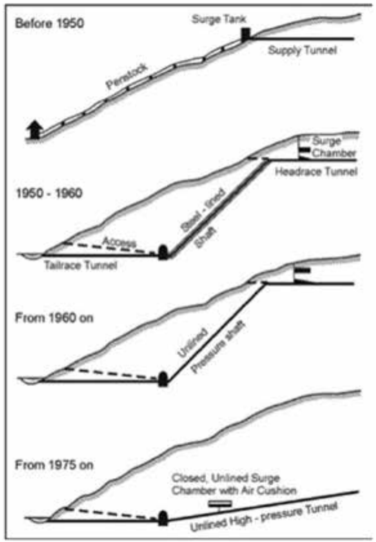


Figure 1: Unlined Pressure Tunnel Concept

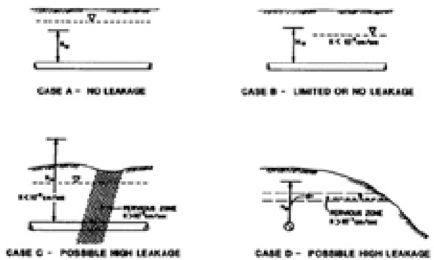


Figure 2 : Leakage Ilustration in Pressure Tunnel (Benson, 1989)

Background

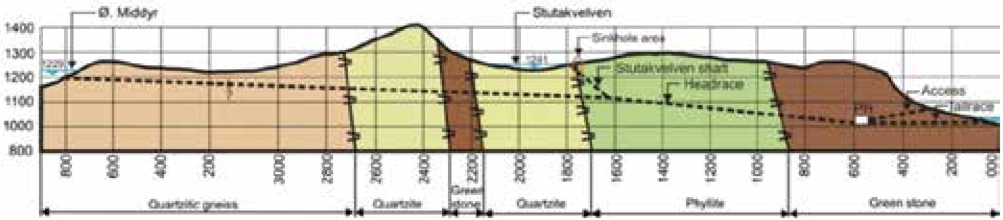
Most of the waterway system in Norwegian hydropower plants consists of low-, medium-, and high-pressure headrace tunnels, high-pressure shafts, and tailrace tunnels. In recent years, some of the high-pressure shafts and tunnels have experienced partial collapses. One such took place at Stutakvelven inclined shaft at Svandalsflona hydropower project (HPP) back in 2009. This master thesis is an assessment on the structural geological and engineering geological condition of the weakness zone at Svandalsflona HPP, and is closely related to the PhD research on the effect on frequent start-start sequences on the long-term stability of waterway system.

The objectives

- Theoretical review of the design principal of Norwegian hydropower projects
- Review on the regional structural geological conditions of the area
- Detail structural geological and engineering geological surface mapping of the project area with more focus on weakness zone area of the Stutakvelven inclined shaft
- Collect rock samples from the weakness zone area and carry out engineering geological testing at IGP
- Present structural geological engineering geological conditions of the project area and the weakness zone
- Carry out stability assessments of the weakness zone area and analyse the potential reasons for the collapse
- Discuss and conclude the work

The objectives will be achieved by field mapping, laboratory testing and stability assessments.

Fig. 1. Geological setup of the waterway system at Svandalsflona hydropower project (Panthi 2014)



MASTER THESIS

Aleksander Olvik Thorbergsen

Department of Geoscience and Petroleum

Spring 2019

In-depth assessment on the structural geological and engineering geological condition of the weakness zone at Svandalsflona HPP

Supervisor: Krishna K. Panthi
Co-supervisor:
Bibek Neupane
In cooperation with:
Norsk Hydro Energi

NTNU

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

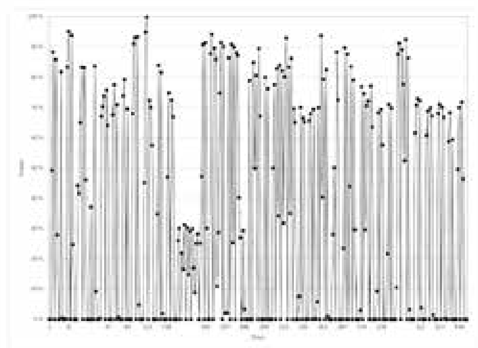
Background

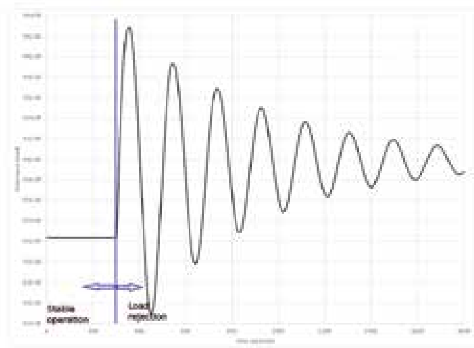
In the future, most countries in Europe will be switching to renewable energy. In this context, water reservoirs in Norway are planned to be used as a ¨battery¨ for the European power grid.

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

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.

Lena Selen

Department of Geoscience and Petroleum

2017 – 2021

Effects of swelling rock and swelling clay in water tunnels

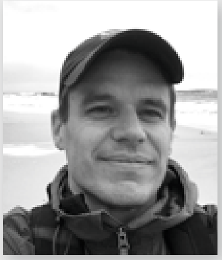
Supervisor:
Krishna K. Panthi
Co-supervisors:
Siri Stokseth (Statkraft),
Bjørn Nilsen

NTNU HydroCen

PHD THESIS

PHD THESIS

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

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.

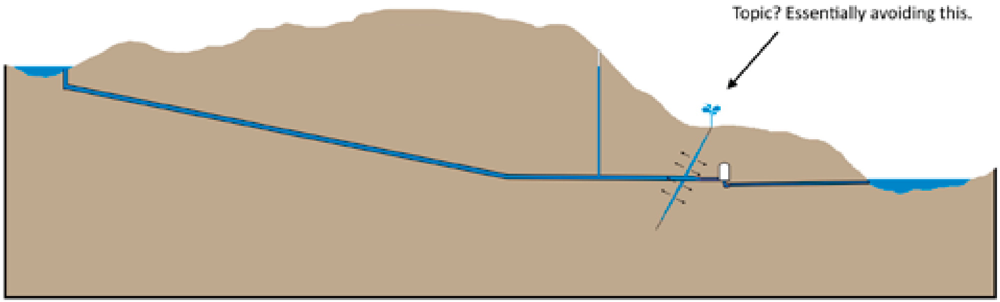
Testing is usually carried out by hydraulic fracturing or jacking tests, performed at defined locations close to the transition zone. There is good reason to advocate more frequent testing as this can reduce the uncertainty of actual stress situation and will also give early indications of stress levels.

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.

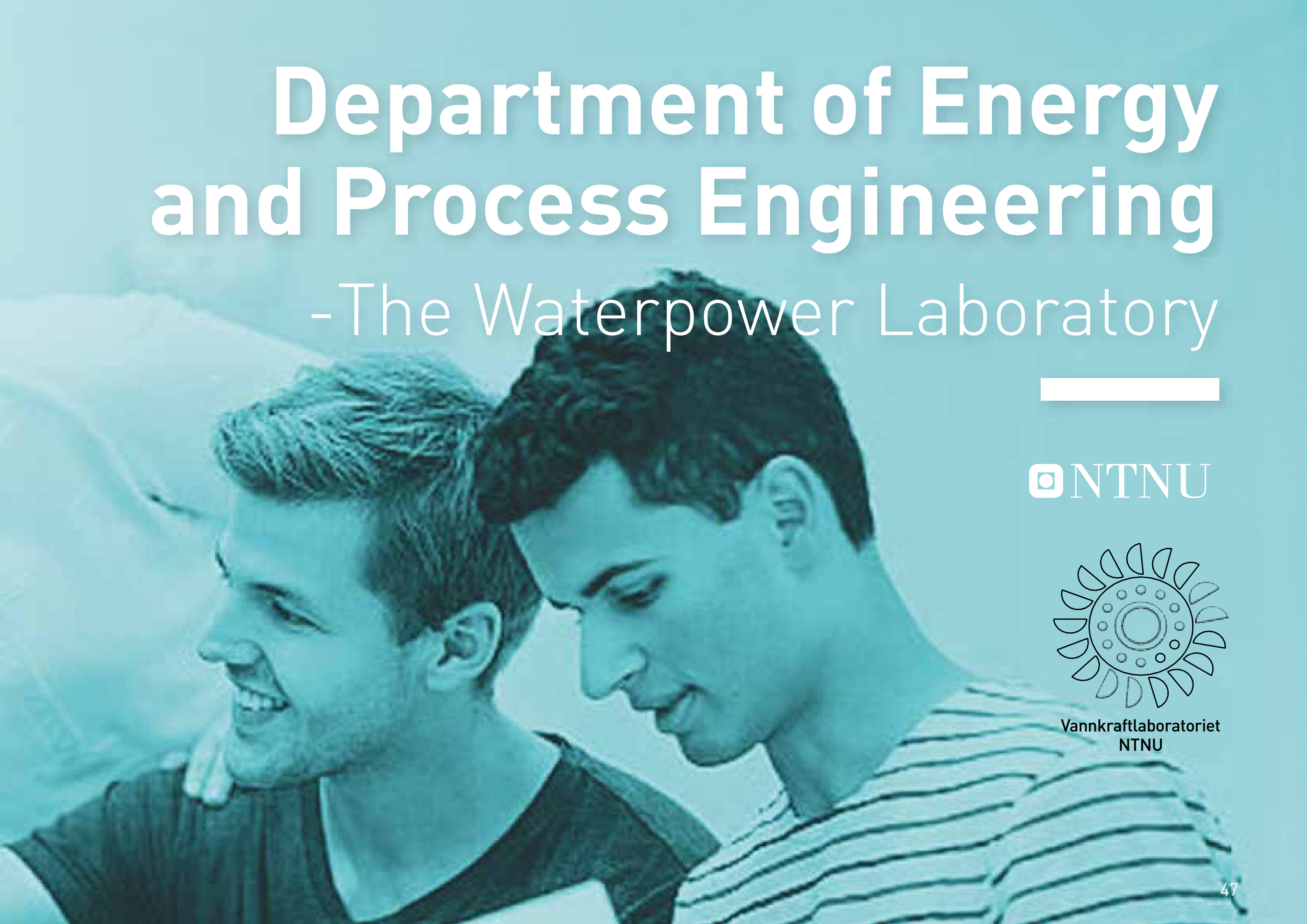
Further work

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



Department of Energy and Process Engineering

-The Waterpower Laboratory



NTNU

Vannkraftlaboratoriet
NTNU

MASTER THESIS

Julia Bådsvik

Department of Energy and Process Engineering

Fall 2018

Development of a Francis Turbine Test Rig at Kathmandu University

Supervisor:
Ole Gunnar Dahlhaug

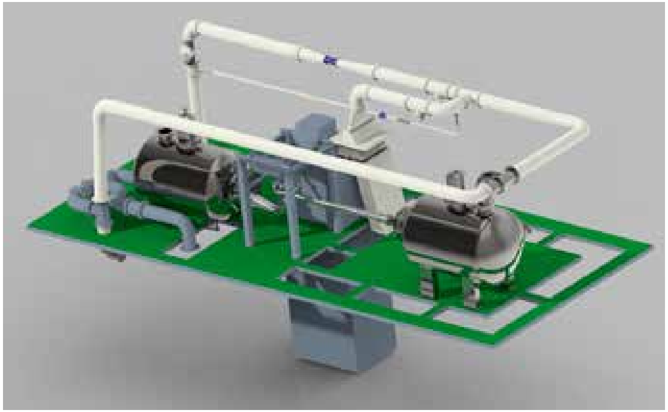
NTNU

Background

This Master's thesis is a part of the EnergizeNepal project, which aims to build a state-of-the-art Francis turbine test rig at Kathmandu University that fulfils the requirements of the IEC60193. Nepal has great hydroelectric power resources, where only a small percentage has been utilised. The main issue is that the high content of sediments in the water causes the turbines to erode. The purpose of building the lab is therefore to be able to test for these conditions and find effective solutions.

In this Master's thesis a way of measuring and calibrating the axial load has been tested. The idea is to place strain gauges at the lower part of the bearing block. The strain gauges will measure the strain caused by the axial forces when the turbine is running, and the axial force can then be found by comparing the strain value to a calibration curve.

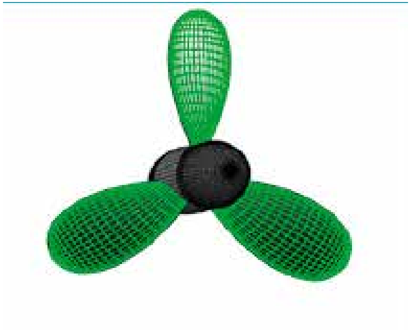
Experiments have been conducted in the Waterpower Laboratory, where the lower section of the bearing block has been tested at different axial loads and wall thicknesses. Further work will be to continue this testing as well as to try to measure and calibrate the friction torque using this section.



Background

Norway has 50% of the European hydro reservoir energy storage, and many of these sites are highly suitable for retrofitting of pump-storage capabilities. To be able to reuse existing power plants by retrofitting with Reversible Pump Turbines (RPTs), the problem of cavitation in pumping mode must be solved. This has been proposed solved by the use of an axial booster pump in front of the RPT. An axial pump for the use as such booster pump for the use at Roskrepp hydropower plant must be designed. Preliminary findings suggest that for the needed performance of a booster pump at Roskrepp, conventional single stage axial machines will have very low efficiencies. It is therefore proposed to design a counter-rotating two-stage axial pump to increase the pump efficiency. The objective of this thesis is to develop a user friendly way of designing counter-rotating axial pumps. Utilizing lifting line blade design theory and modeling the interaction between the two pump stages lays the foundation for the design process. Developing an extension of the open-source propeller design code OpenProp as well as an independent design code are considered as design options.

Additionally, the possibility of a hubless rim-driven pump design is to be considered. Hubless designs have the advantage of less flow obstruction when operating a pumped hydropower plant in turbine mode. It also facilitates retractable designs, thus providing the possibility of only having the axial pump present in the flow when operating the RPT in pump mode.



MASTER THESIS

Pål Dahle

Department of Energy and Process Engineering

Spring 2019

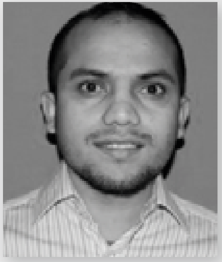
Impact from Flexible Operations on High Head Francis Turbines

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

NTNU

MASTER THESIS

Tilak C. Dhital



Department of Energy and Process Engineering

Spring 2019

Flow and efficiency measurements by use of clamp-on ultrasonic equipment

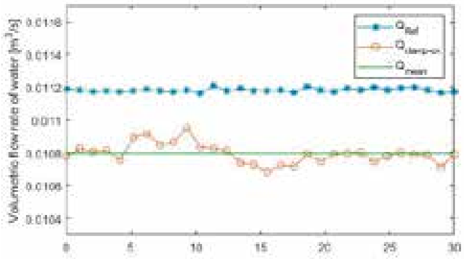
Supervisor:
Torbjørn K. Nielsen
Co-supervisor:
Harald Hulaas
In cooperation with:
Norconsult

NTNU

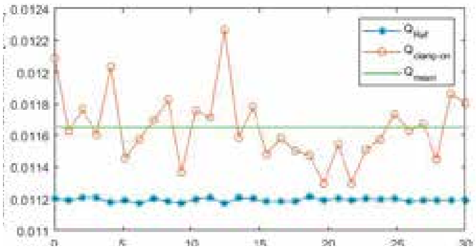
Background

For finding the efficiency of a hydro turbine, the challenge is to measure the flow. One method is to use clamp-on ultrasonic method, which measures the mean velocity in a pipe. The method has been investigated in the project work during the autumn of 2018. The Master Thesis will continue the investigation on accuracy and repeatability of the clamp-on ultrasonic method. Unlike many other discharge measurement methods, the clamp-on ultrasonic method is non-invasive in nature as they are mounted onto the outside of the pipe work, without any interruption to flow or process.

The tasks that will be considered are designing and planning experiments in the laboratory for clamp-on meters relevant to hydropower plants, and studying the effects of systematically rotating the clamp-on angle at constant flow by measuring the flow velocity profile using reference flowmeter in the same direction.



This figure shows discharge measurements taken by a clamp-on flowmeter (Qclamp-on) and a reference flowmeter (QRef).The clamp-on meter was placed 24.7D away from a partially opened valve in this case.



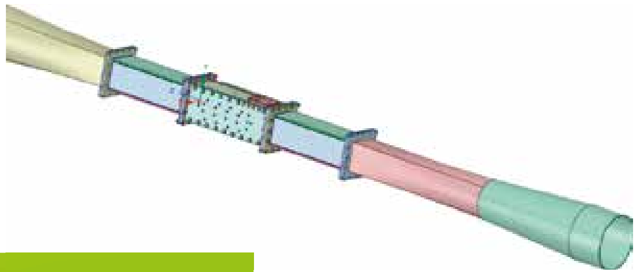
The above figure shows discharge measurements taken by the clamp-on flowmeter (Qclamp-on) and the reference flowmeter (QRef). The clamp-on meter in this case was placed 3.93D away from the valve. High scattering of the measured data from its mean value indicates low repeatability of the measurements in this case

Background and objective

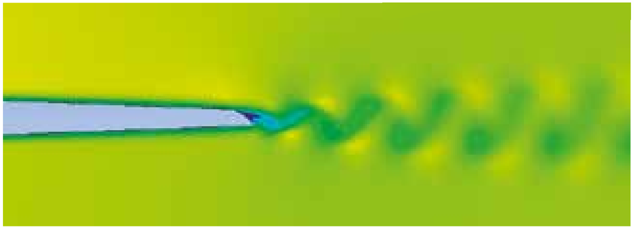
When fluid flows past a solid body, vortex shedding may occur. For hydraulic turbines, the shedding frequency of guide vanes, stay vanes and runner blades should not overlap with the natural frequencies of the blades. This is because the vortex-induced vibrations may lead to unnecessary fatigue and risk of failure. A new design concept for such hydrofoils have been proposed, with the intention of reducing the frequency and strength of vortex shedding at the trailing edge. This should mitigate some of the negative effects the vortex shedding phenomenon gives. The design concept have been verified numerically, but further computational fluid dynamics (CFD) simulations are to be undertaken to investigate the relation between accuracy and computational cost of some state of the art turbulence models.

The objective of this master thesis is hence to perform and validate, with existing data, CFD simulations to determine the flow field characteristics behind the trailing edge of a hydrofoil in the blade cascade rig at the Waterpower laboratory.

a)



b)



Picture a) shows a geometry model of the blade cascade rig, and picture b) shows vortex shedding behind the trailing edge of the hydrofoil in a CFD simulation.

MASTER THESIS

Solveig Therese Eiane

Department of Energy and Process Engineering

Spring 2019

CFD simulations in a blade cascade rig

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

NTNU

MASTER THESIS

Kathrine Albjerk Hamran

Department of Energy and Process Engineering

Spring 2019

Simulations and measurements of friction in oscillating flow

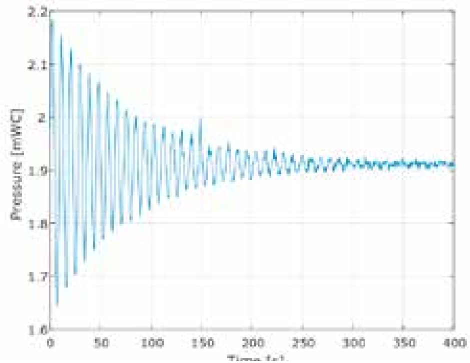
Supervisor:
Pål-Tore Storli
Co-supervisor:
Torbjørn Kristian Nielsen

Background and objective

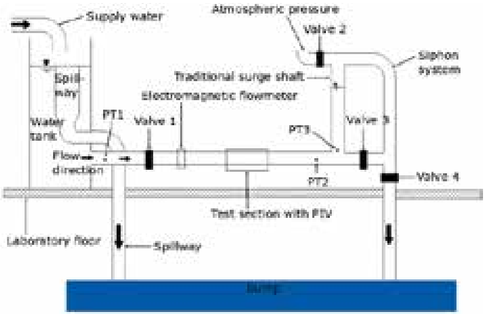
The friction in oscillating flow in pipes and tunnels is not well described, despite being important for energy efficiencies and system stability. Without a good representation of the frictional losses, the operation of hydraulic systems such as hydropower plants might be suboptimal. Different friction models for oscillating flow will therefore be investigated in this thesis.

Simulations of oscillating flow will be performed with the Euler method and the method of characteristics. The different friction models will be implemented, and the simulations will be compared with experimental results.

The experiments will be conducted in a test rig which consists of a small reservoir, a horizontal pipe, and a surge shaft. Mass oscillations will be induced by closing a valve downstream of the surge shaft. Pressure and flow will be measured.



Pressure measurements in the test rig.



The test rig used in the experiments.

Background

The source for the project is the high variations of axial force on the turbines at Duge power plant. At one of the units, the runner tends to lift at certain operation points resulting in a turbine that cannot be fully utilized at all operation points.

The purpose for this master thesis is to investigate the axial forces for a reversible Francis pump turbine. This will be investigated by developing tools to calculate the forces, perform tests and analyze the forces in the Waterpower Laboratory at NTNU. The aim is to find some of the factors that affect the axial forces and investigate different solutions that be used to control the forces. The results will be linked to Duge Power plant and similar tests and analyzes will be conducted.

The labyrinth seals will be investigated when analyzing the axial forces

Duge power station with the two 100 MW reversible pump turbines

MASTER THESIS

Johannes Harbo

Department of Energy and Process Engineering

Spring 2019

Axial Forces on Reversible Pump Turbines

Supervisor:
Torbjørn K. Nielsen
Co-supervisor:
Kaspar Vereide
In cooperation with:
Sira-Kvina Kraftselskap

NTNU

MASTER THESIS

Rune H. Larsen

Department of Energy and Process Engineering

Spring 2019

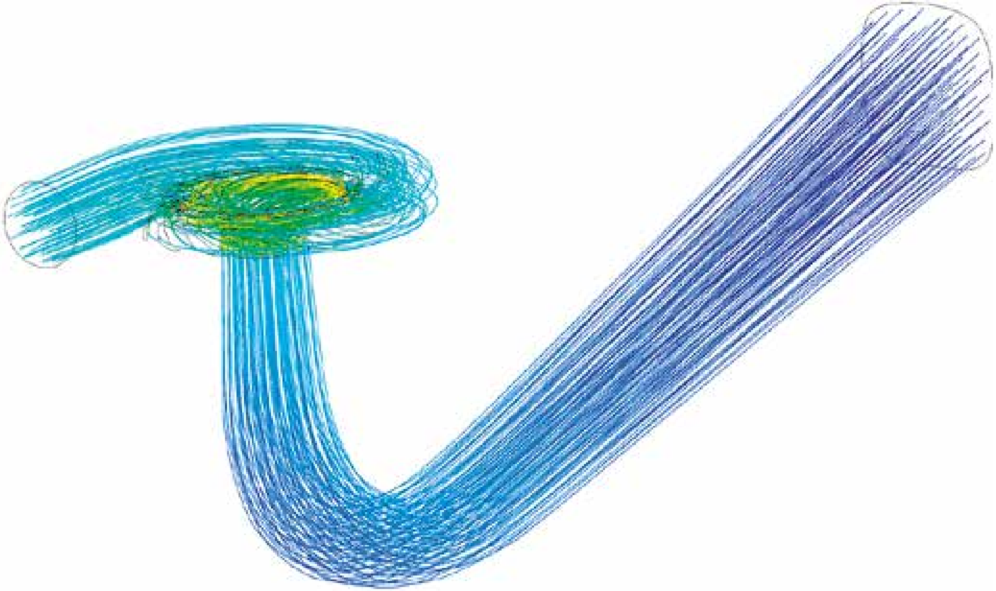
Pre-rotation of inlet flow for a reversible pump turbine in pump mode

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

NTNU

Background

Norway has 50% of the European hydro reservoir energy storage, and many of these sites are highly suitable for retrofitting of pump-storage capabilities. To be able to reuse existing power plants by retrofitting with Reversible Pump Turbines (RPTs), the problem of cavitation in pumping mode must be solved. This has been proposed solved by the use of an axial booster pump in front of the RPT. A booster pump will create a rotational component in the flow leaving the booster pump. How this component will evolve as the flow approaches the RPT is uncertain, and how the rotation actually is at the inlet of the RPT is important for the operation and characteristics of the RPT, especially since it affects the cavitational properties of the unit, and might counteract the initial suggested solution by using the booster pump in the first place.



Background

The expansion of intermittent renewable energy sources in the European energy market is leading to an increasing demand of regulatory energy sources to stabilize the energy grid. Hydropower can act as a regulatory energy supply, but that is requiring a more flexible day to-day operation of turbines. This leads to turbines having to operate to a larger degree in unfavorable operating conditions when it comes to efficiency and fatigue, and an increase in start-stop cycles.

Objective

This thesis aims to investigate the effect variable speed operation can have on the fatigue life of the runner. To accomplish this, pressure measurements for a scaled model of a low-specific-speed Francis turbine has been conducted.

Ideally, calibrated strain gauges would have been used to measure the stresses on the runner blades, regrettably, this wasn't feasible to do during the experiments. Instead, a calibration of strain gauges was conducted with Ansys Mechanical and a physical model.

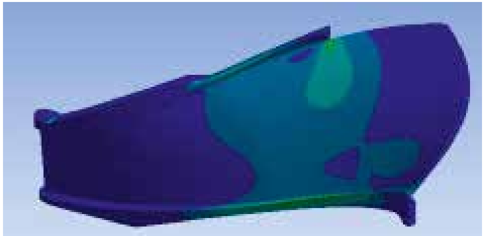


Figure shows the Ansys model usedto calibrate strain gauges.

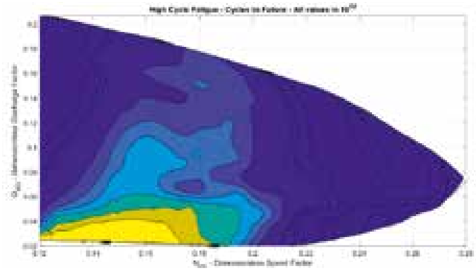


Figure shows cycles to failure for differentoperating conditions

MASTER THESIS

Eirik Lødemel

Department of Energy and Process Engineering

Fall 2018

Fatigue Loads in a Francis Turbine Runner

Supervisor:
Roy Johnsen,
Ole Gunnar Dahlhaug
Co-supervisors:
Chiraq Trivedi, Igor Iliev,
Einar Agnalt

NTNU

MASTER THESIS

Marte Mestvedthagen

Department of Energy and Process Engineering

Spring 2019

Increasing Operational Flexibility of Hydropower by New Technology

Supervisor:
Pål-Tore Selbo Storli

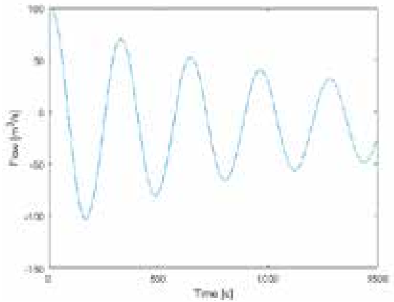
NTNU

Background and objective

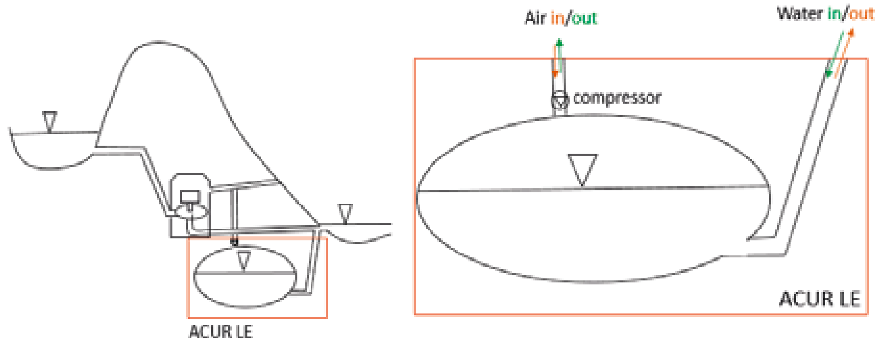
The energy production in Europe is heading towards a renewable, green shift, adding more wind and solar energy to power system. As power cannot be stored in the grid, these intermittent sources need balancing power to keep the energy system stable.

Hydropower plants are suited for this balancing task, but some have strict restrictions regarding the operation, due to river at the outlet. Rapid flow changes and discharge fluctuations will cause unacceptable environmental impact. By introducing a low energy, regulated buffer reservoir, ACUR LE, near the outlet the net flow into the river can be controlled and be held within the given restrictions, independent of the hydropower operation.

The Purpose of this master is to develop a numerical model, based on the Method of Characteristics, for the hydropower plant Bratset, where simulations with and without ACUR LE can be performed.



The osciliating flow from a shutdown in 10 seconds without an active ACUR LE element.



This illustration shows the principle of ACUR LE. (not to scale)

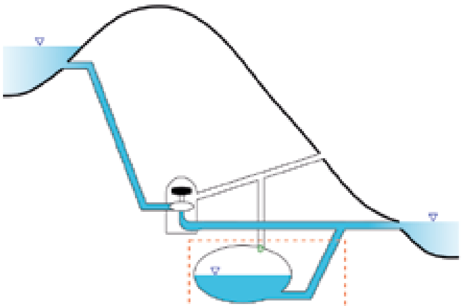
Background

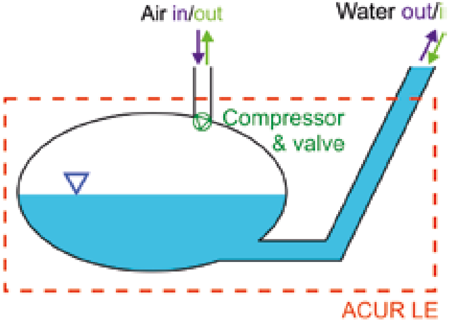
As wind power and solar photovoltaic (PV) continues to develop, an increasing part of the total energy production mix comes from fluctuating intermittent energy sources. This causes the need for stable energy providers that can help balance the total energy supply. The flexibility of hydropower makes hydroelectric production highly suitable to counteract changes in other renewable sources. However, there are several challenges related to the development of future hydropower systems, and increased flexibility in hydropower plants with an outlet to a river is one of the qualities future hydropower needs. In these hydropower plants, the highly fluctuating flows from varying power production, known as hydropeaking, can have a detrimental impact on the river ecosystem. To reduce these impacts, the idea of ACUR LE has been developed.

The Air Cushion Underground Reservoir (Low Energy) is a pressure-regulated water storage volume in connection with the tailrace tunnel of a hydropower plant. By regulating the air pressure inside the chamber, the total discharge to the downstream river can be controlled.

An accurate model of ACUR LE is developed in the LVTrans simulation program and used to simulate startup, shutdown and flood control for the case hydropower plant Bratsberg. The results highlight the benefits of ACUR LE considering a more flexible power operation with decreased response time, as well as flood mitigation.

The development of ACUR LE is a part of the HydroFlex project.





MASTER THESIS

Thomas Svensson Moen

Department of Energy and Process Engineering

Fall 2018

Mitigation of Discharge Fluctuations from Hydropower Plants by Active Measures

Supervisor:
Pål-Tore Storli
Co-supervisor:
Bjørnar Svingen

NTNU

MASTER THESIS

Anja Mærlie

Department of Energy and Process Engineering

Spring 2019

PIV measurements of a Francis turbine

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

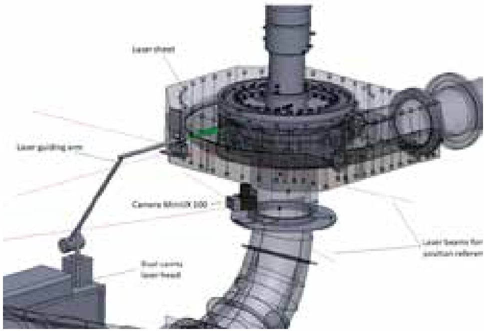
NTNU

Background and objective

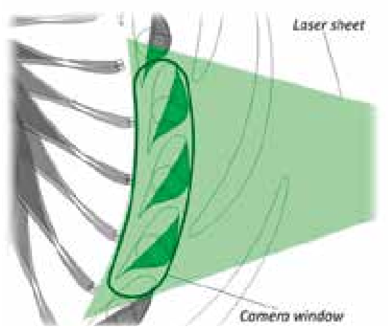
To balance the production and consumption in the power system, it is important that hydraulic turbines are able to operate at off-design conditions. It is hypothesized that the flow characteristics in the vaneless space are related to several undesirable phenomena occurring at off-design conditions in Francis runners. The vaneless space is the narrow region between the outlet of the guide vanes and the inlet of the runner.

The Francis test rig at the Waterpower Laboratory at NTNU has been modified for Particle Image Velocimetry (PIV) measurements in the vaneless space. PIV is an optical, non-intrusive measurement technique that makes it possible to capture the whole velocity field in a cross-section of a flow. It combines the use of a laser and a high-speed camera to track the movement of tracer particles added to the flow.

The objective of this thesis is to perform PIV measurements of the flow in the vaneless space of a Francis turbine. Measurements in part load, best efficiency point and full load operating points will be executed.



Overview of the experimental set-up[1]



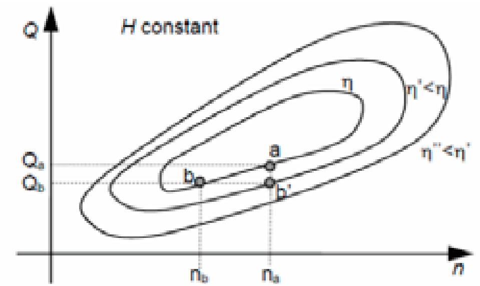
Area of interest[2]

[1]Sagmo, K. (2018). Measurement Report WP2.1.
[2]Straume, S. G. (2018). PIV measurement of the flow in the vaneless space of a Francis Turbine.

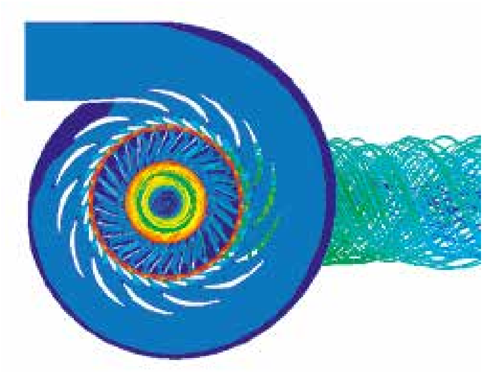
Background

The purpose of this master thesis is calibration of a numerical method for efficiency calculations of Francis turbines. Runners, intended for variable speed operation, is preferable simulated prior to making. This ensures higher efficiency, and makes it possible to look at changes to the initial design. Simulations will be performed to determine the hill chart of an existing runner, the Francis-99 turbine. The simulated hill chart will be compared to the hill chart of the exciting turbine, to investigate the accuracy of the model.

Variable speed hydro turbines can increase the flexibility of hydropower by allowing the turbines to operate more efficiently outside the design point. More flexible hydropower could significantly help the green transition by allowing for more intermittent energies like wind and solar to be included in the grid.



This picture shows the concept behind variable speed Francis turbines by means of a hill diagram.



This picture shows the flow patterns of water through a Francis turbine solved in ANSYS CFX

MASTER THESIS

Andreas Nordvik

Department of Energy and Process Engineering

Spring 2019

Variable speed operation of Francis turbines

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Igor Iliev, Chirag Trivedi

NTNU

MASTER THESIS

Magnus Farstad Perkunder

Department of Energy and Process Engineering

Spring 2019

Interaction between turbine pressure pulsations and transients in the penstock

Supervisor:
Torbjørn K. Nielsen
Co-supervisor:
Celine Faudot

NTNU

Background and objective

There is an ongoing research project called Fatigue loads in Hydro Turbines, where one of the main issues is to understand how pressure pulsations from the turbine interact with fluid transients in the attached system. These pressure pulsations create fatigue loads and might damage the turbine. Field measurements will be performed at Kvilldal power plant in spring 2019.

Kvilldal power plant has four identical Francis turbines but two of them seem to function in a more problematic way (vibrations, cracks, etc.). The goal of the field measurements is to find out if and to which extend the differences in the nearest penstock geometry can affect the transient behaviour upstream the turbines and hence the fatigue loads at each turbine.

The objective of this work is to identify the interaction between the pressure pulsations caused by the turbine and the attached system, with focus on fatigue loads, using both numerical model, model tests and field measurements.

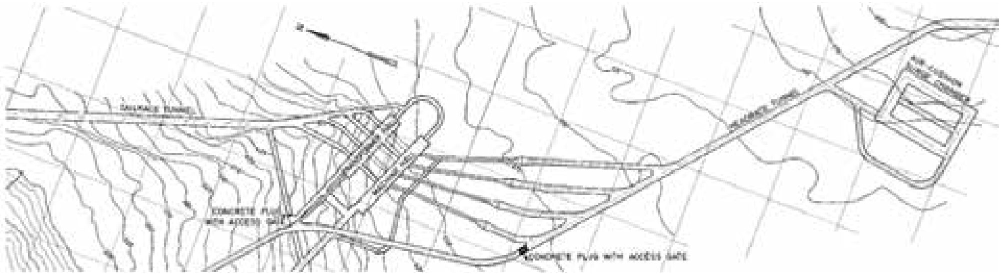
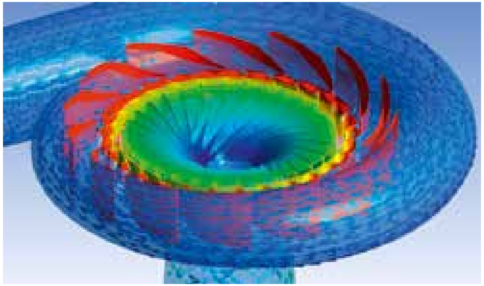


Figure 1. Overview of Kvilldal power plant.

Background

The purpose of this master thesis will be to optimize the design of a runner without guide vanes due to the effects of sediment erosion. The guide vanes are very vulnerable to erosive wear, and in areas with high concentration of sediment in the rivers, like the Himalayas, erosive wear is a source of expenses - both direct and indirect. The damage it does to a runner, can in the worst cases cause maintenance to be required annually. As a consequence, the plant will not be able to produce energy during the maintenance period.
During the monsoon period, when water flow is at it's highest, the sediment concentration is too high for operation to be economically sustainable. It is therefore desirable to reduce the effects of erosive wear, and hereby keep maintenance costs low, and hours of energy production high.

Sand erosion on a guide vane blade



Computational fluid dynamics simulation of a Francis turbine

Nanna Moland Wahl

Department of Energy and Process Engineering

Spring 2019

MASTER THESIS

Hydraulic design of a Francis turbine without guide vanes

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisors:
Nirmal Acharya, Igor Iliev and Bjørn Solemslie

NTNU

PHD THESIS

Nirmal Acharya

Department of Energy and Process Engineering

2018 - 2021

Design of a Francis turbine that accomodates high sediment concentration

Supervisor:
Ole Gunnar Dahlhaug
Co- Supervisor:
Chirag Trivedi

NTNU HydroCen

Background

Sediment erosion has proved as an inevitable challenge in hydraulic turbines from operation and maintenance perspective in Himalayan regions. The hard mineral particles, which are carried by rivers reach the turbines and erode the surface in contact. In Francis turbines, guide vanes, cover plates, hub at runner inlet and blades at runner outlet are the most affected areas due to the sediment erosion.

The main objective of this work is to study the effects of sediment erosion in hydro turbines, to see how the flow phenomena is causing the erosion, what the off-design operation of turbine causes and how the eroded profile is aggravating the flow and efficiency again. Within the frame of HydroCen, 3 universities viz; Norwegian University of Science & Technology (NTNU)-Norway, Kathmandu University (KU)-Nepal and Indian Institute of Technology- Roorkee, India (IIT-R) are collaborating which aims towards scientific and technological breakthroughs to enable hydropower turbines to operate with high sediment concentration and sediment load. This PhD studies is a part of FRANSED project which is being coordinated by NTNU.

Iso surface contours of swirling strength

Objective

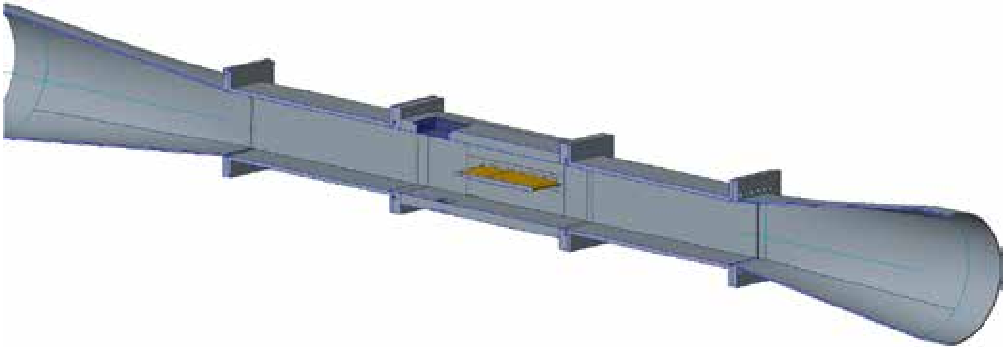
- Develop a new hydraulic design of a Francis turbine based on analytical and empirical knowledge.
- Develop a Francis turbine design tool for turbines operation in sediment laden water.
- Possible solutions to the erosion problem by design optimization, sediment erosion model (IIT-R) and verification through model tests (KU).
- Technology/Knowledge co-operation between Norway and Himalayan countries.

Erosion at Guide Vane's facing ends and facing plates at Bhilangana-III HEP

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 - 2019

Dynamic response of Francis turbine blades

Supervisor:
Ole Gunnar Dahlhaug

NTNU

PHD THESIS

PHD THESIS

Einar Agnalt

Department of Energy and Process Engineering

2016 - 2019

High head Francis turbines

Supervisor:
Ole Gunnar Dahlhaug

NTNU

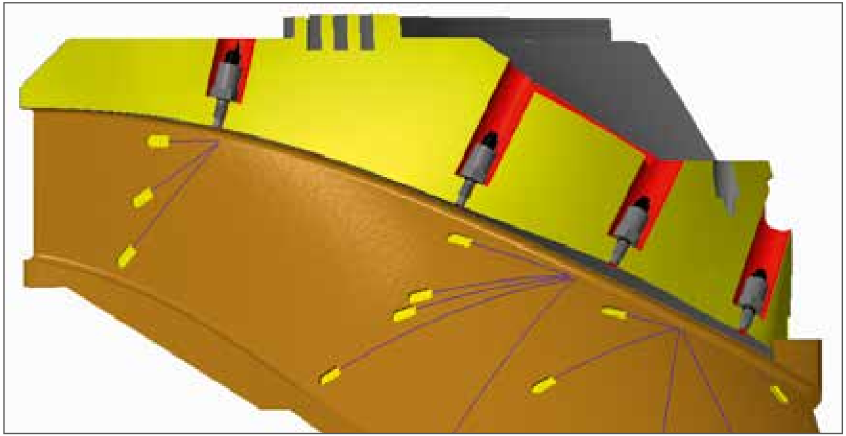
Background

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

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.

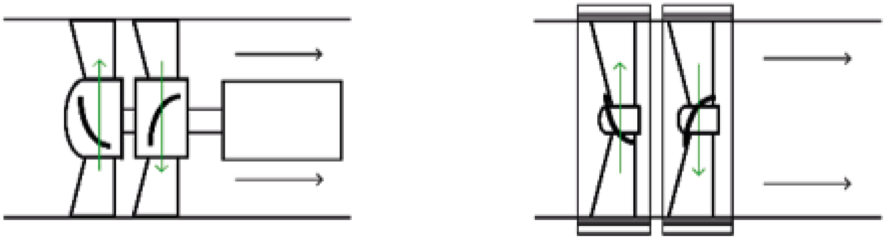


Figure 1: Possible booster pump solutions:
1) Generator installed inside draft tube. 2) Rim-driven generator.

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

PHD THESIS

POST DOC.

Celine Faudot

Department of Energy and Process Engineering

2017 – 2020

Fatigue loads on turbines attached to a conduit system

Supervisor:
Torbjørn K. Nielsen

NTNU HydroCen

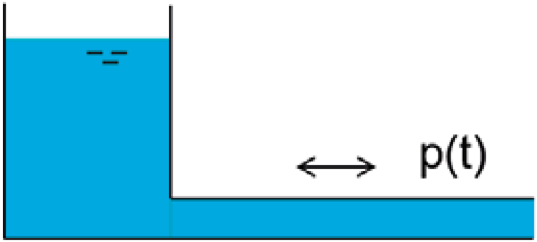
Background

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.

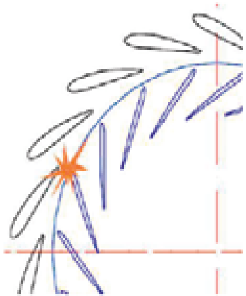
Full 3D-CFD simulation of the whole system is naturally out of the question due to the time consume of such simulations. The system dynamic simulations are more effectively done by 1D. The 1D simulations can be implemented as input to the 3D simulations.

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.



1D - simulations



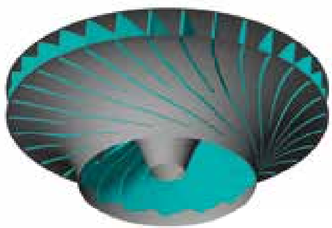
3D - simuleringer

Background

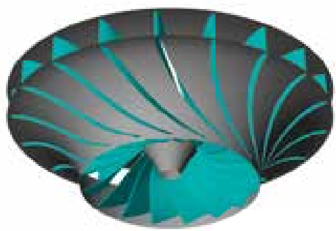
Traditionally speaking, hydraulic turbines are designed to operate at a constant rotational speed. Connected to a synchronous generator, the turbine is coupled with the power grid and rotate at a certain speed in order to be synchronized with the grid's frequency. This type of operation can sometimes cause problems with decreased efficiency, increased dynamic loading and cavitation when the turbine is being operated away from it's design conditions.

Modern trends are now to decouple the rotational frequency of the turbine from the frequency of the grid by means of variable-speed devices. This type of operation has the potential to increase the flexibility in the operation of hydraulic turbines. However, as reported in the open literature, the benefit from variable-speed operation can be insignificant for some types of Francis turbines and, in order to improve this, a better understanding of the hydraulic design methodology is needed.

This PhD thesis aims to design and optimize a replacement runner for increased efficiency during variable-speed operation. A model of the replacement runner will be manufactured and tested in the turbine testing rig at the Waterpower laboratory. Finally, it's performance will be compared against a reference case for verification and validation of the proposed design methodology.



The reference case (F-99)



Initial replacement runner (F-100)

Igor Iliev

Department of Energy and Process Engineering

2017 – 2019

Fatigue loads on turbines attached to a conduit system

Supervisor:
Torbjørn K. Nielsen

NTNU HydroCen

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

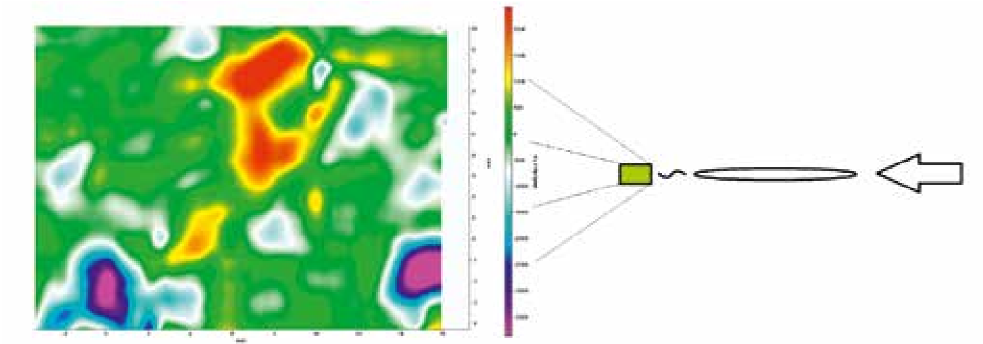
NTNU HydroCen

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.

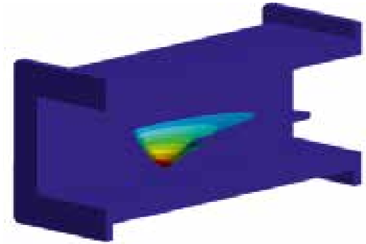
Background

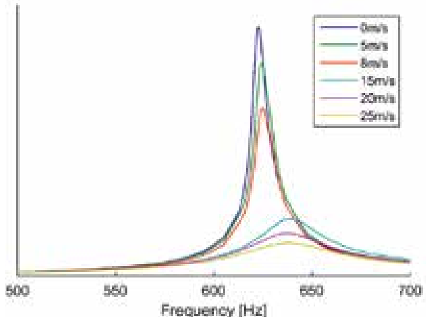
In the last two decades several high head Francis turbines have failed due to rotor-stator interaction (RSI) and resonance issues.

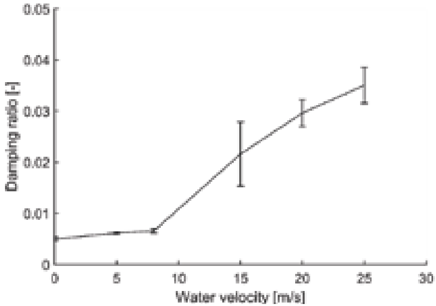
Some have failed after a few hours, others have lasted months, or years, before failing. To prevent such failures, it is important to understand the physics behind these failures.

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

2018 - 2020

Resonance and pressure pulsations in High Head Francis Runner

Supervisor:
Ole Gunnar Dahlhaug

NTNU HydroCen

POST DOC.

Magni Fjørtoft Svarstad

Department of Energy and Process Engineering

PHD THESIS

2014 - 2019

Dynamics and stability in reversible pump turbines

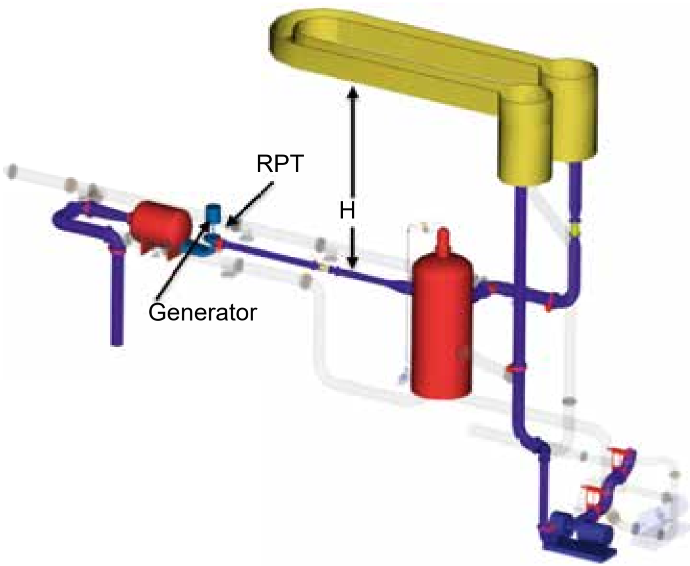
Supervisor:
Torbjørn K. Nielsen

NTNU

Background

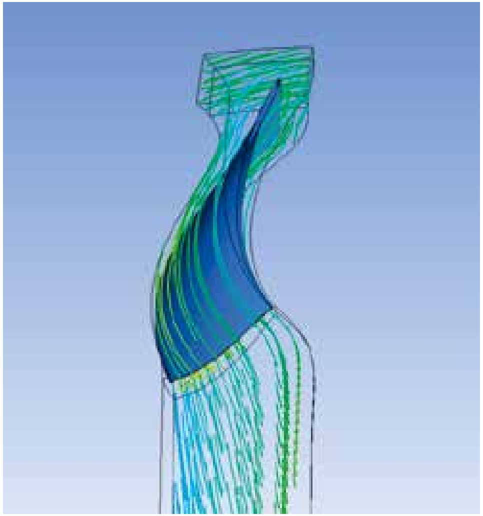
In the Norwegian power market, reversible pump turbines (RPT) for the most part change from pump to turbine mode of operation on a seasonal basis. In the future power market, the RPT are often given the role of balancing the power production.
This will require more frequent and faster changes between 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.



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

NTNU

INDUSTRIAL PHD

Ingrid K. Vilberg

Department of Energy and Process Engineering

2015 - 2019

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

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.

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

INDUSTRIAL PHD

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

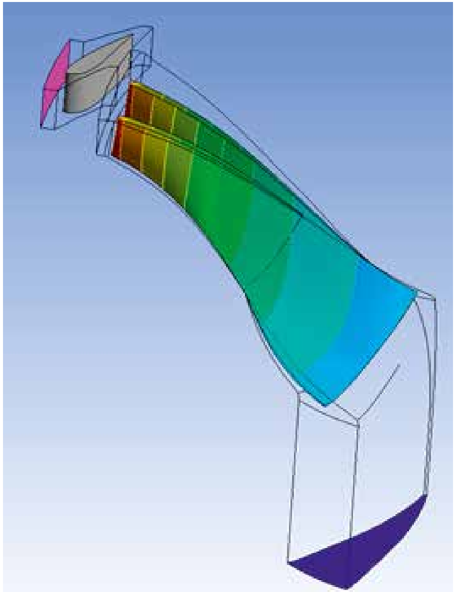
NTNU

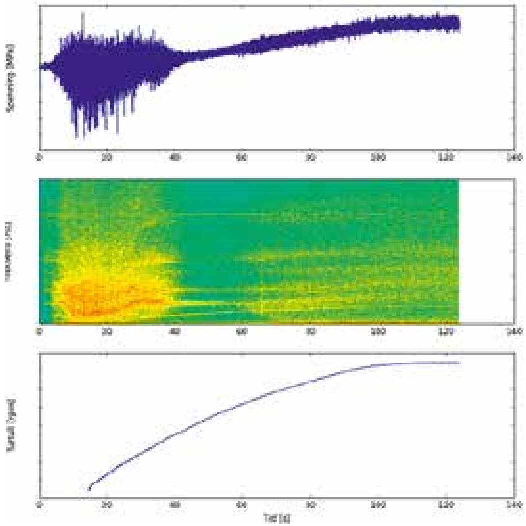
Background

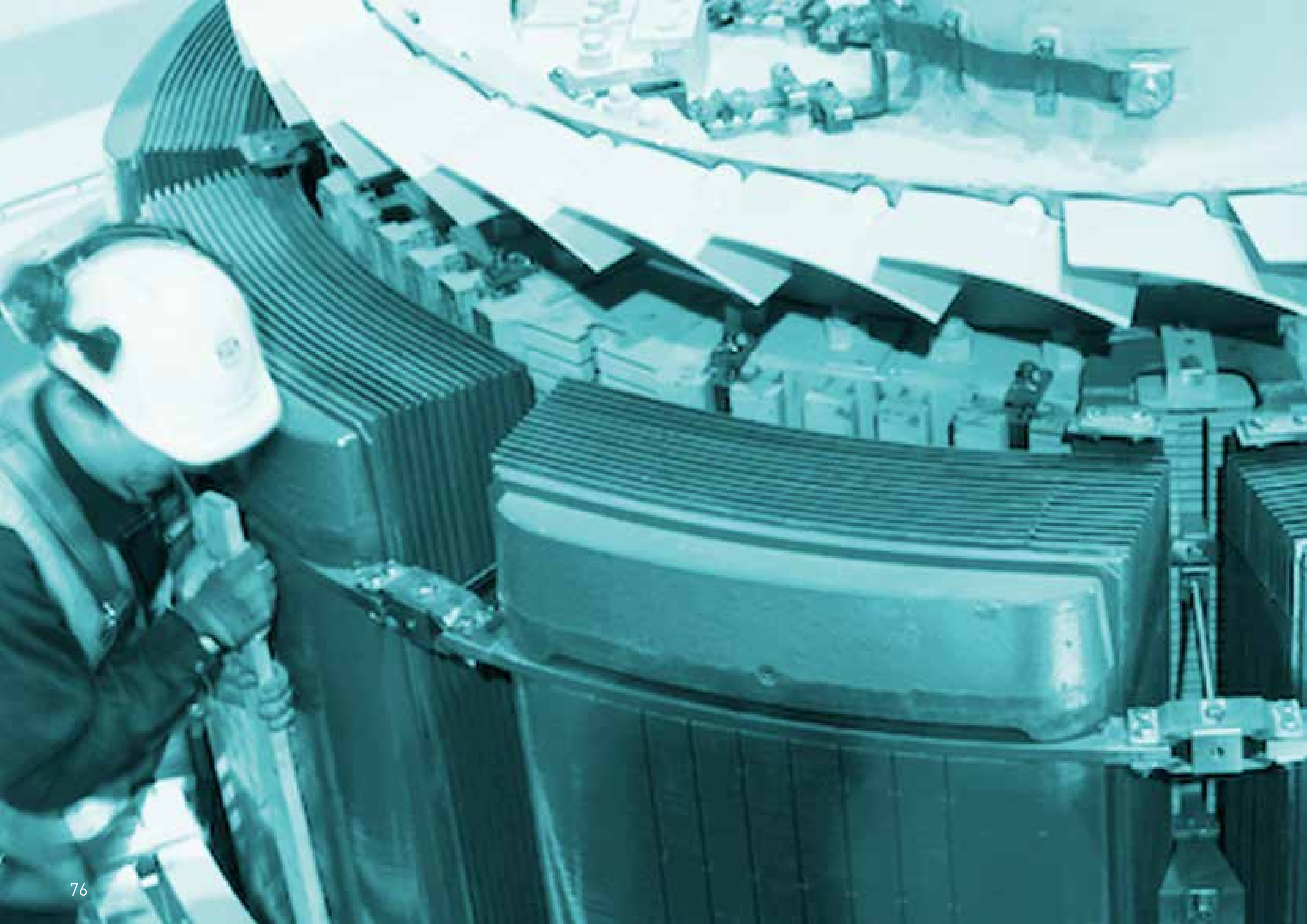
Due to recent failures of high head Francis turbines, there is a need to improve the understanding of the physics related to dynamic stresses in high head Francis turbines.

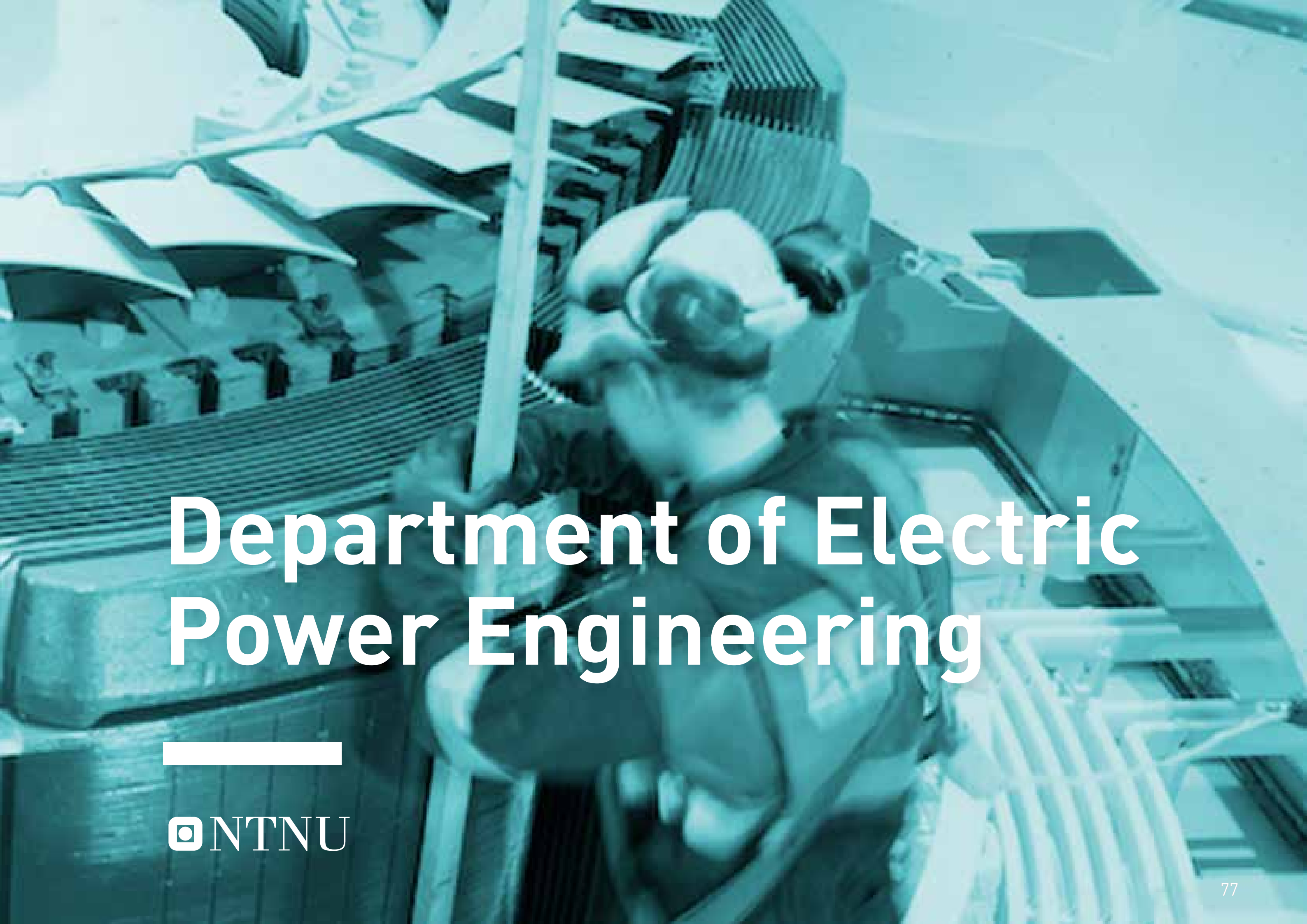
Objective

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.









Department of Electric Power Engineering

NTNU

MASTER THESIS

José Armando Romero Amaya

Department of Electric Power Engineering

Spring 2019

Active front end converter used in adjustablespeed hydro

Supervisor:
Roy Nilsen

NTNU

Background

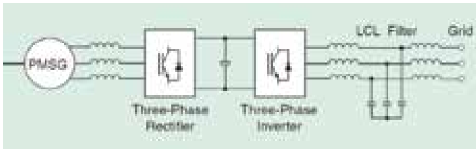
The full frequency converter used with the variable speed pump turbine consists of two main parts; the machine side converter, which does the variable speed operation of the generator and that feeds a DC link, and the grid side converter, which converts the energy from the DC side to an AC grid frequency and interacts with the electric grid. The grid side converter or active front end converter (AFE) is the one which deals directly with the electric grid.

The AFE control scheme consists of cascade control loops, which are the following:

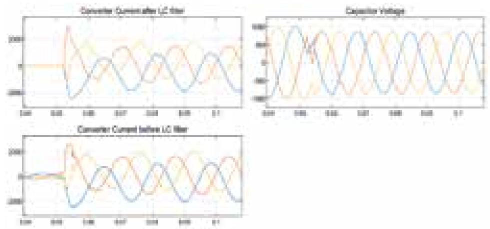
- Inner Current Control Loop, consisting of a hysteresis current controller
- Voltage Control Loop, consisting of a resonant current controller
- Outer Control Loops, which contain other additional functions such as virtual impedance, unbalance control, active and reactive power frequency droop, harmonic compensation, synthetic inertia, among other features.

In this master thesis, the controls of the AFE converter will be developed, together with the lab implementation. In this sense, three main tasks will be performed:

- Literature review to identify the latest research about this topic
- Complete and finalize the simulations already started during the specialization project for the identified as the most appropriate control scheme.
- Implement the lab setup to test the control functionalities simulated for the AFE



Power Circuit



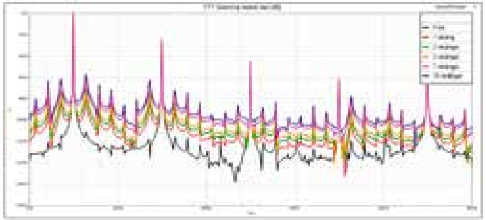
Converter Current and Capacitor Voltage

Background

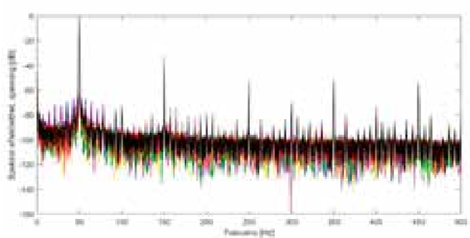
On-line monitoring of the generator gives the opportunity to detect faults at an early stage. Formerly two master students at NTNU have investigated the possibility of detecting rotor short circuit faults and rotor eccentricity faults by analysing the stator voltage and current in a FEM software. The mentioned faults lead to an unsymmetrical magnetic field, thus causing unsymmetrical and potentially damaging forces. The induced voltage in the stator windings is a product of the rotating magnetic field. A change in the rotor field will result in a change in the frequency distribution in the induced stator voltage/current.

Objective

This thesis will investigate rotor faults on a 100 kVA laboratory generator, validate earlier FEM models and find a suitable way to both extract and analyse the stator voltage and current.



FFT-analyses of the voltage in ANSYS Maxwell



FFT-analyses of the voltage of a real generator

MASTER THESIS

Henrik Ebbing

Department of Electric Power Engineering

Spring 2019

On-line detection of rotor faults in hydropower generators

Supervisor:
Arne Nysveen
Co-supervisor:
Mostafa Valavi

NTNU

MASTER THESIS

Ingrid Linnea Groth

Department of Electric Power Engineering

Spring 2019

On-line Electromagnetic Fault Detection in Hydropower Generators

Supervisor:
Arne Nysveen

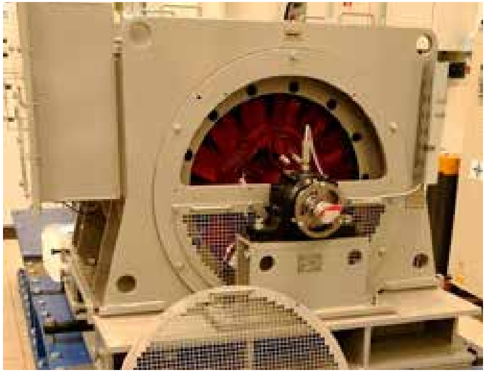
NTNU

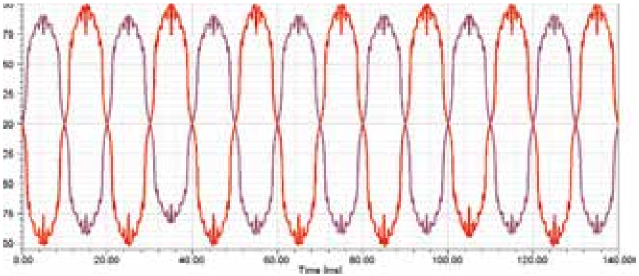
Background

Inter-turn short circuits in the field winding and static/dynamic eccentricity can cause unbalanced magnetic pull, increased vibration, bearing wear and local overheating of the field winding in hydropower generators. Severe cases may force an unplanned shut-down or subject the generator to irreversible damage.

By on-line condition monitoring of the machine, faults can be detected at an incipient stage and may provide an improved and more cost-effective preventive maintenance strategy.

This thesis will investigate the use of magnetic sensors for detection of electrical and mechanical faults in hydropower generators. Sensors will be mounted in the air gap of a 100 kVA salient-pole synchronous generator in addition to measurement of the leakage flux at the end winding of the machine. The fault detection method will possibly also be tested on a 22 MVA hydropower generator. Measurements during healthy and faulty operation along with finite element analysis will be studied in order to identify fault-related signatures in the magnetic field and to propose how on-line electromagnetic fault detection can be implemented in hydropower generators.





Håkon Laaveg Mjell

Department of Electric Power Engineering

Spring 2019

Sensorless Control of Synchronous Machines used in ASH

Supervisor:
Roy Nilsen

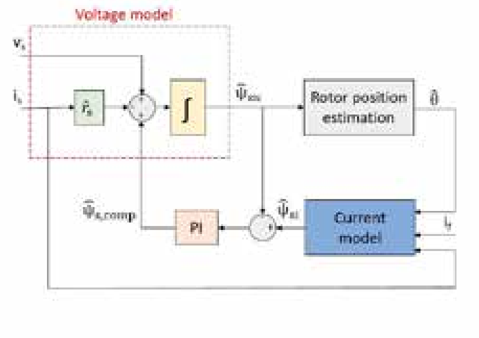
Background

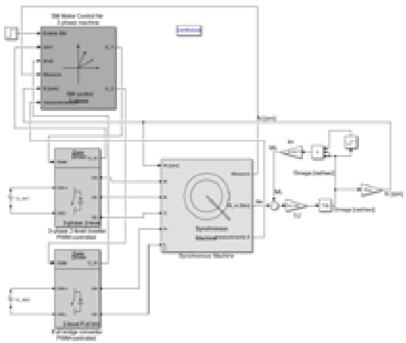
In the last decades, use of renewable energy sources have increased drastically. Energy sources like wind and solar power are weather dependent and vary throughout the year, so to be able to maintain a stable power supply, a hydropower plant can be used to as a renewable energy storage system.

Synchronous machines are suitable for high-power applications, as for instance in pumped storage hydropower plants. In this master thesis, synchronous machines used in ASH (Adjustable Speed Hydro) will be analyzed. Sensorless control means controlling the machine without speed or position sensors. Instead, the currents and voltages are measured, and then these values can be used for flux estimation.

Advantages of sensorless control include increased reliability and decreased cost. A well-known problem for sensorless control methods is operation at low speeds.
To be able to operate without sensors, flux models were developed based on the voltage model and the current model. A combination of these two models, with a PI controller in the feedback loop was able to improve the performance during simulations in Simulink.

In this master thesis, sensorless control of a synchronous machine will be investigated in the laboratory. Controller routines for a picoZed board will be developed and used for implementation.





NTNU

PHD THESIS

Hossein Ehya

Department of Electric Power Engineering

2018 – 2021

Electromagnetic Analysis and Online Fault detection of Hydropower Generators

Supervisor: Arne Nysveen

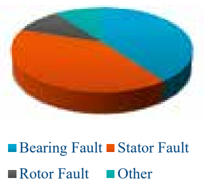
Background

Large synchronous generators play an important role in the power generation industry and its duty in this way is indispensable. Although synchronous generators are reliable, they are subjected to some modes of failures. If a generator continues to operate under faulty conditions, its efficiency drops considerably and its life span is shortened. As a matter of fact, the generator stoppage and outage from the energy generation process causes huge economic loss. Consequently, fault diagnosis at initial stages of occurrence not only prevents the fault extension, high periodical expenses and outage of the generation loop but also preserves the nominal life of the generator. These failures in synchronous generators may be inherent itself or due to the operating conditions. Faults in synchronous machines include: static, dynamic, and mixed eccentricity, stator, and rotor Inter-turn and ground short circuit fault, broken damper, and end ring fault. Few methods have been proposed and applied in order to detect several kinds of failures in synchronous generators at different stages, however, most of them are unsuccessful in detection procedures.

The basis of any reliable fault diagnosis method is the inclusion of the real behavior and conditions of the faulty machine. Consequently, a proper and at the same time the most important step will be modeling of the problem. Modeling method is the foundation for the next step of fault detection. In this study, Ansys Electronic will be used as a way to simulate a synchronous machine in a healthy and different type of faults from no-load to full load. Experimental results should be used to certify the simulation results. For this purpose, experimental set up which is provided with different types of fault like Static Eccentricity, Excitation short circuit fault, and broken damper bar fault.

The main goal of this project is based on the fact that new indices should be introduced in order to detect the fault at its early stage, as a matter of fact, novel theoretical indices for eccentricity short circuit and broken damper faults based on magnetic flux, electromotive force and vibration should be extracted. These analytical indexes should be precise enough for fault detection purpose therefore, the saturation and stator slot effects should be taken into account. The output of the FEM simulation of the synchronous generators such as current, electromotive force, magnetomotive force, air-gap magnetic flux, vibration and shaft flux, and voltage should be analyzed using time or frequency domain based processors. Novel theoretical indices should be demonstrated in the processed signals of nominated processors. Finally, classifier and artificial intelligence tools should be used to discriminate the severity and type of faults.

Experimental set-up: 100 kVA, 14 poles salient pole synchronous generator



Different type of Fault in Electrical machines based on EPRI and IEEE report

NTNU HydroCen

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.

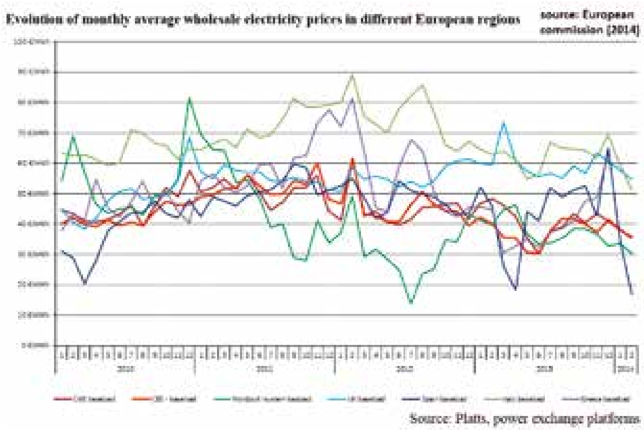
Those ancillary services are the current topic of the ongoing research in this PhD project. The current questions consist of – how do the different services interact; what potential and risk exists for prospective future services; how do market participants realize their goals through offering or calling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

PHD THESIS

Tor Inge Reigstad

Department of Electric Power Engineering

2018 – 2020

Grid integration of variable speed hydro power plant

Supervisor:
Kjetil Uhlen

NTNU HydroCen

Background

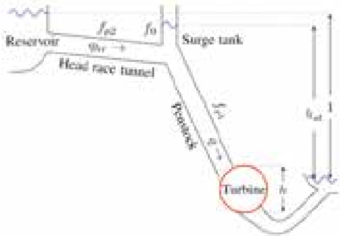
As the share of wind and solar energy production increases, more flexible production and loads are required to control the balance of the grid. A potential use of Variable Speed Hydro Power (VSHP) is to provide this flexibility and compensates the production of variable renewables. The hypothesis is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

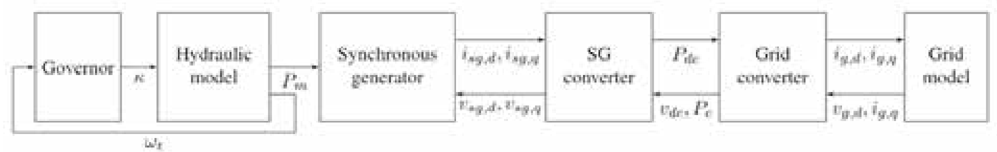
Objective

The focus of the PhD work is 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 control possibilities is investigated from a system perspective while considering the limitations given by the water/ turbine system.

Results and ongoing work

- A new hydraulic model for grid integration of VSHP are developed and tested against excising hydraulic models for grid integration of conventional power plants.
- This model is implemented and tested in a grid with both VSHP and conventional hydropower, including models of VSHP generator, generator-side converter, grid-side converter and a representatively test grid.
- Next, different methods for virtual inertia (VI) control methods for VSHP are compared
- A model predictive control (MPC) is under development. It is used together with VI for optimize the frequency support capabilities of the VSHP, while keeping the electric and hydraulic variables within their limits.





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

Raghbendra Tiwari

Department of Electric Power Engineering

2017 – 2021

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

Supervisor:
Roy Nilsen

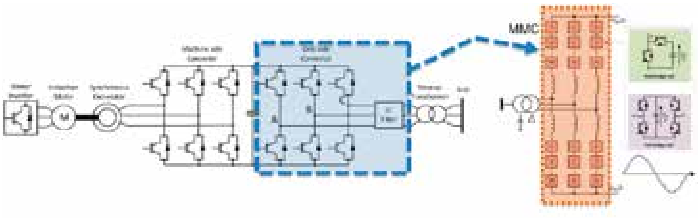
NTNU HydroCen

Background

The power production from renewables like wind and solar are increasing rapidly over past decade and will continue in future. As the power from these sources are not constant, it needs a large storage system that can balance the power into the grid. The pump storage hydropower plant is the best option for such a large scale storage. At present, the pump storage plants cannot dynamically change its mode from pumping to generating or vice versa because the electrical machines are directly connected to the large AC network. Also, the hydraulic and electrical 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 and dynamic transition in modes of operation (pumping and generating) 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 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

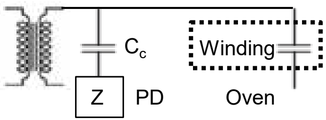
The majority of the Norwegian hydropower generators was installed between 1960 and 1990, and many of these will soon reach the expected lifetime and need refurbishment. One main root cause for failure in hydro generators is generally located to the groundwall insulation. It is therefore important to 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

Department of Industrial Economics and Technology Management

NTNU

PHD THESIS

Andreas Kleiven

Department of Industrial Economics and Technology Management

2017 – 2021

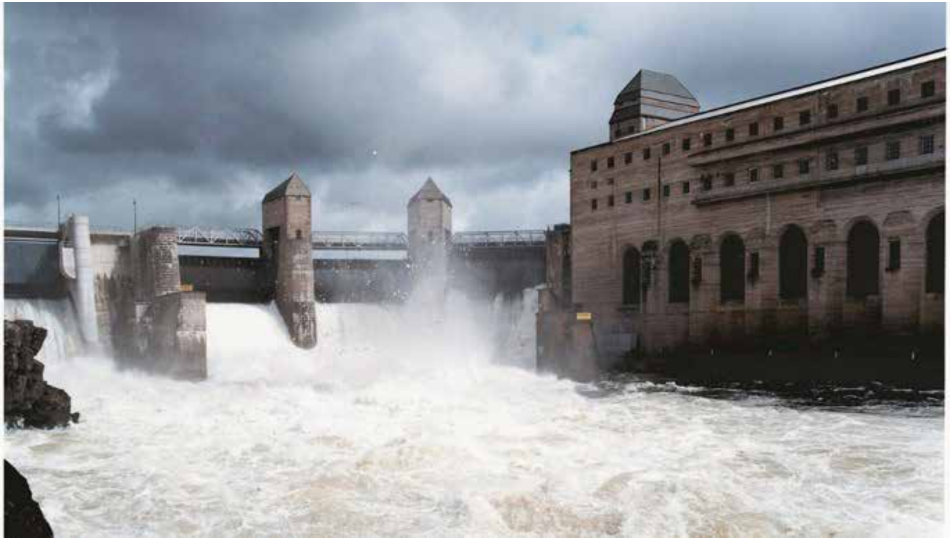
Investment decisions in upgrading and refurbishment of hydropower plants

Supervisor:
Stein-Erik Fleten

NTNU HydroCen

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

USN
The University of South-Eastern Norway

Background

The operation of the power system is becoming towards sustainability, where different power system operators try to operate in a connected network. Moreover, the network topology, load pattern and control methods are changing due to the technological development. Therefore, steady state and dynamic performance of the modern power system required to be investigated through reliable power system component models and reliable computer based simulation tools.

Objectives

- Two test power systems, containing 10 buses and 11 buses will be interconnected and simulated.
- The 10 bus network represent a transmission network where large signal stability and small signal stability will be investigated.
- The 11 buses network represent a simplified regional distribution power network. Model reduction techniques will be applied to obtain 11 bus network from the simplified Telemark regional power network, Norway.
- Both steady-state and time domain analysis will be performed to analyse voltage stability.

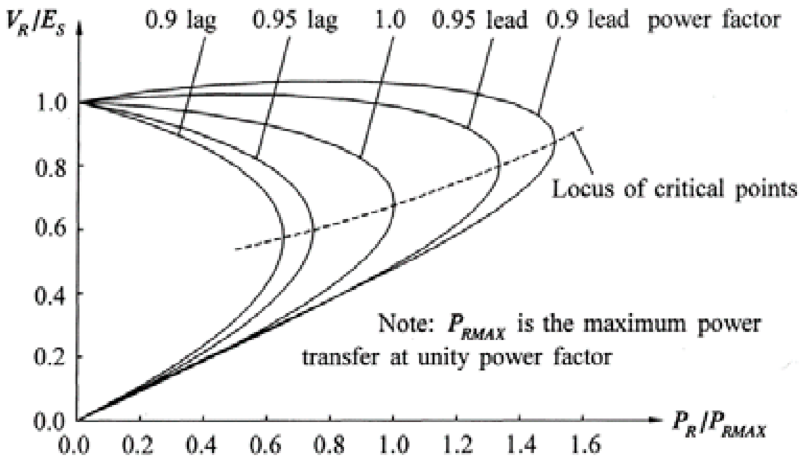


Figure 1: PV characteristics of a simple radial power system with different load-power factors (Reference: P. Kundur, Power System Stability and Control, 1993, page 31)

MASTER THESIS

Upendra Agrahari

Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

Voltage stability analysis of integrated two test power systems

Supervisor:
Manjula Edirisinghe
In cooperation with:
Skagerak Kraft

University of South-Eastern Norway

MASTER THESIS

Eirik Bakko

Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

Online monitoring and visualizing of a generators capability with Modelica

Supervisor: Dietmar Winkler
Co-supervisor:
Thomas Øyvang
In cooperation with: Statkraft

University of South-Eastern Norway

Background

In a recent PhD study (Øyvang, 2018), the possibility of modelling and controlling the thermal development in a synchronous generator was developed. To monitor the reactive power output of generators and operate them to keep appropriate reactive power reserve at generators at all time is one of the most important countermeasures for voltage collapse.

This task contains the development and implementation of the PQ capability diagram for online monitoring and control in Modelica. The approach and methodology can be used for the implementation of the user real-time P-Q diagram whose limits change dynamically in accordance with operating conditions when the generator operates on the grid. This enables better insight into the operational limits which ensures better utilization of the synchronous generator.

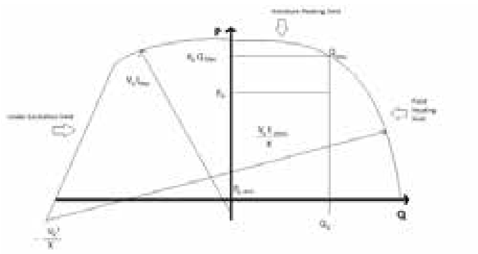


Figure 1: Generator capability curve.

Objectives

- Survey on voltage stability and collapse phenomena.
- Survey on a generators capability and how it operates.
- Develop a simulation model of the Prabha Kundur's 11 bus system and do long term voltage stability analysis of the system.
- The modelling shall be carried out in Modelica using the OpenIPSL library and results verified to (Kundur, 1994).
- Develop an automatic visualization tool for a generators capability and implement it in the 11 bus system.
- If time allows, implement the hydro generator used in (Øyvang, 2018) as the «local» generator in the 11 bus system.

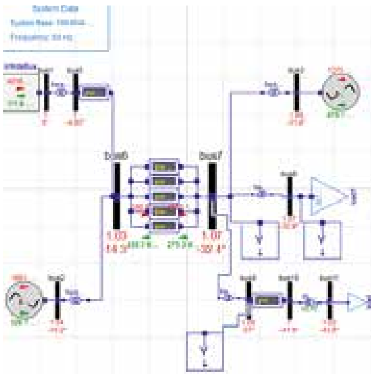


Figure 2: 11 bus system, implemented with Modelica.

Background

Duge is the only pumped hydro power plant owned by Sira-Kvina Kraftselskap and has an installed capacity of 2x100 MW by the use of reversible Francis turbines. The power plant is located in Forsand municipality and is the first power plant in the waterway of Sira. The power plant is utilizing a height difference of 215 m from the upper reservoir Svartevatn to the lower reservoir Gravatn. The annual production is 248 GWh a year.

The background for the thesis is that the power production company desires to change the conventional start-up procedure in pump-mode for the power plant Duge. Today's start-up method is provided by the help of a pony motor which causes heavy stress to the equipment and the synchronization towards the grid is not optimal. Therefore a few alternative start-up methods will be covered in this thesis with mainly focus on using a soft starter.

The varying energy prices throughout Europe will be adapted to the Nordic power marked when increasing the capacity of power flow to the continent. These price differences will be advantageous to utilize by pumped hydropower plants and investing in such energy sources may be more feasible in future years. In addition, more intermittent power sources are introduced to the Norwegian power system, especially in the South-West part of Norway. This will lead to more variations in power production and the need of balancing the grid is increasing. Therefore, it is also preferable to look at the possibility of upgrading the power plant with an adjustable speed drive. There are advantages and drawbacks with the various alternatives and those will be covered in the thesis.

Furthermore, it will be investigated how to fit the various alternatives in the existing power plant regarding dimensions of the equipment. Evaluation of future power marked will also be discussed and the cost of implementing the various alternatives will be presented. Both technical and economically aspects will be considered when advising the external partner to choose one of the alternatives.

Photo: Per Berntsen

MASTER THESIS

Sandra Grave Breiland

Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

Reconstruction of the pumped hydro power plant, Duge

Supervisor:
Gunne John Hegglid
Co-supervisor: Bjarne Tufte
In cooperation with:
Sira-Kvina Kraftselskap

University of South-Eastern Norway

MASTER THESIS

Gunhild Marie Grimstvedt

Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

Transient and long-term power system stability with Modelica

Supervisor:
Dietmar Winkler
Co-supervisor:
Thomas Øyvang

University of South-Eastern Norway

Background

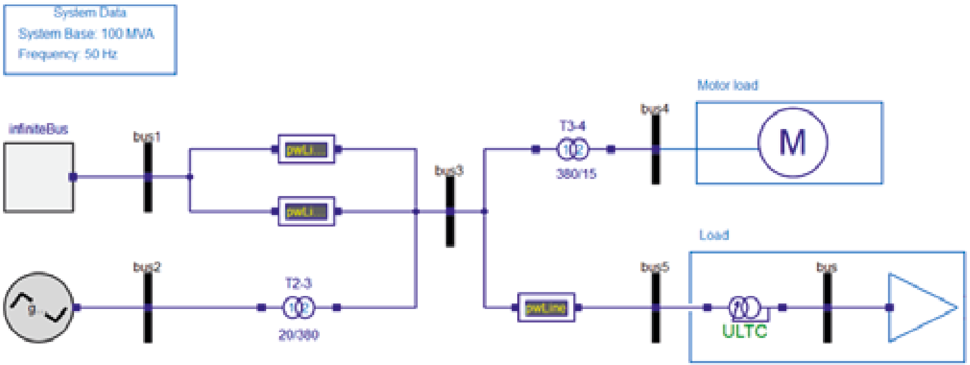
In 2011 Rujiroj Leelaruji developed an "All-in-one" test system for investigation of transient and long-term power system stability.

The main task is to develop the "All-in-one" test system in Modelica with OpenIPSL and implement Åbjøra hydrogenator with corresponding control systems.

This system will be further used to investigate both transient and long-term stability with respect to requirements and guidelines for stability as ENTSO-e, FIKS, IEC and IEEE.

Objectives

- Survey on power system stability and collapse phenomena, generators capability and how it operates.
- State and discuss the ENTSO-e and Norwegian requirements or guidelines for stability with respect to voltage and transient stability.
- Develop and simulate the "All-in-one" bus system (Leelaruji, 2011) in Modelica with OpenIPSL.
- Implement Åbjøra Hydro generator which includes implementation of power system stabilizer, excitation system and hydro governor system.
- Investigation of the Phasor Measurement Unit (PMU) model in Modelica.



Background

The power system architecture is becoming more complex, where different power system operators try to operate in a connected network. Therefore, relaying techniques of the modern power systems required to be investigated through reliable power system component models and reliable computer based simulation tools.

Objectives

- Two test power systems, containing 10 buses and 11 buses will be interconnected and simulated.
- The 10 bus network represent a transmission network.
- The 11 buses network represent a simplified distribution regional power network in a Nordic country.
- Model reduction techniques will be applied to obtain 11 bus network from the simplified Telemark regional power network, Norway.
- Integrated two systems will be analysed considering distance protection, overload protection and automatic load shedding.
- Finally it will be investigated how to improve interconnected-area-oscillations / angular stability by enhancing the speed of the relay operation time.

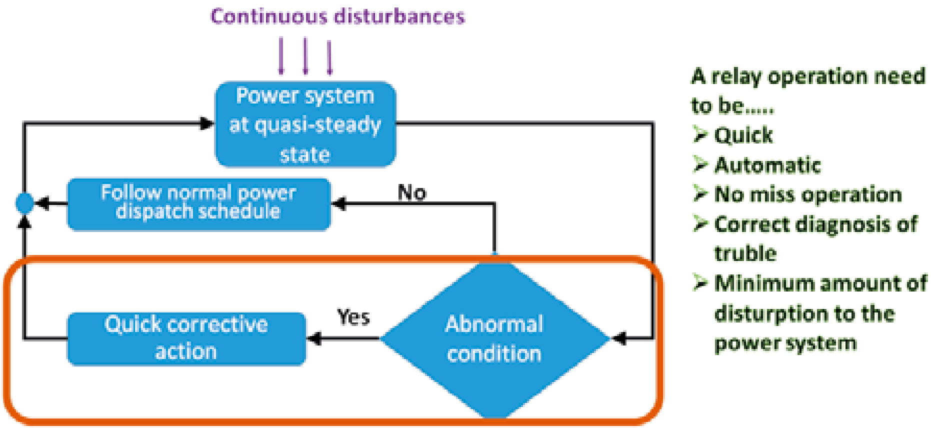


Figure 1: Importance of a relaying system in an electrical power system

MASTER THESIS

Roger Lid

Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

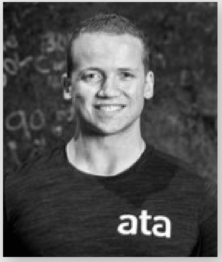
Investigate relaying techniques to improve the stability of the integrated two test power systems

Supervisor: Manjula Edirisinghe
In cooperation with: Skagerak Kraft AS

University of South-Eastern Norway

MASTER THESIS

Jonas Hetland Mong



Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

Transient and long-term power system stability with Simulink

Supervisor:
Thomas Øyvang
Co-supervisor:
Dietmar Winkler

University of South-Eastern Norway

Background

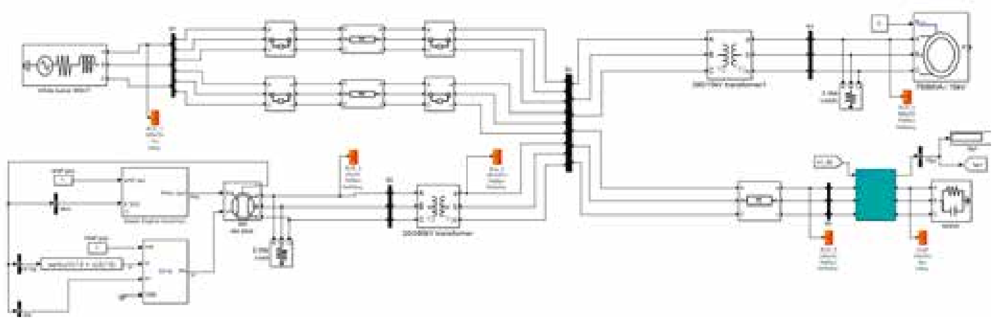
In an electrical power grid, disturbances and faults can create large problems for most equipment. In this task the goal is to implement Leelaruji's, (2011) developed All-in-One test system for investigating both transient and long-term power system stability phenomena's using Simulink.

By using this test system there will be possibilities to test the ability
of synchronous machines of the interconnected power system to remain in synchronism after being subjected to different disturbances.

Further interest is to develop this model to investigate Norwegian requirements for transients and long-term voltage stability.

Objectives

- Complete an survey on the power system stability and collapse phenomena using Simulink.
- Do an survey on a generators capability and how it operates.
- Implementing the hydrogenator Åbjøra, with corresponding control systems created by Thomas Øyvang (2018).
- State and discuss the ENTSO-e and Norwegian requirements or guidelines for stability with respect to voltage and transient stability.



Leelaruji's "All in one system" implemented in Simulink.

Background

The trade-offs between choosing a higher and lower power factor are usually qualified below 0.86, normally, in a hydropower system. A higher Power Factor means less reactive power (unexploited power) and more active power (exploited power) through the system, however, results in more currents, resulting in more heating of the hydro-generators. Thus, relaxation on qualified Power Factor should be balanced with thermal heating for the longevity of the generator. Lie (2018) developed a thermal model similar to Øyvang (2018). It is of interest to further extend the model with electrical model, model fitting, and state estimation.

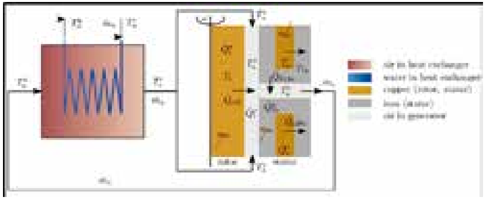
Objective

The prime objective of the study is to implement and analyse the model using a suitable language. Modelica and Julia language are open source scripting language and robust for model development. OMJulia is a tool for integrating Julia with OpenModelica. It is easier to formulate a model in OpenModelica and run it from Julia using OMJulia interface resulting in faster computation. Furthermore, OMJulia and Julia itself makes trivial for computation of model fitting and state estimation. For state estimation algorithms an Unscented Kalman Filter is used and compare with Ensemble Kalman Filter, in Julia.

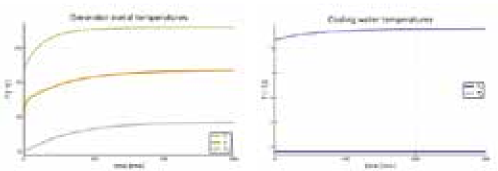
References

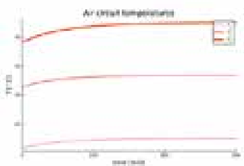
Øyvang, Thomas (2018). Enhanced power capability of generator units for increased operational security. Ph.D.-thesis, University of South-Eastern Norway.

Lie, Bernt (2018). Group project task, course FM1015 Modelling of Dynamic Systems. University of South-Eastern Norway.



Thermal Model of Air-cooled Synchronous Generator (Lie (2018))

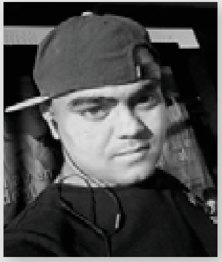




Temperature variation in Air-cooled Synchronous Generator

MASTER THESIS

Madhusudhan Pandey



Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

Model Fitting and State Estimation for Thermal Model of Synchronous Generator

Supervisor:
Bernt Lie
Co-supervisor:
Thomas Øyvang

University of South-Eastern Norway

MASTER THESIS

Stian Rasmussen

Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

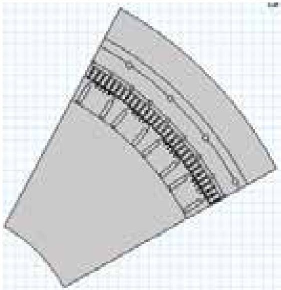
Limited FEM modelling of synchronous generator in COMSOL Multiphysics

Supervisor: Thomas Øyvang
Co-supervisor: Jonas Nøland
In cooperation with: Skagerak

University of South-Eastern Norway

Background

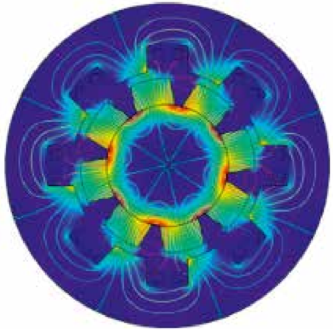
In a recent Ph.D. study (Øyvang, 2018), the possibility of modelling and controlling the thermal development in a synchronous generator was developed. A part of this study was to do a limited Finite Element Method (FEM) analysis of an air-cooled hydrogenerator. To monitor the reactive power output of generators and operate them to keep appropriate reactive power reserve at generators at all time is one of the most important countermeasure for voltage collapse.
This thesis is focused on using FEM simulation to study the physics of a synchronous generator air-cooled machine. Detail multi-physical modelling of a generator is of great interest in future power system applications. Investigation on the thermal and electrical behaviour of a synchronous generator during enhanced performance are of interest.



Model for SG Geometry in Comsol

Objectives

- Survey on COMSOL documentation and present the most important aspects related to the task.
- Survey of the physics of a synchronous generator (SG) and how the SG is constructed.
- Develop a tutorial for implementation of a SG in COMSOL.
- Develop a 2D electromagnetic model of the SG in COMSOL.
- Investigate losses of the FEM model and relate them to a heat-run test of the machine.
- If time allows, develop a 3D thermal model of rotor and stator in COMSOL Compare results to a heat-run test of the machine. Investigate the hot-spot of the machine. Do a simplified transient analysis.
- If time allows, explore the application builder in COMSOL .



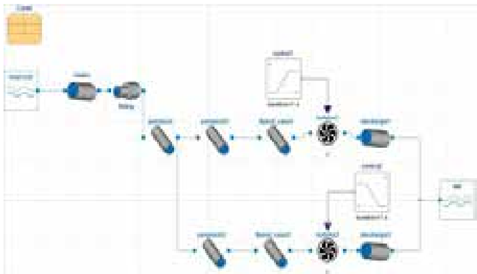
Example of simulated generator in Comsol

Background and obectives

In cooperation with Icelandic oldest engineering firm Verkís consultant engineers a task is assigned to design hydraulic model of Hvalarvirkjun power station, Hvalarvirkjun lies in the Westfjord region of Iceland where power reliability is worst due to extreme climatic condition. To enhance power the supply in the northern part of the Westfjords a new power plant, Hvalarvirkjun, has been proposed. Both the electrical and the hydraulic part of this powerplant will be modelled and coupled together. The main objective of developing such a model is to study the feasibility and operational behaviour of the power plant, such as load rejection under guide vane operation and to determine worst-case scenario during complete shutdown of the plant. Furthermore, investigate the effect on the model while parameters such as speed, flow, pressure and distributor opening of the turbine are taken into consideration.

The effect of such parameters cause a special behaviour of powerplants since Hvalarvirkjun's water-way has no surge tank installed. To design such a model and to simulate these different scenarios the object-oriented modelling language Modelica is used in combination with the commercial modelling and simulation environment Dymola. In addition, two separate libraries, the Open Hydro Power Library (OpenHPL) and the Open Instance Power System Library (OpenIPSL) will be coupled together in order to represent the complete hydropower system .

Screenshot of disruption in the Westfjord power system



Screenshot of OpenHPL components of Hvalarvirkjun power station

MASTER THESIS

Nitesh Thapa

Department of Electrical Engineering, Information Technology and Cybernetics

Spring 2019

Hydro-Electric Modelling and Simulation of Hvalarvirkjun in North West Iceland

Supervisor: Dietmar Winkler
In cooperation with:
Verkís consultant engineers

University of South-Eastern Norway

PHD THESIS

Manjula Edirisinghe

Process, Energy and Automation Engineering

2016 – 2020

Transient stability in high voltage power systems

Supervisor:
Gunne John Hegglid
Co-supervisors: Svein Thore Hagen, Jonas K. Nøland

University of South-Eastern Norway

Background and objectives

Transmission system operators in most of the European countries work together to standardize 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 mostly 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 will also be investigated.

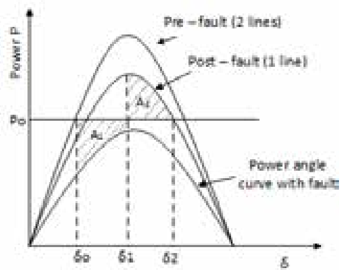


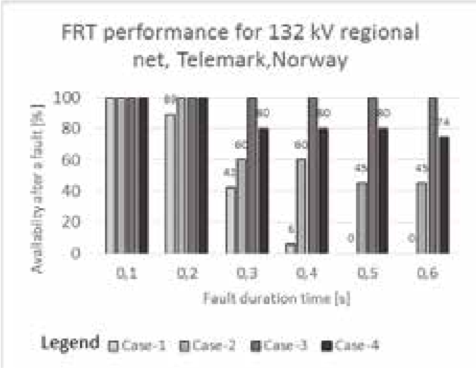
Figure 1: Representation of FRT capability using equal-area method.

Some Results

The results from the preliminary study confirm that the number of generating stations connected continue to decrease when the fault duration increases.
Case-1: when the fault location is close to the transmission network, there are few generators connected in synchronism after 0.3 s fault duration.
Case-2-4: When the fault is in the distribution network, only nearby generators go out of synchronism.

Study case

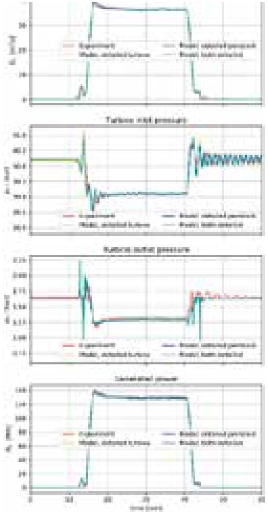
The electricity transmission network in Sri Lankan power system will analyze for voltage and transient stability.



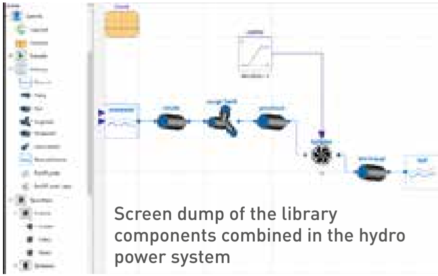
Background

A transition towards more renewable energy sources is currently happening in Europe and all over the world. This situation leads to increase in the use of flexible hydropower plants to compensate the highly changing production from intermittent energy sources such as wind and solar irradiation. All these factors highlight the importance of modelling and simulating hydropower systems in order to develop a control structure and to make efficient analysis tools for testing a designed controller for stability and performance in different operating regimes.

In this study a hydropower Modelica library OpenHPL is developed using OpenModelica as an open-source Modelica-based modelling and simulation environment, see figure above. The library includes a set of unit 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. Interaction with other libraries "downstream" from the generator is possible, e.g., connection to OpenIPSL (power system library).
The application of OpenHPL to model the Trollheim hydropower plant including model fitting and validation to experimental data has been performed, see plots to the right. Different methods for analysis of models such as state estimation, automatic linearization, etc. are also the aims of the study. The developed methods are implemented as tools in Python/Julia (open source scripting languages), which can be interfaced to OpenModelica via Python/Julia APIs.

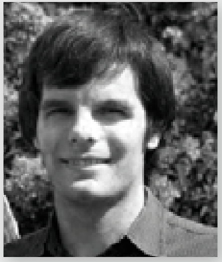


Comparison of model simulations with measurements



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

Liubomyr Vytvytskyi



Process, Energy and Automation Engineering

2016 – 2019

Dynamics and control of hydropower system

Supervisor:
Bernt Lie
Co-supervisor:
Roshan Sharma

University of South-Eastern Norway

PHD THESIS

Shohreh Monshizadeh

Process, Energy and Automation Engineering

2018 – 2021

The Flexible Hydro Power Unit

Supervisor:
Gunne John Hegglid
Co-supervisor:
Svein Thore Hagen

University of South-Eastern Norway

HydroCen

PHD THESIS

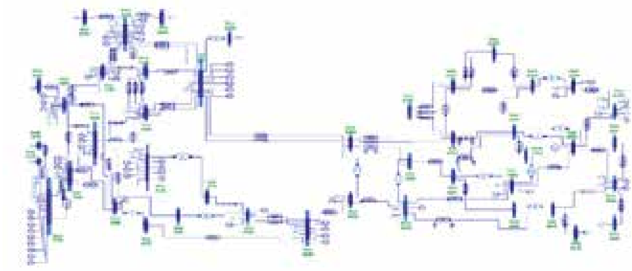
Background and objectives

Optimal power flow (OPF) problems has a vital role for planning and operation of Electrical power system under reliable, flexible and secure manner of transmission power system. Mathematically, it is recognized as large scale and nonlinear optimization problem with a large number of variables, including equality and inequality of constraints that aims at minimization the objective functions, including power losses, fuel cost, improve the stability and voltage profile. Over the past decades, numerous methodologies have been proposed for solving OPF problems that are called conventional and intelligent methodologies. The traditional methodologies like Interior point method, nonlinear programming, linear programming, quadratic programming. The prominent intelligent methods are Particles Swarm Optimization method (PSO), Genetic Algorithm and Evolutionary Programming (EP).

Minimization the total power losses

Motivation:

- The main goal of my research plan is adaption of optimal power flow (OPF) in day-to-day operation of a hydroelectric dominated power system in Norway.
- The study work focuses on using several methodologies (Classical and Intelligent methods) to minimize the transmission power losses in Electrical power netwrok of Norway, Finland and Sweden called, Nordic 44.
- This study invistigted the load flow analysis of Nordic 44 with Digsilent and MALTAB software.
- This study used of PSO algorithm and IPM method to solve ORPD in Nordic 44.
- This study invistigated the evaluation of FACTS devices for minimization the power losses for several IEEE networks.



Nordic 44 [Ref;L.Vanfretti,T.Rabuzin. ''Nordic 44 bus test system in modelica'' . Elsevier, 2016].

HydroCen Report nr.8

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