HydroCen

HydroCen

NORWEGIAN RESEARCH CENTRE FOR HYDROPOWER TECHNOLOGY

OVERVIEW OF MSC - PHD - POST DOC.

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Content

HydroCen

The main objective of HydroCen (Norwegian Research Centre for Hydropower Technology) is to enable the Norwegian hydropower sector to meet complex challenges and exploit new opportunities through innovative technological solutions.

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

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

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

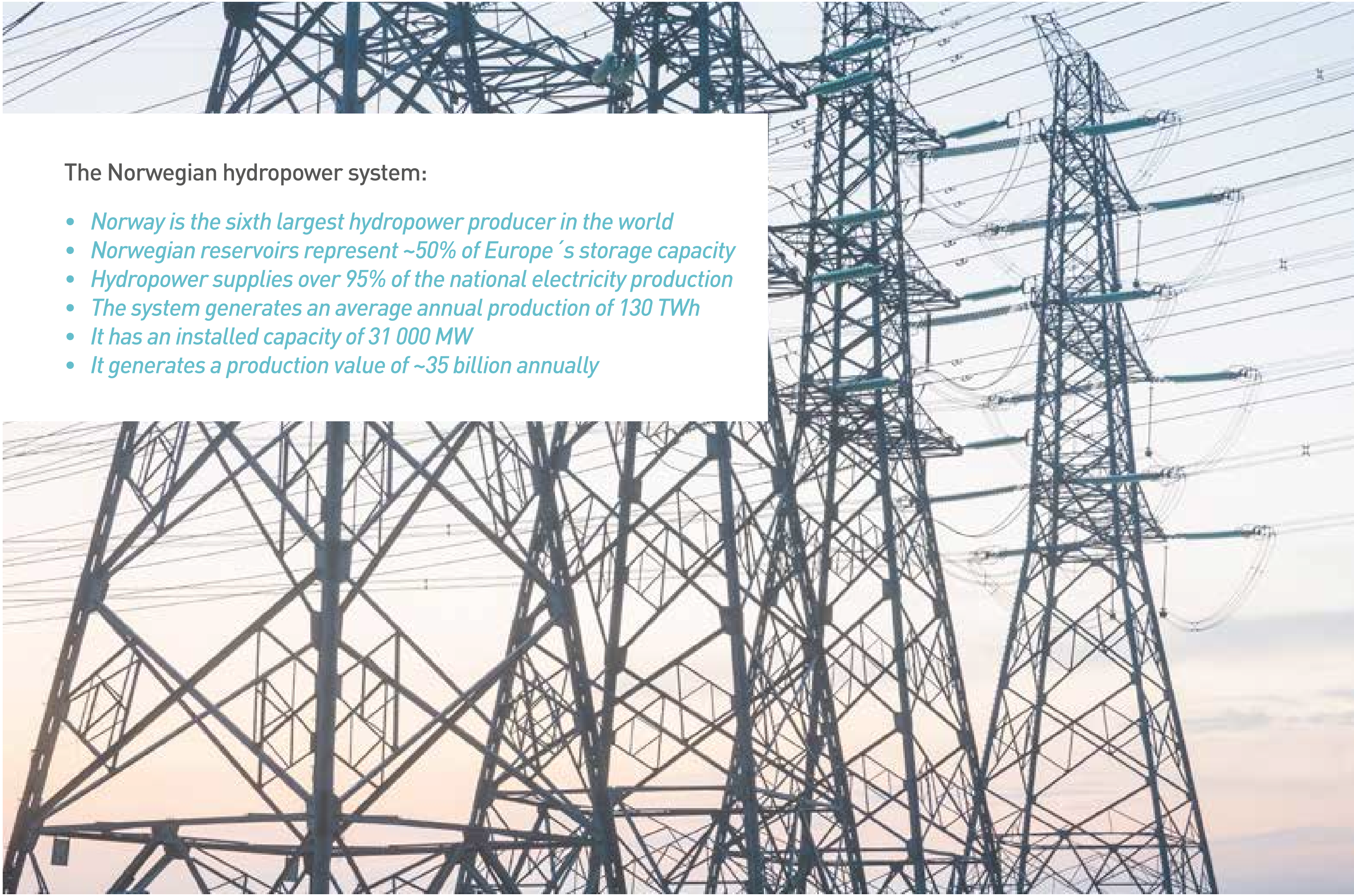
The annual budget is NOK 48 million per year, totalling NOK 384 million in eight years. HydroCen is a Centre for Environment-friendly Energy Research (FME).

The FME scheme is established by the Norwegian Research Council.

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

The Norwegian hydropower system:

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



HydroCens' partners

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Future competence

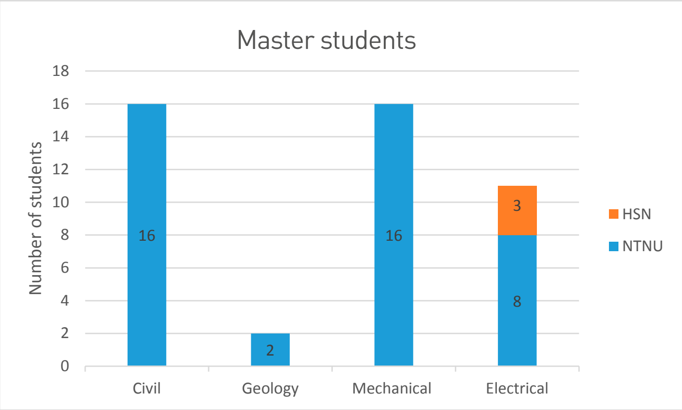
It is a pleasure to present this compilation and outline of the ongoing master theses and research fellowships within hydropower at NTNU and HSN. This represents a vital and important part of HydroCen – The Norwegian Research Centre for Hydropower Technology. The centre is a cross-disciplinary collaborative platform, with NTNU as host institution and SINTEF Energy, NINA and the Norwegian Hydropower Centre as key partners.

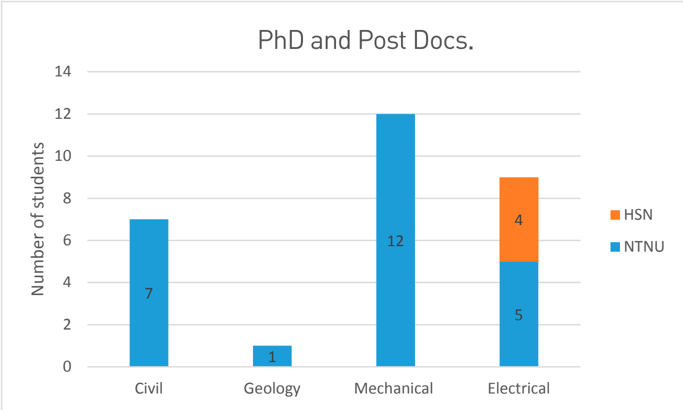
The catalogue shows an diversity in its approach towards important research-issues regarding hydropower technology. The strategic mission in HydroCen is to develop new solutions and new knowledge to strengthen the value creation in the Norwegian hydropower sector and secure a solid base for further growth for renewable energy. The people and projects presented here define the competence and knowledge that will bring us the future of innovation for hydropower in Norway and abroad.
Enjoy!

Participating masterstudents on the annual hydropower excursion, autumn 2016. Picture taken at the inlet tunnel at Vamma 12

Overview of students and research fellows

Overview of the number of master students, PhD and Post Docs. connected to NTNU and HSN in spring 2017. The candidates are sorted within the respective fields; Civil, Engineering geology, Mechanical and Electrical.





NTNU – Norwegian University of Science and Technology

HSN – University College of Southeast Norway

Department of Civil and Environmental Engineering

NTNU

Baard Aasmund Utvik Gjerde

Department of Civil and Environmental Engineering

Spring 2017

Dam Storlivatnet Spillway – Model Tests of a New Spillway

Supervisor:
Leif Lia
Co-supervisor:
Kiflom Belete
In cooperation with:
Saudefaldene

NTNU

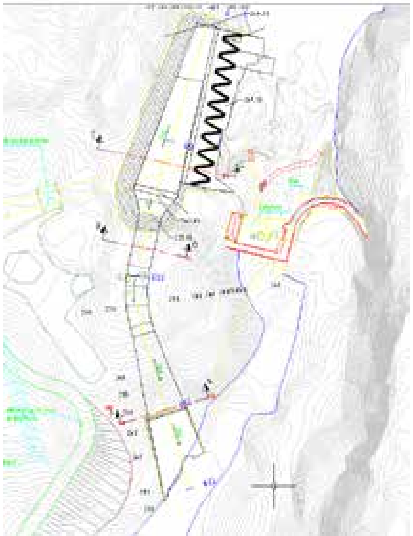
Background

With the increased focus on floods during the last few years, the spillway at Dam Storlivatnet is found to have insufficient capacity relative to new flood calculations. The NVE have imposed Saudefaldene to increase the capacity at Dam Storlivatnet.

Because of the difficulties in the topography and the fact that the dam has a historical value because it is the first arch dam in Norway, it is found that a reasonable solution is to build a side-weir connected to a closed spillway at the right side of the dam. This is in addition to maintaining the already existing roller gate through the dam.

The objective of this thesis is to build a physical model at Vassdragslaboratoriet in Trondheim to verify the capacity and investigate hydraulic situations for the chosen solution.

The topography forces the new weir to be placed very close to the already existing roller gate. It is very difficult to calculate the influence the weir and the roller gate will have on each other, and this is to be examined in the model tests.



Background

According to the regulation on dam safety (Damsikkerhetsforskriften), the downstream slopes of rockfill dams need to be protected with placed riprap. Placed riprap means stones placed one by one in an interlocking pattern. Today there is a lot of ongoing reconstruction and rehabilitation work on rockfill dams to oblige requirements from the government. Therefore, it is of interest to look closer at the behaviour of the placed riprap.

The purpose of this thesis is to investigate placed riprap exposed to overtopping. Also, practical conditions for calculating the required rock size used in the field will be investigated. This is done by looking into the background of the formulas and given form factors from the guidelines for embankment dams.

Placed riprap exposed to overtopping will be tested in the laboratory, and the displacement that occurs will be measured. The discharge of overflow is increasing until the riprap fails, and this concludes the test.

Testing in the laboratory

MASTER THESIS

Guri Holte Veslegard

Department of Civil and Environmental Engineering

Spring 2017

Placed Riprap on Rockfill Dams

Supervisor:
Fjóla Guðrún Sigtryggsdóttir

NTNU

MASTER THESIS

Karoline Mittet Brøste

Department of Civil and Environmental Engineering

Spring 2017

Testing of Air Entrainment in the Spillway at Follsjø

Supervisor:
Kaspar Vereide
Co-supervisor:
Leif Lia
In cooperation with:
Statkraft

NTNU

Background

In 2016, Statkraft Region Midt Norge hired NTNU to perform a model study of the spillway at Dam Follsjø to check whether the capacity was satisfying. A model was built in the lab and capacity measurements were performed.

The commercial project finished in 2016, but the model is still at Vassdragslaboratoriet. The purpose of this master thesis is to find ways to measure the air entrainment in the spillway and examine the amount of air entrained. Factors like roughness and water velocity influences the amount of air entrained and these will be examined. This is an important part of model studies which is often taken extra account for by letting in too much air in the system. It will be exciting to find out more about the mechanisms of air entrainment.

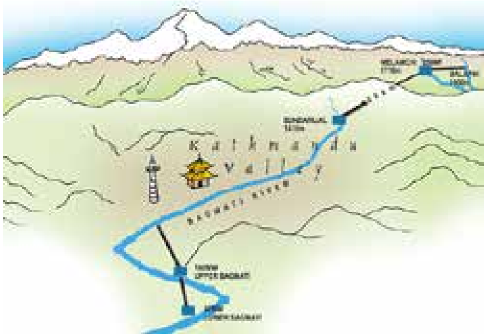
The model in the laboratory

Dam Follsjø with the spillway to the right

Background

In the mountainous Nepal a significant amount of electricity is produced through hydropower, approximately 800 MW. Several of the hydropower plants are built with influence from Norway and Norwegian organizations, and companies still have ownership in the power production. Because of the topography in the country, the steep valleys and the high mountains, significant season reservoirs have not yet been built. That leads to a very unreliable power production. In the dry seasons and during winter and spring, the electricity is switched off 16-17 hours per every 24 hours. This is still the situation in Nepal, and the big earthquake in 2015 slowed the construction-phase of many new hydropower plants.

The Kathmandu Valley is about to get a new water supply through the Melamchi-project. Transmission tunnels have been constructed between rivers northeast of Kathmandu, that supposedly shall transfer water with good quality in copious amounts to citizens and industry. It has earlier been investigated if the project can combine water supply and power production, but because of political – and financial matters the hydropower part has not been prioritized. There is still potential to make the Melamchi-project into a Multipurpose Project (MPP) and I will investigate alternative ways to accomplish this.



The Melamchi tunnel under construction

MASTER THESIS

Kristine Nyvoll

Department of Civil and Environmental Engineering

Spring 2017

Building a Hydro-Power Plant with Water Supply in the Melamchi-Project in Kathmandu, Nepal

Supervisor:
Leif Lia
Co-supervisor:
Oddbjørn Bruland
In cooperation with:
PEEDA

NTNU

MASTER THESIS

Lars Skeie

Department of Civil and Environmental Engineering

Spring 2017

Hydraulic Modelling of Hydro Power Operation in Tokkeåi

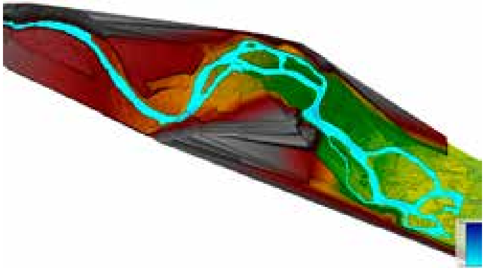
Supervisor:
Knut Alfredsen
Co-supervisor:
Morten Stickler
In cooperation with:
Statkraft

NTNU

Background

A two-dimensional hydraulic model is to be created for the purpose of studying the effects of different operation regimes of the hydro power station in Tokkeåi. The model used is HEC-RAS 5.0 which has the capability to simulate the shallow-water equation (2D). The terrain is created from LIDAR-data, which was measured/collected by AHM, and self-measured data from field surveys. The model will be calibrated against measured water surface elevations (WSEL) from field surveys for different discharges, where the Manning's number will be used to fit the simulated and measured WSELs.

After the model is calibrated it will be used to look at the different effects with regards to both static and dynamic hydro power operations. The methods from EnviPEAK's "Miljøvirkninger av effektkjøring" will be applied as a part of the study. The results will then be related to biological data previously collected for the river, with focus on dry areas and fish habitat.



Renate Musum Stangvik

Department of Civil and Environmental Engineering

Spring 2017

Effect of Location of Asperity and Shearing Direction on Shear Strength

Supervisor:
Leif Lia
Co-supervisor:
Dipen Bista
In cooperation with:
LTU, NORUT

NTNU

Background

In Norway, a big number of concrete dams have been built related to hydro power. Due to the hydrostatical water pressure and ice loads, the dams require sufficient stability for safe operation. Several dams do not fulfill the requirements for safety factor against sliding, and several dam owners are facing big investments to fulfill the requirements.

The shear strength of a rock-concrete interface is often decisive for the sliding stability of a dam, however, not all factors contributing to shear strength are properly understood. If the contribution of these factors can be understood and included in the stability analysis, this could help some of the dams to fulfill the stability requirements. Research is still carried out and currently focused on shear resistance and criteria for sliding stability.

The scope of this thesis is to analyze how the location of an asperity and the shearing direction will affect the shear strength, by studying existing models and conduct laboratory shear tests. The work with this thesis is integrated in a large laboratory test program hosted by NORUT. The shear tests will be carried out at LTU in Luleå.

A concrete dam which do not fulfill the requirements for sliding stability

Test apparatus used for shear testing
Photo: Master thesis by Simen Liahagen

MASTER THESIS

Stian Løbø Aaker

Department of Civil and Environmental Engineering

Spring 2017

Anchoring of Bend on Penstock with PU Foam

Supervisor:
Leif Lia
Co-supervisor:
Tor Oxhovd Svalesen
In cooperation with:
Statkraft AS

NTNU

Background

The drop in Norwegian electricity prices in recent years has reduced the potential income for new small hydro projects, and therefore measures to reduce the costs must be introduced. Today the most commonly used backfill for penstocks for small hydro are gravel and rockfill, which is time consuming and costly due to transportation. Penstock BV with Guy Harris developed a method with polyurethane foam as a replacement for gravel and rockfill which may lead to lower investment costs and reduced construction time. Statkraft AS initiated a research project to verify this method.

The project involves the construction of Lille Måsevann Pump with a buried penstock connecting Lille Måsevann to Store Måsevann – the intake reservoir for Adamselv hydropower plant. Lille Måsevann Pump is the first of its kind where sections of the penstock, including two bends, are enveloped in polyurethane foam (PU foam).

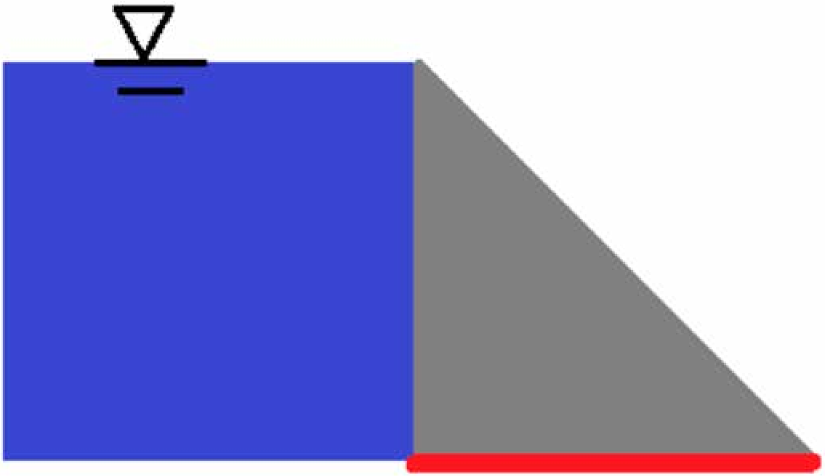
The main objective of this master thesis is to further develop the use of PU foam for the anchoring of bends. Two laboratory tests will be carried out to investigate the structural properties of foam in bends and adhesion between foam and pipe.

Buried penstock connecting Lille Måsevann to Store Måsevann

Background

Calculation of the safety of lightweight gravity dams are built on a model of the failure of the dam. The mechanisms of failure for such dams are not sufficiently understood, and for us as a society to have safe dams we need better understanding of these mechanisms.

My master thesis deals with numerical modelling of the concrete rock interface in the FEM program Atena, and the design of a large scale shear test that is to be carried out in the summer this year.



MASTER THESIS

Sigurd Sætherø Steen

Department of Civil and Environmental Engineering

Spring 2017

Roughness in Sliding Stability of Concrete Dams

Supervisor:
Leif Lia
Co-supervisors:
Dipen Bista & Gabriel Sas

NTNU

MASTER THESIS

Niklas Kovanen Sæten

Department of Civil and Environmental Engineering

Fall 2016

Testing of Snorkel for Coanda Intake

Supervisor:
Leif Lia
Co-supervisor:
Knut Alfredsen

NTNU

Background

The Coanda intake's self-cleaning capabilities has proven to work well, but it is prone to blockage due to frazil ice. A snorkel has been made, which is intended to maintain the circulation of the water in the canal underneath the screens, when the intake is blocked by ice. This will prevent ice from forming in the canal, thus leaving the system ready for operation as soon as the water finds its way under the ice. A snorkel has been mounted on the intake at Dyrkorn power plant over a long time period, but its function has never been documented.

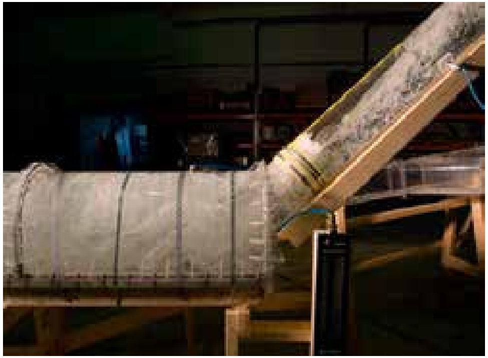
A physical model of the snorkel was built and tested on a full scale Coanda screen model. The intake at Dyrkorn have been monitored via webcam and observations done with the webcam, as well as observations made by several field trips.

The snorkel's capacity has been estimated to see if it can deliver enough water to avoid stopping the power plant during the event of the intake being blocked. Model tests have revealed that the snorkel, in extreme cases, could act as a siphon, a situation that should be avoided. As a siphon the snorkel could drain the reservoir and deliver a flow different from the natural flow of the river. It is shown that the snorkel may contribute to reduce the cooling of the water due to surface heat exchange, and to earlier establish surface ice on the reservoir. It's main contribution is assumed to be that the water on the bottom of the reservoir is warmer than the surface water and that it does not contain frazil ice. This has not been proven and should be the next step in the documentation of the snorkel.

The Coanda intake at Dyrkorn

Background

During construction of hydropower plants in an alpine landscape, long transport tunnels with many small brook intakes are often built. Bad design can lead to air entrainment into the system by water flowing through the shaft. If not handled properly, the air will accumulate into larger air pockets which may result in head loss or harmful blowouts.



Model used in previous studies at NTNU in 2009

Objective

Specialization project on air entrainment and blowouts in brook intakes written in the autumn of 2016 resulted in the conclusion that there is a need for a research on air pocket behaviour in steep shafts in terms of hydraulic conditions needed for the air to return. In order to study two-phase flow in detail, a physical model has to be built. The aim of this master thesis is to design and build a physical model needed for the research, and further to set up a testing program for air return in shafts. The results of the experiment are to be compared with previous experiments and field observations. The conclusion and report will be written based on the research process and findings of the experiments.

Air blowout at Holmaliåna

Stefan Perzyna

Department of Civil and Environmental Engineering

Spring 2017

Air Return in Brook Intake Shafts

Supervisor:
Prof. Leif Lia
Co-supervisor:
Morten Skoglund

NTNU

MASTER THESIS

Aslak Bøhle Foss

Department of Civil and Environmental Engineering

Spring 2017

Measuring Ice Loads on Dams with Varying Water Level

Supervisor:
Leif Lia
Co-supervisor:
Bård Arntsen
In cooperation with:
NORUT

NTNU

Background

Ice layers that lays on top of a reservoir or water will establish a crystalline structure that corresponds to the structure of a metal. Ice will behave like a crystalline material with thermal expansion, plastic deformation and cracking. Ice layers on reservoirs could therefore apply large forces on watercourse structures because of thermal expansion or water level variations.

Most models are designed for static ice load, while models including dynamic ice load or ice load with water level variations are rare. Ice loads largely influence the stability and static properties of low concrete dams and the upper 7-8 m of concrete dams. In many cases the ice load is the most critical load and has an impact on mandatory rehabilitations of dams. It is therefore important that the ice load is correctly projected in the form of maximum load and behavior.

Measurements

New measuring equipment and new measurement methods have made it both easier to perform measurements and easier to achieve more valid results. NORUT in Narvik has been one of the leading firms in the Nordic countries on this kind of measurement. NORUT has an ongoing measurement program. The measurements are performed on a water supply reservoir in Taraldsvika just upstream of Narvik, and measuring equipment is installed for the winter 2016/2017. The reservoir in Taraldsvika is small and can therefore be adjusted to create water level variations, which will provide particularly interesting measurements.

Measurement stations mounted at Dam Taraldsvikfossen.
Photo taken during snow fall on 17 Jan 2016

Background

Over the last few years, reasonably priced methods for measuring rock-blasted tunnel geometries with laser scanners have become available. This information can be used to find tunnel friction factors. The Research Council of Norway has made a contribution to a project in which selected tunnels are tested in a hydraulic laboratory. Here, friction loss, water velocity and turbulence are measured.

At the same time, it is desirable to find these quantities using a three-dimensional numerical model solving Navier-Stokes' equations. The latter is the topic for this master thesis. The CFD program OpenFOAM will be used.

OpenFOAM

The Open Source CFD Toolbox

From laser scanning at Litjfossen. Photos: Eirik Leknes

MASTER THESIS

Mari Vold

Department of Civil and Environmental Engineering

Spring 2017

Three-Dimensional Numerical Modeling of Water Flow in a Rock-Blasted Tunnel

Supervisor:
Nils Reidar Bøe Olsen
In cooperation with:
Trønderenergi, BKK, NVE

NTNU

MASTER THESIS

Sigurd Sørås

Department of Civil and Environmental Engineering

Spring 2017

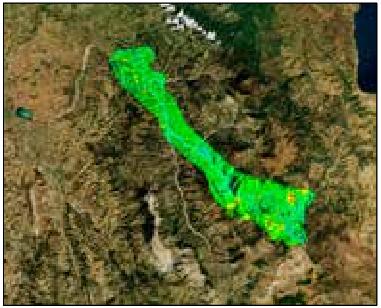
Establishing a Suspended Sediment Rating Curve for Banja Hydropower Reservoir by means of ADCP Data

Supervisor:
Nils Rüther
Co-supervisor:
Hanne Nøvik & Massimo Guerrero
In cooperation with: Statkraft

NTNU

Background

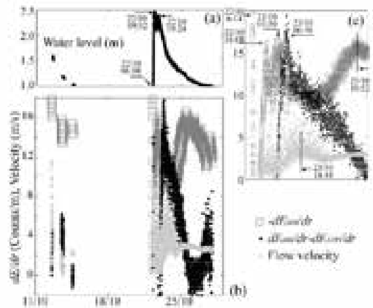
Hydropower is one of the main sources of sustainable energy in the world today. Electricity is produced by harnessing the potential energy in water stored in man-made reservoirs. The construction of such artificial storages of water will disturb the natural processes in the river, with one of these processes being the transportation of eroded material. This eroded mass, or sediments, will accumulate in the reservoir created for energy production and can cause large problems for the power plant. Many reservoirs are today facing big problems due to the original designer ignoring or underestimating the issue at the time of construction. This could have been avoided by better and cheaper predictions of sediment yield used in the design process.



InSAR coverage of Devoll catchment

Data from such predictions will also be very useful for designing sediment handling measures in already existing plants.

The present study investigates the possibility to monitor suspended load concentration with an advanced, continuous logging system in order to establish a concentration rating curve for a hydropower plant in the Devoll river catchment in Albania. The system will utilize the technology in ADCP. The project will also compare this to other techniques, such as continuous satellite measurements with InSAR. If proven to be successful, this system can be used for many other cases in order to improve the data base for planning and designing.



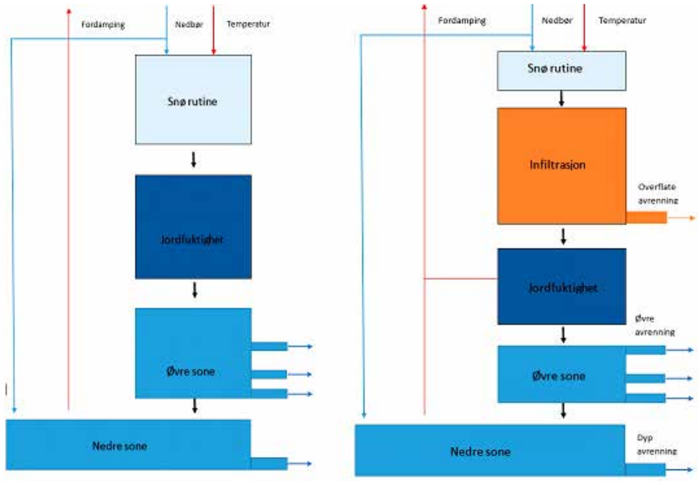
Suspended sediment concentration in the Devoll River (Guerrero et al., 2016)

Background

Increased stormwater runoff is a growing issue for urban areas. To be able to handle the problem, better hydrological tools for dimensioning stormwater systems are needed. The HBV model is well known for good estimates on natural catchments. To make the model perform better for urban areas with impervious surfaces and modified soils, an implementation of an infiltration routine is suggested.

Green-Ampt with a redistribution modification for rainfall hiatuses is suggested as a basis for the routine. The routine will be coded in C++ and Python so that it will work with the HBV model already existing in SHyFT.

When the code is ready, simulations will be done for a test field. Further, a comparison between the HBV model as it is today and the HBV model with an infiltration routine will decide how well it performs and how to improve it.



MASTER THESIS

Even Nyhus

Department of Civil and Environmental Engineering

Spring 2017

Infiltration Routine in the HBV Model

Supervisor:
Knut Alfredsen

NTNU

MASTER THESIS

Nina Johnsen

Department of Civil and Environmental Engineering

Spring 2017

PU Foam as Anchoring for Small Hydro Penstocks

Supervisor:
Leif Lia
Co-supervisor:
Tor O. Svalesen.
In cooperation with:
Statkraft AS

NTNU

Background

The drop in Norwegian electricity prices in recent years has reduced the potential income for new small hydro projects, and therefore measures to reduce the costs must be introduced. Today the most commonly used backfill for penstocks for small hydro are gravel and rockfill, which is time consuming and costly due to transportation. Penstock BV with Guy Harris developed a method with polyurethane foam (PU foam) as a replacement for gravel and rockfill which may lead to lower investment costs and reduced construction time. Statkraft AS initiated a research project to verify this method.

In my Master Thesis I will do further work with PU foam as replacement for gravel and rockfill. The completed research project will be evaluated and suggestions for the next full-scale project will follow. Also, the mechanical properties of the PU foam will be tested in the laboratory with a high focus on the influence of freeze-thaw cycles.

Background

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

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

Objective

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

Silje Kreken Almeland

Department of Civil and Environmental Engineering

2016-2020

Numerical Modeling of Air Entrainment in Hydraulic Structures

Supervisor:
Nils Reidar Bøe Olsen

NTNU

PHD THESIS

PHD THESIS

Priska Helene Hiller

Department of Civil and Environmental Engineering

2015 - 2017

Riprap Design for Rockfill dams

Supervisor:
Leif Lia
Co-supervisor:
Jochen Aberle

NTNU

Background

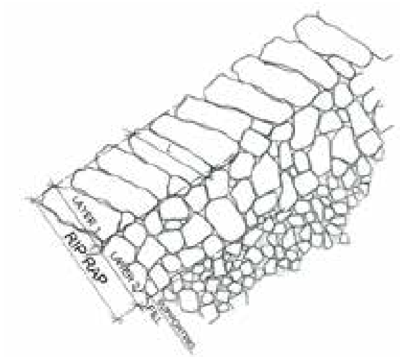
Downstream slopes of Norwegian rockfill dams are strengthened with a placed riprap against accidental overtopping or considerable leakage through the dam. Stones are placed in an interlocking pattern with their longest axis inclined towards the dam axis as shown in the figures. The current guidelines are based on the knowledge about dumped riprap despite the fact that the stones have to be placed in an interlocking pattern. Hence, there is need for a better understanding of the additional strength gained by placed riprap.

Rehabilitation of Svartevatn dam: placement of riprap stones on the downstram slope
(Photo: NTNU)

Objectives of the study

- Literature study of riprap design and practical solutions for steep slopes
- Identification of the hydrodynamic forces due to the flow over steep slopes and flow through the riprap
- Execution and analysis of laboratory tests and large-scale field tests
- Identification of the relevant parameters of the riprap material as well as the effect of placement patterns

This study is financed by Energy Norway and the Research Council of Norway. The support of the collaborating companies in the project "PlaF" is kindly acknowledged.



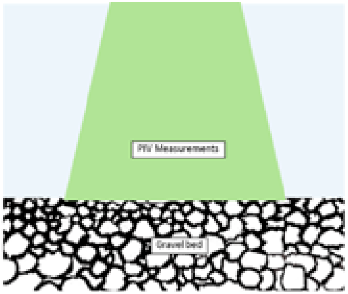
Drawing of placed riprap

Background

Gravel bed rivers represent an important stream type in fluvial environment with regard to many engineering applications such as hydropower. Hydropower generation controls the hydrological regime (e.g. load fluctuations, hydro peaking etc.), and subsequently affects exchange processes between surface and sub-surface flows, the so-called hyporheic exchange. Colmation and decolmation, i.e. the retention of fine particles in the streambed leading to the clogging of the river bed and the resuspension of deposited fine particles, respectively, are two processes in this respect. In fact, colmation processes can affect the spawning areas for salmon and suppress hyporheic exchange by altering bed porosity and hence the near bed turbulent flow structure.This study highlights this issue by focusing on the effect of porosity on the near bed turbulent flow field, shear stress, and flow resistance.

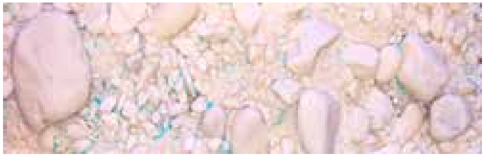
Methodology

In order to isolate the influence of porosity, a novel bed reproduction technique is used to reproduce the impermeable counterparts of a natural gravel bed surface. Turbulence characteristics are determined using Particle Image Velocimetry (PIV) / Volumetric 3-component Velocimetry (V3V) and Aquistic Doppler Velocimetry (ADV). Roughness of the surfaces is determined through Digital Elevation Models (DEMs). The aquired velocity data will be analysed based on the Double-Averaged Navier-Stokes equations.



Sketch of the experimental set-up.

Artificially reproduced surface.



Natural gravel bed surface.

Christy Ushanth Navaratnam

Department of Civil and Environmental Engineering

2013-2017

The Effect of Bed Porosity on the Turbulent Flow Field in Gravel Bed Rivers

Supervisors:
Jochen Aberle
Co-supervisor:
Nils Rüther

NTNU

PHD THESIS

Marcell Szabo-Meszaros

Department of Civil and Environmental Engineering

2015-2018

Safe and Efficient Two-Way Migration for Salmonids and European Eel past Hydropower Structures

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

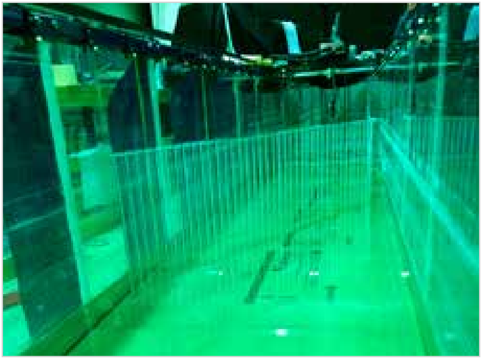
NTNU

Background

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

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

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



Background

Most of the small concrete dams in Norway were built between the 1950s and 70s. The safety of these dams are of high priority due to severe consequences of failure. However, the procedures of structural safety assessment was developed 100 years ago and they need to be updated. Furthermore, most dams which were designed using existing guidelines at the time of design need to be strengthened to meet the increased safety requirements.

This project aims to understand the failure mechanism in a concrete gravity dam and mitigate the impact of increased safety requirements for existing gravity dams.

Objectives of the study

- Enhance fundamental knowledge of dams' behavior
- Propose new assessment steps for verifying the stability of gravity dams
- Identify and test methods and equipment for destructive and (more importantly) nondestructive testing (NDT) of materials and assessing dams' condition.

Dipen Bista

Department of Civil and Environmental Engineering

2016-2018

Sliding Stability of Concrete Dams

Supervisor:
Leif Lia

Co-supervisor:
Fredrik Johansson

NTNU

PHD THESIS

Øyvind Pedersen

Department of Civil and Environmental Engineering

2015 - 2017

PHD THESIS

Method for Reduced Uncertainty in Stage-Discharge Curves

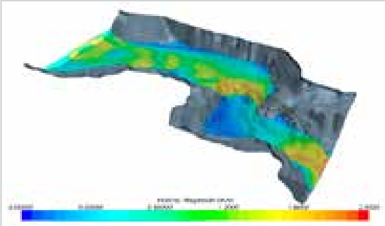
Supervisor:
Nils Rüther
Co-supervisor:
Jochen Aberle

NTNU

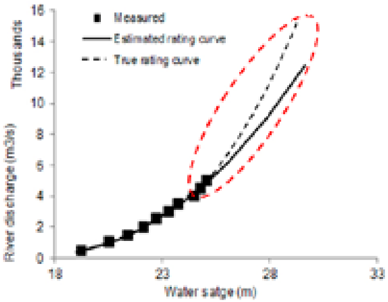
Background

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

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



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



Source: Di Baldassarre et al. 2012

Background

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 the weakest component in the design of tunnel waterways.

Methodology and Outcomes

This aspect is tackled through a combination of analytical considerations, physical scale model studies, and numerical simulations.

- Novel roughness parameters will be defined on the basis of a statistical analysis of high res. tunnel digital elevation models, obtained through Terrestrial Laser Scanning.
- Friction losses and the flow field measured in scale model studies with miniature versions of the tunnels constructed through computer-controlled milling.
- Assessment of roughness parameters and friction losses with regard to the excavation method => improved protocols for physical scale studies used for the design of tunnels.
- High resolution 3D-numerical simulations validated by extensive PIV measurements on the scale model data.

Illustrations of wall roughness in unlined tunnels. Taken from Trinh Q.N., Holmøy K.H., Grøv E. (2015): "Rock engineering service for unlined hydropower tunnels in Vietnam", Vietrock2015, 12-13March 2015, Hanoi, Vietnam.

Pierre-Yves Henry

Department of Civil and Environmental Engineering

2016-2019

Linking Physical Wall Roughness of Unlined Tunnels to Hydraulic Resistance

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

NTNU

POST DOC.

Department of Geoscience and Petroleum

MASTER THESIS

Lena Selen Kvinge

Department of Geo-science and Petroleum

Spring 2017

Study on Material Properties Testing of Various Rock Types

Supervisor:
Krishna K. Panthi
Co-supervisors:
Siri Stokseth & Thomas Shönborn
In cooperation with:
Statkraft

NTNU

Background

Statkraft, and its subsidiaries SN Power and Aqua Imara, have experienced challenging rock behaviour during development of several projects in South America, East Asia and Africa. Many of these challenges were related to a variation of rock properties during construction and operation, compared to the estimated behaviour during planning. Such behaviour included swelling, disintegration, loss of strength and deformability properties, which is less familiar in the Norwegian environment.

Cheves i Peru - tunneling in challenging inhomogeneous field

Fig. Slake durability testing equipment at IGB - NTNU

Objective

This master thesis shall study material properties of various rock types from the actual project sites, to develop a database of parameters and give input to a methodology for rock testing of various rocks in future projects. The thesis will include:

- Brief review of the geological conditions of the case project(s)
- Review and discuss existing test methodologies for rock properties, including Ethylene Glycol test, swelling tests on intact/ crushed rock, cyclic tests, etc.
- Discuss existing data from undertaken testing with the relevant international testing facilities in Norway, Germany, Italy, Chile and Canada
- Sample and test specimen of the various rock types collected from the case project(s), including standard test suits (UCS, PLT, slake durability, etc.) and mineralogical (XRD test)
- Compile test data in a database
- Develop a flow chart for the test suited for different rock types

Background

During the development of several hydropower projects in South America, challenging rock behaviour has been experienced. This includes disintegration, slaking and swelling of rock mass, as well as weakness zones containing swelling clay. The actual behaviour has differed from the estimated. Studies on the properties of the rock mass might lead to a better understanding, which in turn results in a better a better way to predict these challenges.

A project work carried out prior to the thesis, involved a theoretical study on swelling and slaking of volcanic rocks, as well as laboratory tests on samples from a specific case from Chile. X-ray diffraction showed swelling clay in at least one of the samples, together with a swelling pressure of 1.1 MPa on intact rock disks in oedometer. The same sample had a slake durability of 41.4 %, which is characterized as low. The aim of the thesis is to further assess the rock mechanical properties of the samples, to use in a stability assessment together with the results from the project work. Uniaxial compressive strength will be estimated from the Point Load Index test, and tests will also be conducted to determine E-modulus, Poisson's ratio and density. The results will be used in a stability assessment of the tunnel the samples are gathered from, including analytical analysis and numerical analysis in RS2 and RS3.These results will further be compared with each other, and actual stability in the tunnel.

Figure 1: Intact rock discs prepared for swelling pressure test in oedometer

Figure 2: Rock pieces prepared for slake durability tests

MASTER THESIS

Silje-Elin Skrede

Department of Geo-science and Petroleum

Spring 2017

Stability Assessment Of Water Tunnel Passing Through Swelling And Slaking Rock Mass, Chile

Supervisor:
Krishna K. Panthi
Co-supervisor:
Thomas Schönborn
In cooperation with:
Statkraft

NTNU

PHD THESIS

Chhatra Bahadur Basnet

Department of Geo-science and Petroleum

Spring 2014-2018

Applicability of Unlined/ Shotcrete Lined High Pressure Tunnels for Hydropower Projects in the Himalaya

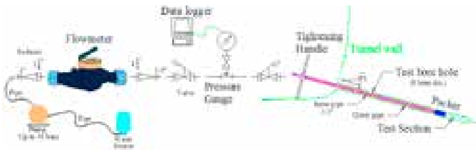
Supervisor:
Krishna K. Panthi

NTNU

Background

The principle of using unlined high pressure tunnels is based on the in situ stress condition. The state-of-the-art in an unlined pressure tunnel is that the minimum principle stress should be greater than the internal water pressure exerted to rock mass from inside the tunnel. This principle has been widely used in the Norwegian rock mass condition. The PhD research is now focused on applicability of this principle in the Himalayan rock mass condition. Stress situation in this region is different from the area of existing unlined pressure tunnels and hence it becomes necessary to find a way forward either for the direct use of existing principle or the modification.

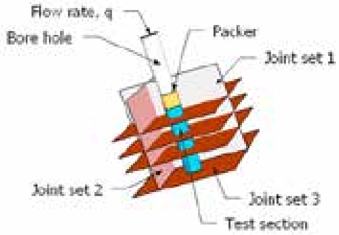
Test output.



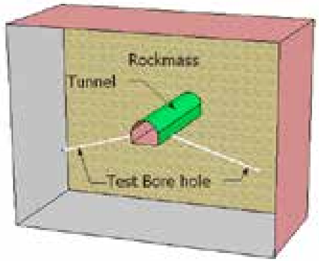
Hydraulic splitting test arrangement in field

Objective

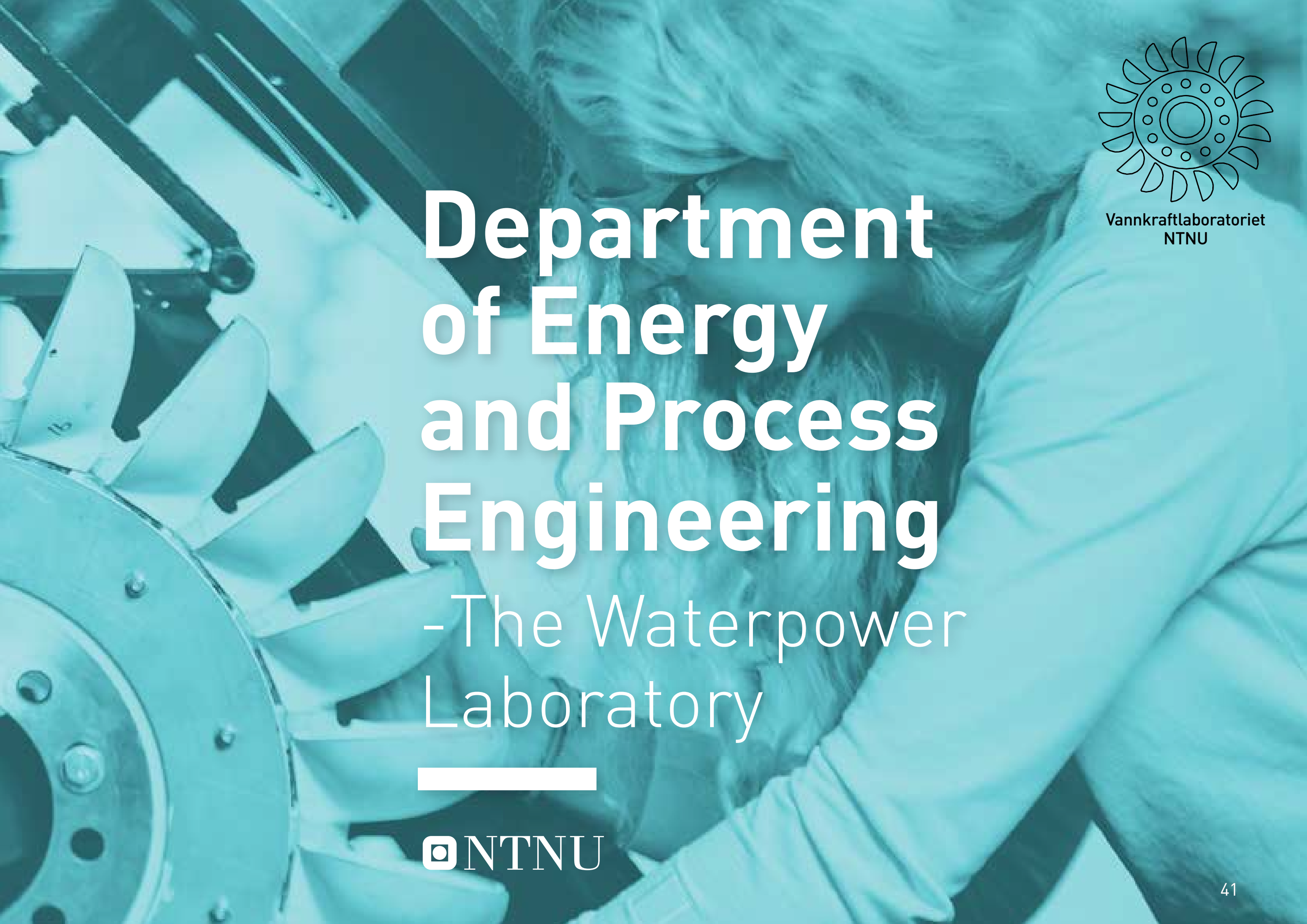
- Carryout hydraulic splitting test in the Himalaya and laboratory test at NTNU
- Numerical modeling of hydraulic splitting in order to assess the state-of-the-art unlined pressure tunnel principle
- Publish the research results in journals and conferences, summarize in a PhD thesis



Testing principle.



Test locations.



Vannkraftlaboratoriet
NTNU

Department of Energy and Process Engineering

-The Waterpower Laboratory

NTNU

MASTER THESIS

Aase Sørum Melaaen

Department of Energy and Process Engineering

Spring 2017

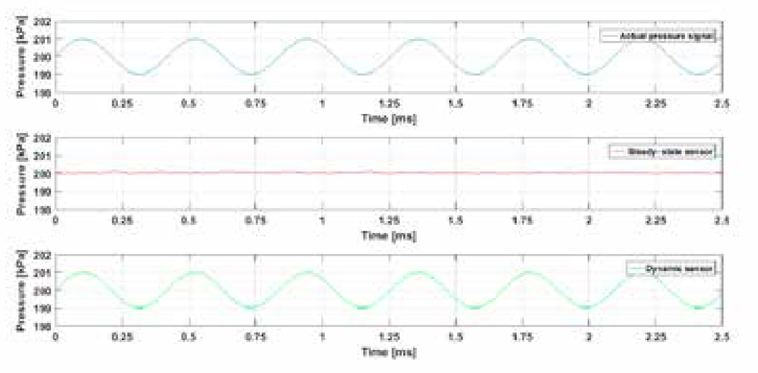
Calibration and Uncertainty Analysis of Pressure Sensors Used for Dynamic Measurements

Supervisor:
Ole Gunnar Dahlhaug

Background

The purpose of this master thesis is to establish a method for dynamic calibration of the pressure sensors in the Waterpower Laboratory. At the moment the pressure sensors are calibrated with steady-state pressure even though the sensors will be used for dynamic measurements. Investigation of the uncertainty in the measurements when using dynamic and steady-state calibration will also be included in this thesis.

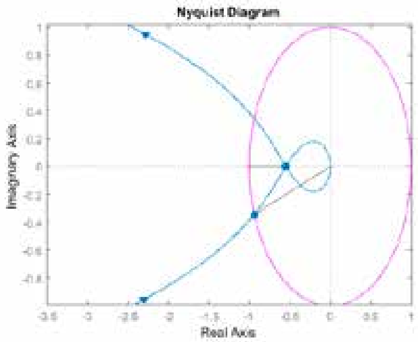
Pressure sensor



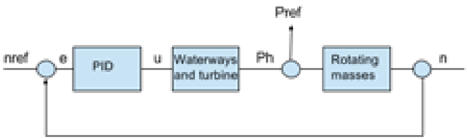
MASTER THESIS

Background and objective

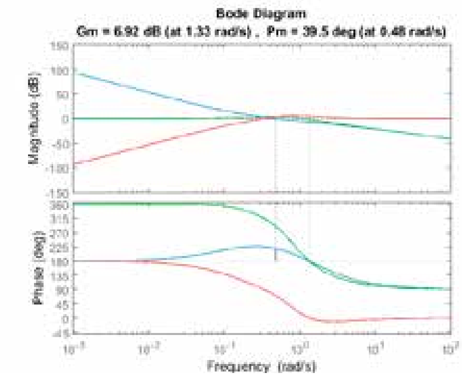
The Nordic TSOs are about to implement new demands for delivery of primary governing, FCR. Power plants may have to undergo qualification tests to participate. The purpose of this master thesis is to develop a numerical model that can be used to simulate the qualification test for FCR delivery for a specified hydro power plant, and determine if the plant can comply with the qualification criteria for different modes of governing and grid stabilisation.



Nyquist plot



Hydro power governor



Bode plot

Anna Holm Aftret

Department of Energy and Process Engineering

Spring 2017

Simulation and Analysis of FCR Operation of a Francis Turbine

Supervisor:
Pål-Tore Storli

NTNU

MASTER THESIS

Eirik Myrvold Hansen

Department of Energy and Process Engineering

Spring 2017

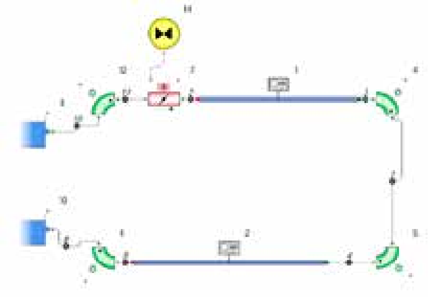
Planning, Start-Up and Testing on a PipeFlow Loop for the Investigation of Transient Characteristics

Supervisor:
Bjørnar Svingen (NTNU)
Co-supervisor:
Morten Kjeldsen (FDB)

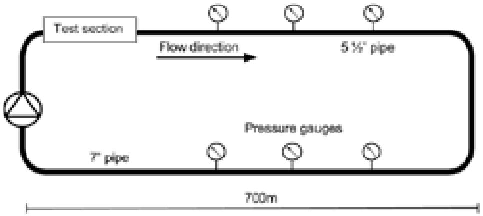
NTNU

Background and objective

A good understanding of transient flows in pipes and ducts is essential to ensure safe operation of hydropower plants. Forced transients can be used actively to improve this understanding by means of frequency response measurements. Experiments involving such transients will be done by Flow Design Bureau AS in a closed flow loop. The purpose of this master thesis is to assist them in their work, considering design, modelling and analysis related aspects.

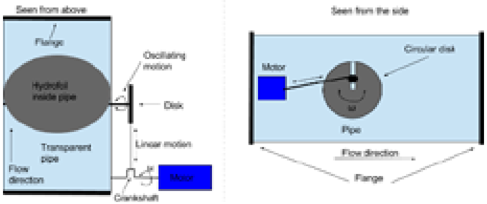


Flowmaster network used for simulations of transients in the flow loop.



System sketch showing the closed flow loop in which the experiments will be performed

Photograph from the test site showing the scale of the flow loop

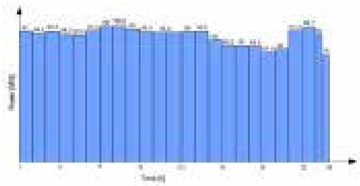


Suggested mechanism for forcing the transients in the system

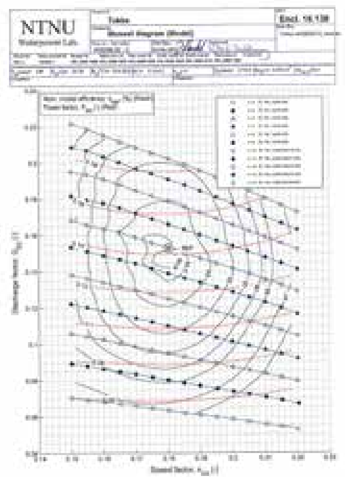
Background and objective

The purpose of this master thesis is to optimize the design of a runner intended for variable speed operation at a specific hydropower plant. In addition, simulations will be performed to determine the hill chart of this runner. The simulated hill chart will be compared to the hill chart of an existing runner, to investigate possible efficiency gain.

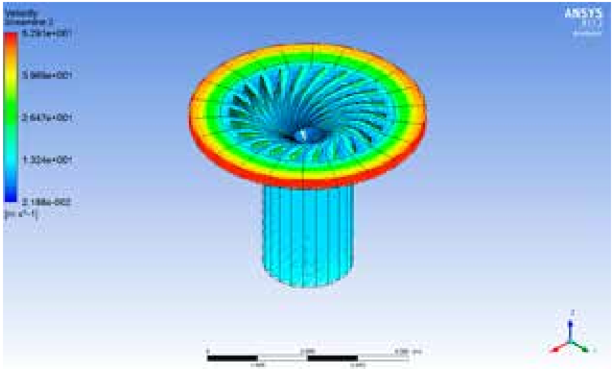
Variable speed hydro turbines can increase the flexibility of hydropower by allowing the turbines to operate more efficiently outside the design point. More flexible hydropower could significantly help the green transition by allowing for more intermittent energies like wind and solar to be included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



This graph shows an average hourly power production for one generator at Tokke power plant.



This picture shows a hill chart for the Tokke model in the Waterpower laboratory



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

MASTER THESIS

Else Høeg Sundfør

Department of Energy and Process Engineering

Spring 2017

Design and Operation of a Francis Turbine with Variable Speed Capabilities

Supervisor:
Pål-Tore Selbo Storli

NTNU

Erik Rognaldsen

Department of Energy and Process Engineering

Spring 2017

Modeling and Simulation of a Hydropower Plant in Scilab

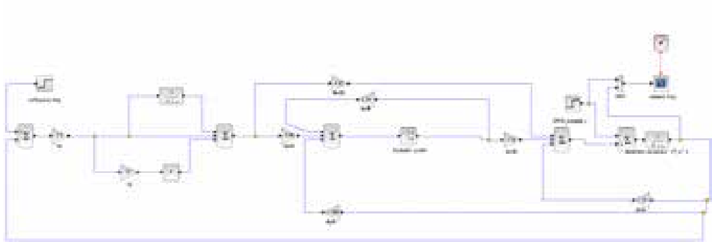
Supervisor:
Bjørnar Svingen

NTNU

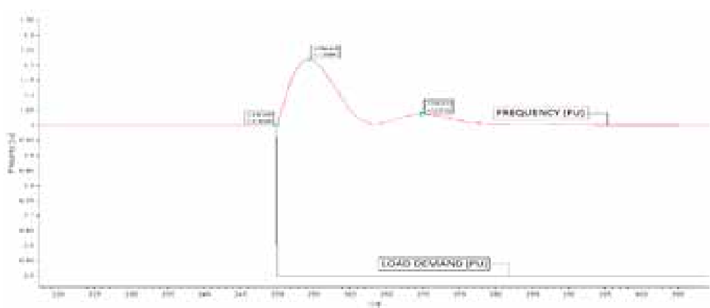
Background and objective

Using block diagrams to describe components in hydropower plants makes it possible to simulate and analyze different power plant designs.
To simulate hydropower plants in both island mode operation and hydropower plants connected to an infinite bus, improvements to the block diagrams with regards to both the hydraulic system and the system design must be made.

An existing model will be expanded with an inlet pipe, surge shaft and dynamic penstock. It is desirable to perform a theoretical deduction of the turbine transfer coefficients by using T. Nielsen's turbine equations. Model verification is done by comparing simulations in Scilab to LVTrans and with experiments done in the laboratory.



The block diagram model made in Scilab. The model utilizes a linearized Francis turbine model controlled with a PI regulator. The penstock is modeled as a rigid watercolumn

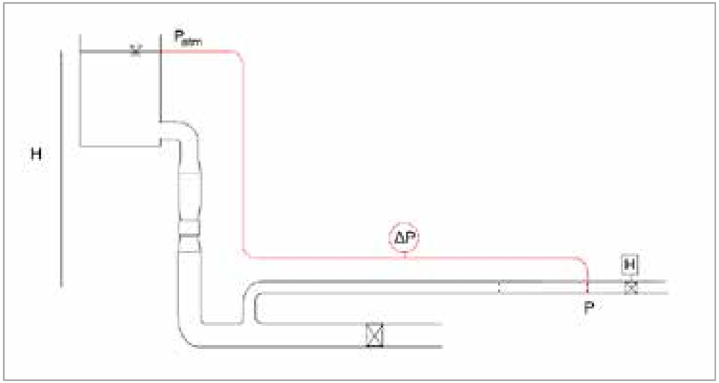


Response in frequency due to a drop in load demand. The graph is from the Scilab model made in the project

Background and objective

Hydraulic efficiency testing is an essential tool to investigate the performance of hydraulic turbines and pumps. The Winther-Kennedy method is a relative efficiency method and is usually preferred when testing the efficiency of low-head turbomachines. This method has shown some inconsistency over time and an alternative method is desired. The pressure-time (Gibson) method may be evaluated as a relative method by using the upper reservoir as one of two measuring sections. This method is simple and cheap to install and could be the alternative.

The objective of this master thesis is to do a relative evaluation of the pressure-time measurements previously performed in the Gibson test rig at the Water Power Laboratory. The relative results will be compared to a numerical MOC code written to simulate the experimental results.



This illustration shows the principle behind relative pressure-time measurements. The atmospheric pressure and a pressure upstream the hydraulic gate is used to calculate the relative, unsteady Gibson flow

MASTER THESIS

Helene Njølstad Dagsvik

Department of Energy and Process Engineering

Fall 2016

Development of the Pressure-Time as a Relative Method

Supervisor:
Michel Cervantes

NTNU

MASTER THESIS

Isak Bergset

Department of Energy and Process Engineering

Spring 2017

Investigations of a Harmonic Oscillatory Flow

Supervisor:
Pål-Tore Selbo Storli

NTNU

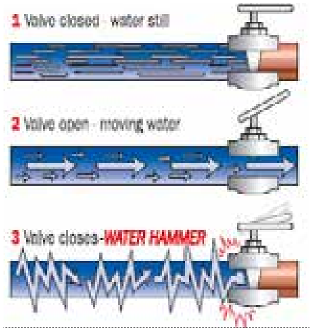
Background and objective

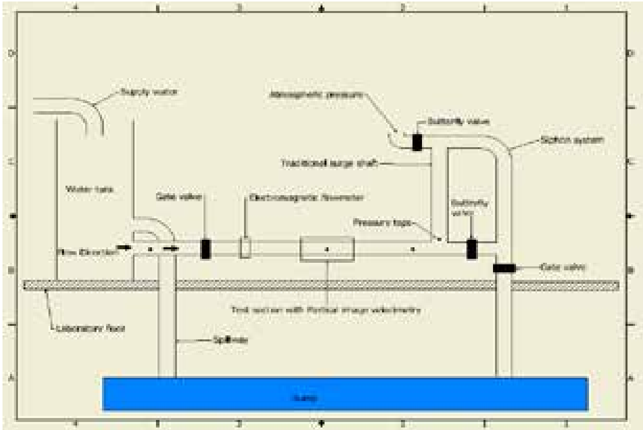
The purpose of this master thesis is to establish a test rig for investigation of transient harmonic flow. Water hammer will be created by rapid valve closure. Additionally, a water column separation in a siphon shaft system will be examined.

Frictional losses in transient flow is not very well described, given the complexity of a fluctuating system. It is thus of great interest for power companies to gain more knowledge about this subject, in order to include this knowledge in their operational strategy.

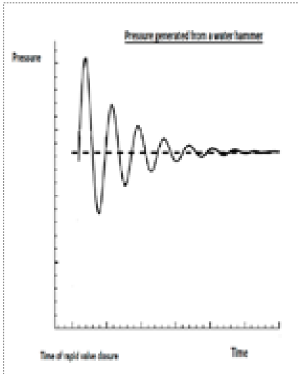
This thesis covers a close study on transient oscillatory losses, where experimental tests are compared with simulation methods.

This picture illustrates the water hammer phenomena





This picture shows a sketch of the final dynamic test rig, including components and instruments



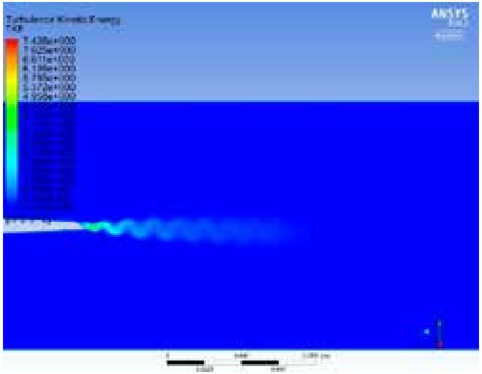
This picture shows the oscillatory pressure wave generated by a water hammer

MASTER THESIS

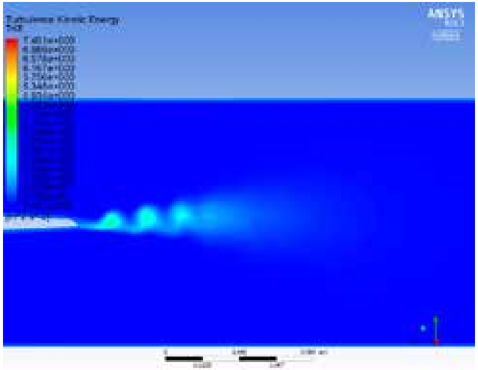
Background

Vortexes may occur when a fluid flows over a solid body. In hydro power plants these vortexes can form when water passes the stay vanes and guide vanes, and will flow into the runner. This can cause high frequency noise and potentially damage the turbine. It is therefore of interest to mitigate vortex shedding and a modified hydrofoil design to achieve this is proposed.

The objective of this master thesis is to perform fluid-structure simulations on the original and the modified hydrofoil to investigate if the modifications have resulted in reduced vortex shedding. The results will be verified by laboratory measurements using PIV.



This picture shows the vortex shedding behind the unmodified hydrofoil



This picture shows the vortex shedding behind the modified hydrofoil

Karoline E Heggebø

Department of Energy and Process Engineering

Spring 2017

FSI Investigation of a Hydrofoil

Supervisor:
Pål-Tore Selbo Storli

NTNU

MASTER THESIS

Sondre Leonhardsen

Department of Energy and Process Engineering

Spring 2017

Numerical Investigation of Flow Field Subject to a Vibrating Structure

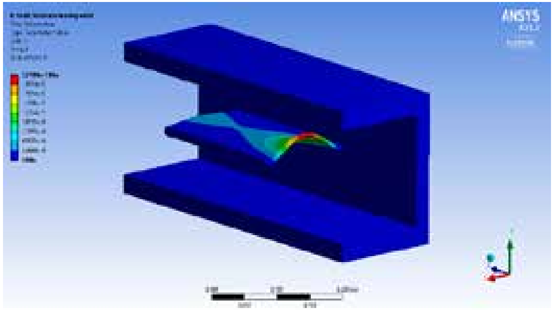
Supervisor:
Ole Gunnar Dahlhaug

NTNU

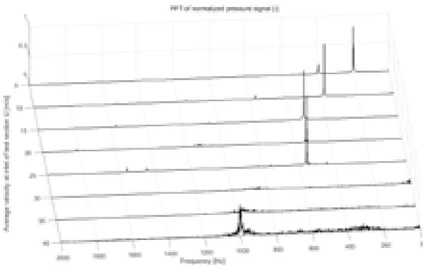
Background and objective

Increased instability in the electrical grid forces hydropower plants to run at off-design conditions. To better understand the unwanted effects present at off-design conditions, a simplified model of a turbine blade, a hydrofoil, is investigated. The goal is to better understand the fluid-structure coupling.

The objective of this thesis will be to design a new hydrofoil, ensuring that the frequencies of the flow do not coincide with the natural frequency of the experimental setup. When a final design has been proposed, a CFD analysis with blade flutter will be performed in order to investigate the fluid-structure coupling. The occurrence of cavitation for higher flow rates will also be investigated.



Total deformation of hydrofoil subject to steady-state pressure from CFD

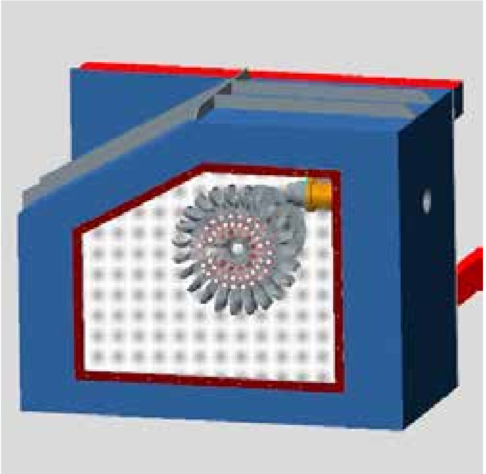


The fast Fourier transform identifying the frequencies of the velocity signals presented to the right

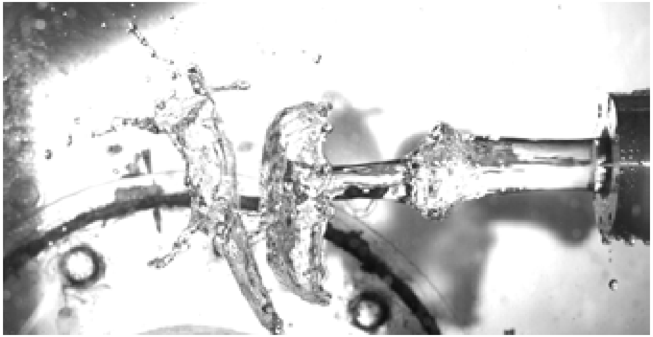
Background and objective

Hydro Power Technologies Inc., (HPT) is a Canadian company that is developing a new Pelton turbine technology. In 2017, HPT will carry out numerical and experimental tests on its pulsating nozzle technology.

The purpose of this master thesis will be to investigate and identify whether the pressure amplitudes from the pulsating nozzle can be dampened by utilizing an accumulator in the hydraulic system.



Nozzle inside the Pelton rig.



Schematics of laboratory test

MASTER THESIS

Thomas Lindseth Bergflødt

Department of Energy and Process Engineering

Spring 2017

Development of an Accumulator System for a Pulsating Pelton Nozzle

Supervisor:
Ole Gunnar Dahlhaug

NTNU

MASTER THESIS

Vegard Fredriksen

Department of Energy and Process Engineering

Spring 2017

Numerical Investigation of Tip Leakage Vortex

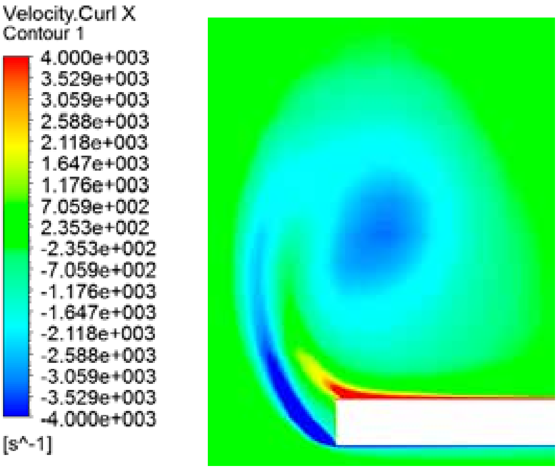
Supervisor:
Michel Cervantes

NTNU

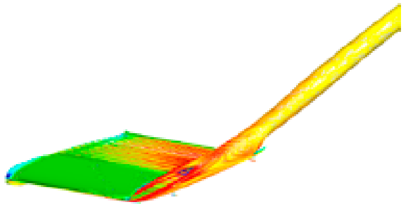
Background

A Tip Leakage Vortex (TLV) sometimes appear in hydraulic machines. Cavitation may develop in the core of the TLV, often leading to severe erosion of the runner blades and the casing.

The objective of this master thesis is to investigate the TLV in a generic test case numerically.



Formation of TLV over the blade tip



Trajectory of the TLV

MASTER THESIS

Andreas Kjerschow

Department of Energy and Process Engineering

Spring 2017

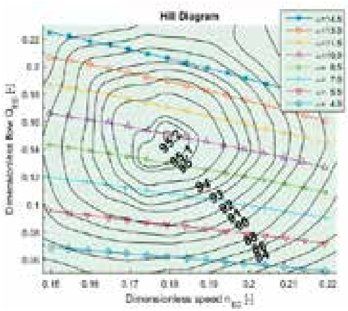
Development of a Francis Turbine Test Rig at Kathmandu University

Supervisor:
Ole Gunnar Dahlhaug

Background

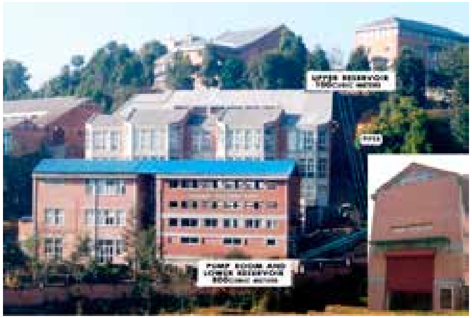
Hydropower plants have been in operation in Nepal since 1911, but most of the knowledge and procedures of building have been imported from foreign countries. That way, a large share of job and revenue opportunities disappear from Nepal. This is why Kathmandu University established a research department and commissioned the Turbine Testing Laboratory in 2011. The laboratory is already in use for research, but still lack a lot of crucial equipment to perform certified model tests in accordance with IEC 60193.

The purpose of this master thesis is to further develop the Turbine Testing Laboratory in Nepal, by proposing suitable measurement sensors, and by producing a full scale logging program for efficiency measurements of Francis model turbines. This will be programmed in LabVIEW.



This picture shows an example of a hill diagram. The data was logged with LabVIEW and processed in MATLAB

This picture shows the Turbine Testing Laboratory at Kathmandu University



This picture shows the Turbine Testing Laboratory with the upper and the lower reservoir

NTNU

Jasmina Pislevikj

Department of Energy and Process Engineering

(Exchange student)
Spring 2017

Numerical and Experimental Investigation of the Unsteady Flow Field Over a Simplified Hydrofoil Plate

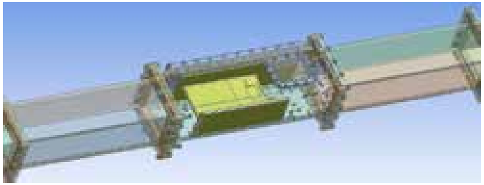
Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Carl Bergan

NTNU

Background and objective

The purpose of this master thesis will be to perform experimental and one-way FSI investigation on a hydrofoil in an unsteady flow field.
Due to varying demand for power, hydro turbines are run with frequent load variations which cause harmful vibrations and has a negative influence on the flow field behavior.

The shape of the trailing edge of the turbine blades influences the vortex shedding behind the blades at particular frequencies. In this work, experimental data will be compared with a numerical investigation, and an analysis of the effect of the shape of the trailing edge on the vortex shedding frequencies will be performed.



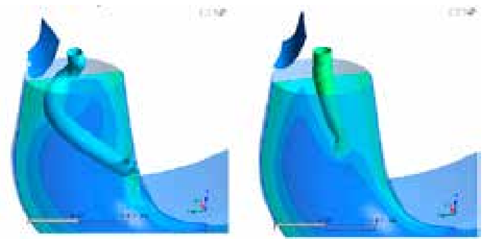
The design model of the simplified hydrofoil in the test rig subjected to FSI simulations

The simplified hydrofoil with mounted transducers for excitation of vibration

Background

The introduction of renewable energy such as wind and solar involves a significant increase of the load variations as well as start/stop cycles for hydraulic turbines to regulate the grid frequency. As a turbine away from the best efficiency point, vortex breakdown may occur in the draft tube, a diffuser found immediately after the runner. Vortex breakdown leads to the formation of a rotating vortex rope (RVR) when a turbine is operated below the best efficiency point for single regulated turbines.

A RVR creates large axial and radial pressure pulsations and thus limits the operating range of the turbine and leads to wear. Mitigation of the RVR has been researched for many years. Air injection is among the most popular methods to decrease the pressure oscillations. Water injection and fins have also been investigated. However, none of these methods have been distinctly successful.



This picture shows the 3D iso pressure surface during part load, without (left) and with (right) jet injection (Resiga 2006,23rd IAHR Symp., 192)

RVR formation during part load operation

RVR formation during full load operation

MASTER THESIS

Livia I. Pitorac

Department of Energy and Process Engineering

Spring 2017

Air Injection in Francis Turbines

Supervisor:
Michel J. Cervantes

NTNU

MASTER THESIS

Mike Mui Bank Ting

Department of Energy and Process Engineering

(Exchange student)

Spring 2017

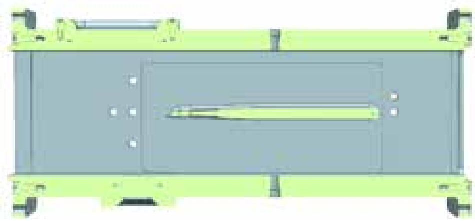
Study of Vortex Shedding from a Vibrating Hydrofoil

Supervisor:
Ole Gunnar Dahlhaug

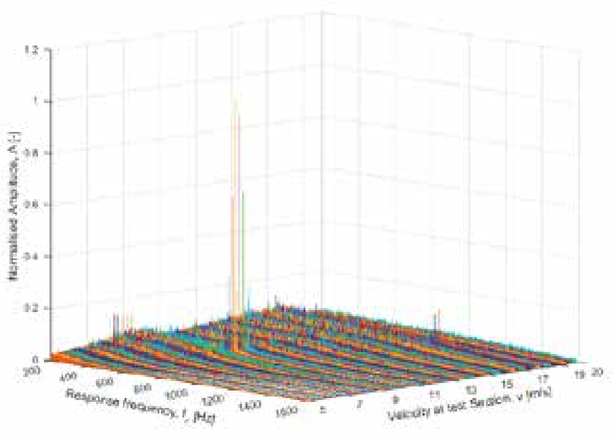
NTNU

Background

The purpose of this master thesis is to measure and analyse the pressure pulsations caused by vortex shedding from a vibrating hydrofoil at various water flow velocities. The hydrofoil is installed in a blade cascade test rig. The measurements are carried out on the hydrofoil both with and without excitation. This will enable the study of the effect of a vibrating hydrofoil on the self-excitation frequencies of the hydrofoil caused by the vortex shedding. The pressure pulsations are measured at the wake of the hydrofoil with quartz sensors.



This picture shows a cross-section of the test section in the blade cascade test rig

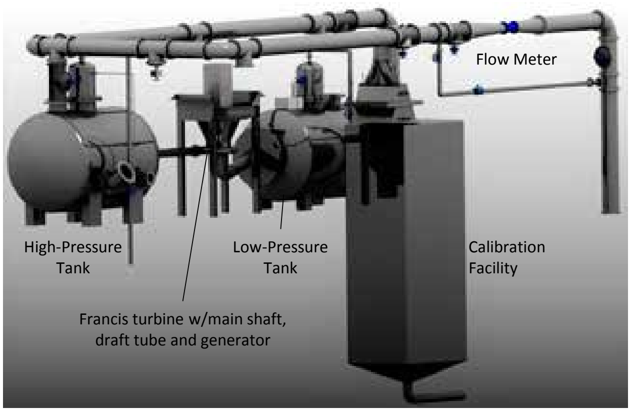


The diagram to the left shows the pressure pulsation frequency at various water flow velocities

Background and objective

Recently, Kathmandu University received a grant from NORAD for a large research program named "Energize Nepal" where one activity is aiming to build a state of the art Francis turbine test rig. NTNU will support the development of this test rig by giving technical support from the Waterpower Laboratory.

The purpose of this master thesis is to design a complete system for the efficiency measurement of Francis turbines in the Turbine Testing Laboratory at Kathmandu University, Nepal. A special focus will be placed on the calibration of measuring devices and the measurement of friction torque and axial load.



The main components of the Francis Turbine Test Rig

Turbine Testing Laboratory

MASTER THESIS

Morten Grefstad

Department of Energy and Process Engineering

Spring 2017

Development of a Francis Turbine test rig at Kathmandu University

Supervisor:
Ole Gunnar Dahlhaug

NTNU

PHD THESIS

Peter Joachim Gogstad

Department of Energy and Process Engineering

2013-2017

Pressure Pulsations in Francis Turbines

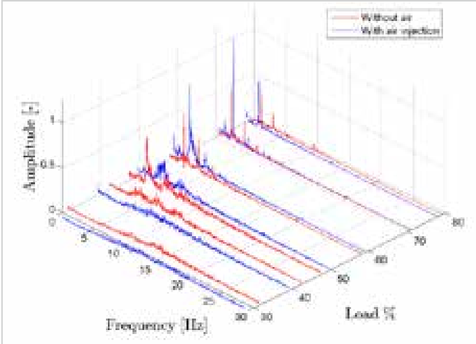
Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Torbjørn K. Nielsen

NTNU

Background

Increased demand for flexibility in the power supply has lead to an increase in operation outside the best efficiency point. Part load operation causes a dramatical changes in the flow regime of the draft tube. For Francis turbines operating at part load, there is a mismatch between swirl generated by the guide vanes and the momentum extracted by the turbine runner. The vortex breakdown that occurs in the draft tube is recognized as the main cause of severe flow instabilities and pressure fluctuations. The consequences are known to be heavy vibrations and noise, which may cause high fatigue load and ultimately lead to mechanical failure. Mitigation of pressure pulsations is considered an important task since it will increase the life time of the turbine.

Different methods for mitigating the vortex rope and the pressure fluctuations, such as air injection, water injection, and runner shaft extension have been investigated. The aim of this thesis is to further investigate these methods to find the best way of mitigating pressure pulsations.



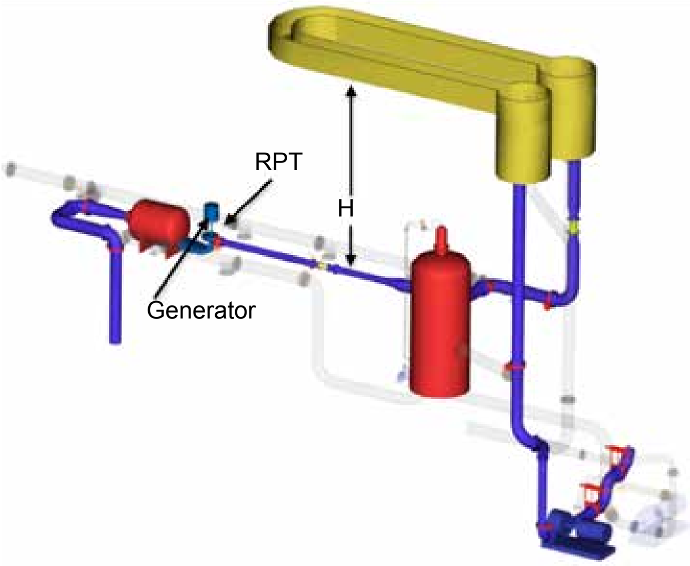
Frequency analysis of a pressure pulsations in a Francis draft tube

Background

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

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

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



Magni Fjørtoft Svarstad

Department of Energy and Process Engineering

2014-2018

Dynamics and Stability in Reversible Pump Turbines

Supervisor:
Torbjørn K. Nielsen

NTNU

PHD THESIS

PHD THESIS

Einar Agnalt

Department of Energy and Process Engineering

2016-2019

High head Francis Turbines

Supervisor:
Ole Gunnar Dahlhaug

NTNU

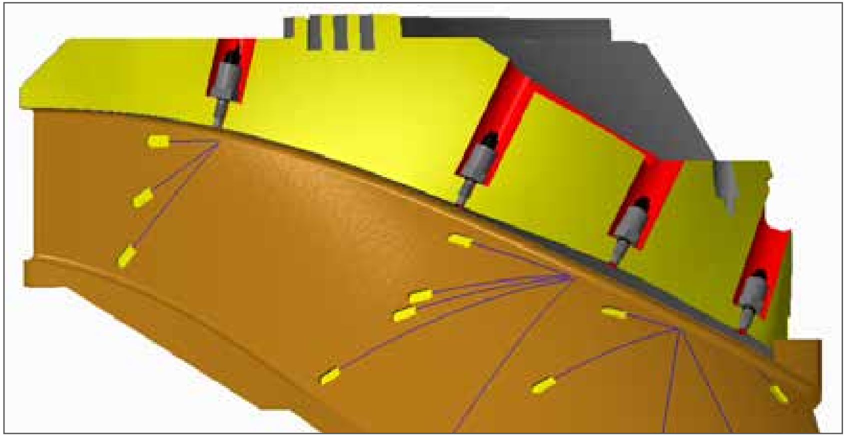
Background

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.

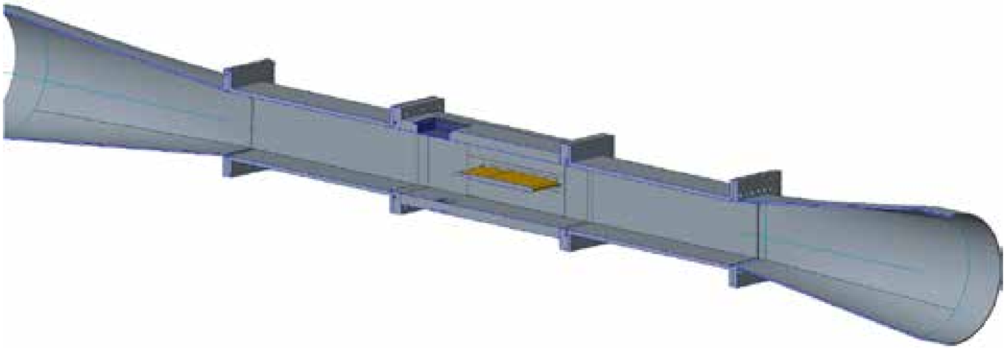


Pressure sensors in the hub of Francis99 model runner

Background

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

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



Carl Bergan

Department of Energy and Process Engineering

2014-2018

Dynamic Response of Francis Turbine Blades

Supervisor:
Ole Gunnar Dahlhaug

NTNU

PHD THESIS

Igor Iliev

Department of Energy and Process Engineering

2016-2019

Design of a High-Head Francis Turbine for Variable Speed Configurations

Supervisor:
Ole Gunnar Dahlhaug
Co-supervisor:
Chirag Trivedi

NTNU

PHD THESIS

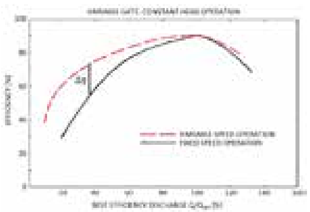
Background

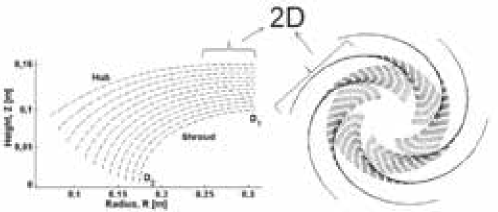
Traditionally speaking, the runners of hydraulic turbines have always been designed to operate at synchronous speed. This is governed by the fact that the generator has a certain number of poles and it has to rotate at a certain synchronous speed in order to produce the required grid frequency. This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

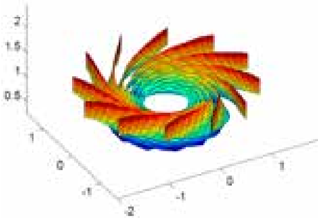
On the other hand, synchronous speed turbines have certain challenges when they are operated at off-design load. Nowadays, turbines are indeed required to operate at either part-load or full-load much more frequently than before. Despite the decreased efficiency at these operating points, there is a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

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

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







Background

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

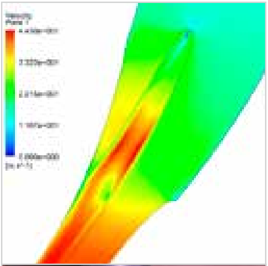
Objectives

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

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

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

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



Flow through a clearance gap of GV cascade rig

Erosion in GV of Jhimruk HP, Nepal

Sailesh Chitrakar

Department of Energy and Process Engineering

2015-2018

Secondary Flow and Sediment Erosion in Francis Turbines

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

NTNU

Chirag Trivedi

Department of Energy and Process Engineering

2014-2017

Fluid Structure Analysis of a Model Francis Turbine

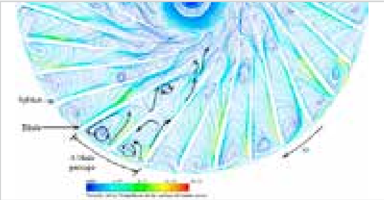
Supervisor:
Ole Gunnar Dahlhaug

NTNU

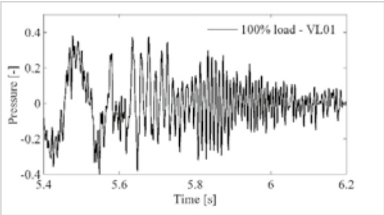
POSST DOC.

Background

Hydraulic turbines are used extensively to stabilize power grids because they can restart rapidly and/or change the power output before the grid collapses completely or black out. In recent years, a dramatic increase in grid-connected wind and solar power has resulted in problems related to power grid stability and reliability. Operating life of the hydraulic turbines has been affected. The runner blades experience more fatigue.



Swirling flow inside the blade passages during run-away operating condition of the model Francis turbine



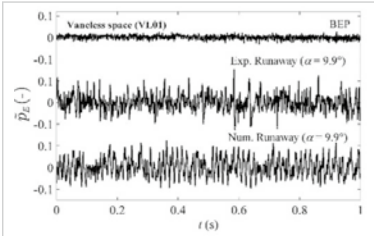
Unsteady pressure variation/pulsations in the vaneless space during transition from steady state full load operating condition to the total load rejection of the model Francis turbine

Current work

Present work is related to the series of Francis-99 workshops, which are organized by NTNU and LTU. I am needed to perform experimental and numerical investigations on the model Francis turbine. The experimental investigations include both, steady state and transient measurements. The work also focuses on fluid structure analysis on the Francis runner. Under this work, two-way coupling simulations will be performed.

The following objectives have been defined:

- CFD and mechanical analysis of the Francis turbine.
- Investigate the fatigue loading on the runner blades.
- Investigate the consequences of rotor stator interactions.
- Investigate the effects of added mass on the runner natural frequency.



Pressure pulsations developed in the vaneless space during the best efficiency operating point (BEP) and runaway condition

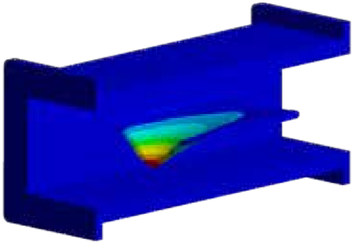
Background

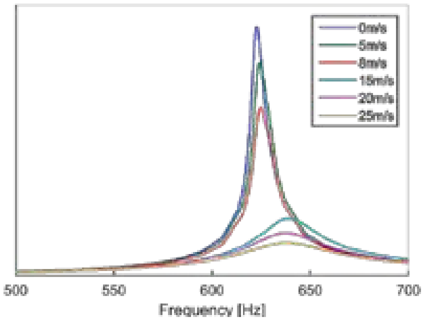
In the last two decades several high head Francis turbines have failed due to rotor-stator interaction (RSI) and resonance issues.

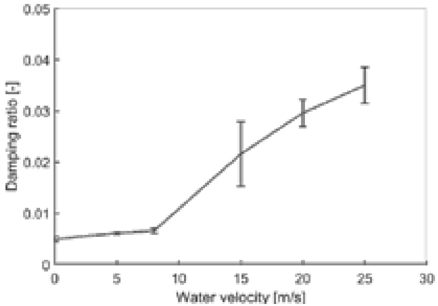
Some have failed after a few hours, others have lasted months, or years, before failing. To prevent such failures, it is important to understand the physics behind these failures.

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

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







Bjørn Winther Solemslie

Department of Energy and Process Engineering

2016-2018

Pressure Pulsations and Fatigue in High Head Francis Turbines

Supervisor:
Ole Gunnar Dahlhaug

NTNU

POST DOC.

INDUSTRIAL PHD

Ingrid K. Vilberg

Department of Energy and Process Engineering

2015-2018

Consequence and Active Use of Free Gas in Hydro Power

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

NTNU

Background

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

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

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

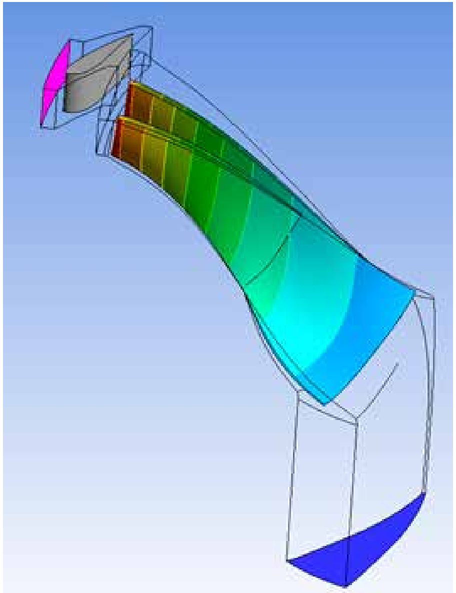
Plexiglass windows are installed on the draft tube of Svorka power plant (25 MW), operated by Statkraft

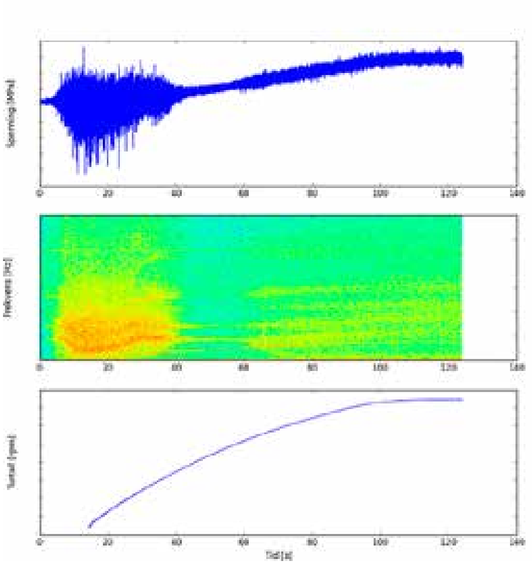
Background

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

Objective

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





Petter T. K. Østby

Department of Energy and Process Engineering

(Associated)

2015-2019

Dynamic Stresses in High Head Francis Turbines

Supervisor:
Bjørn Haugen
Co-supervisor:
Ole Gunnar Dahlhaug

NTNU

INDUSTRIAL PHD

Eirik Volent

Department of Energy and Process Engineering

2016-2019

Solid Particle Erosion in Control Valves

Supervisor:
Ole Gunnar Dahlhaug
Co - supervisor:
Nils Braaten

NTNU

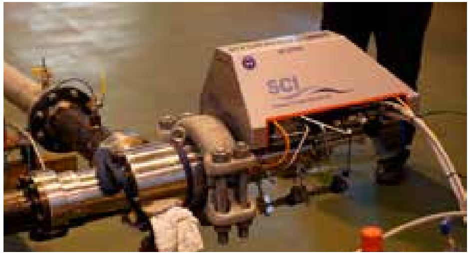
Background

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

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

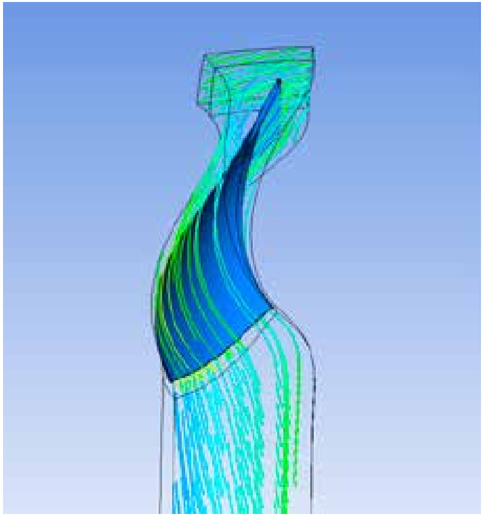
The objective of this industrial PhD is to study particle trajectories and erosion in a laboratory environment, and compare with numerical models. The aim is to develop a method for designing relevant valve geometries and predicting erosion in control valves and nozzles.

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



Background

About 30% of all High Head Francis turbines installed worldwide are located in Norway. The average age of a Norwegian hydro power 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 develop 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

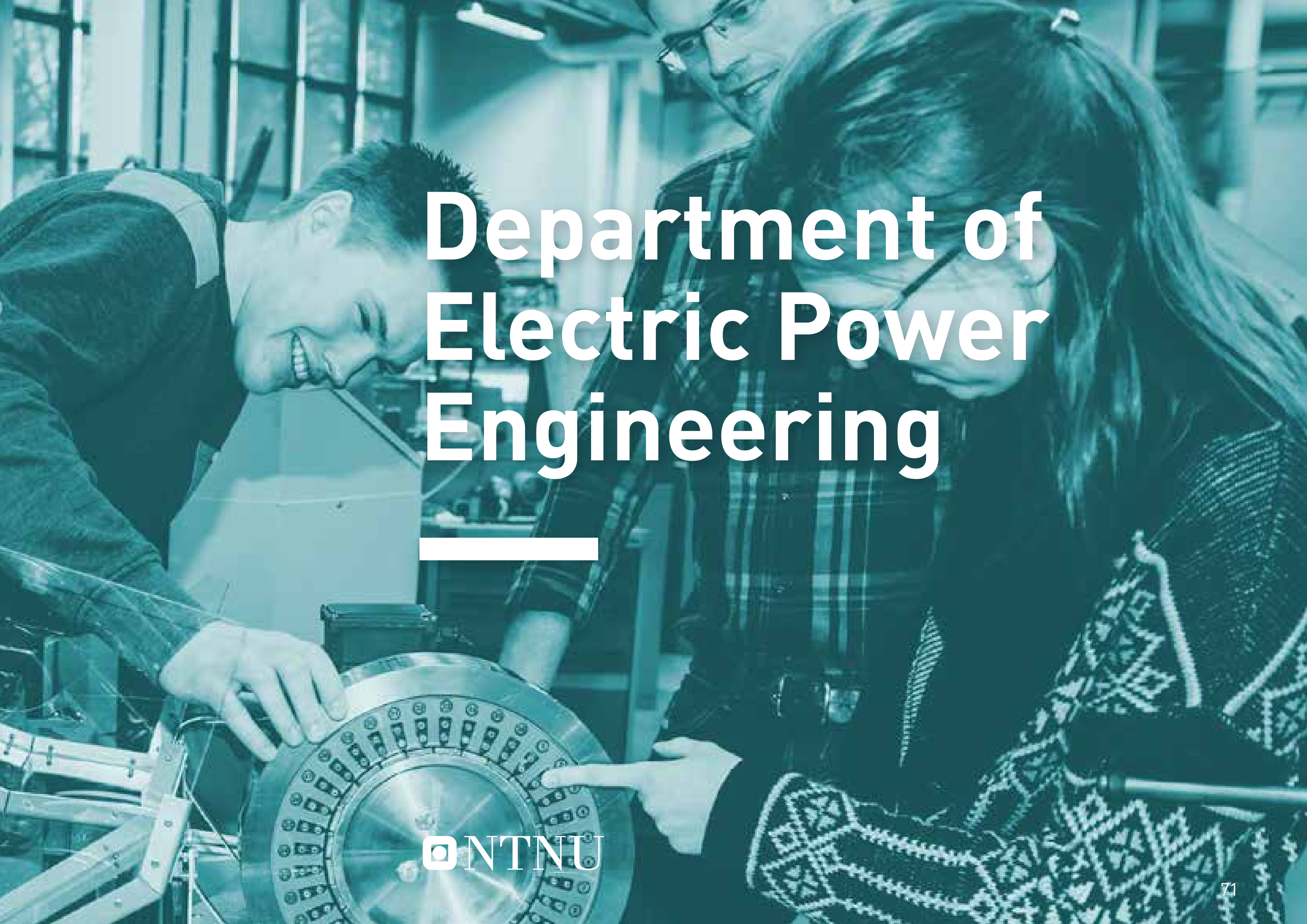
FSI Simulation of Steady and Transient Operation of a High Head Francis Turbine

Supervisor:
Pål-Tore Storli

NTNU

INDUSTRIAL PHD

Department of Electric Power Engineering



NTNU

MASTER THESIS

Erik Hildre Bjørkhaug

Department of Electric Power Engineering

Spring 2017

Adjustable Speed of Synchronous Machines for Hydropower Applications

Supervisor:
Trond Toftevaag

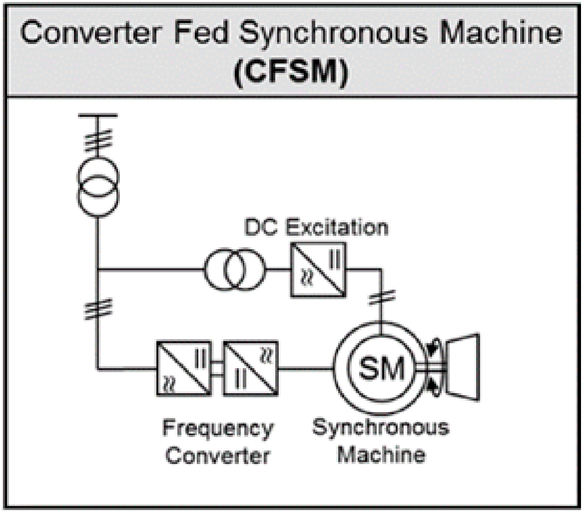
NTNU

Background

Conventional hydro power plants use synchronous machines/generators which are directly connected to the grid, and can only run at a constant speed. Variable speed operation is possible by installing an AC/AC converter between the grid and the machine, which controls the stator frequency of the machine.

With variable speed, the power plants can be operated with higher flexibility, such that the active power can be regulated faster. This will be important in the future power system, as the production from intermittent sources, such as wind and solar, is going to increase. Variable speed operation is most advantageous for pumped-storage plants, since it is the only way of adjusting the power during pumping. In this way, it can also contribute to frequency stability of the grid.

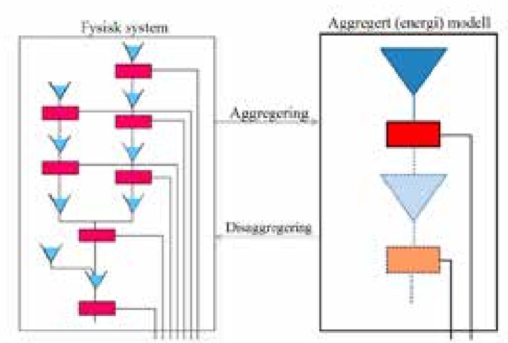
The work includes realisation of a lab set up, where an 8 kVA synchronous machine is fed by a voltage source converter. It is planned to perform tests in both motor and generator mode.



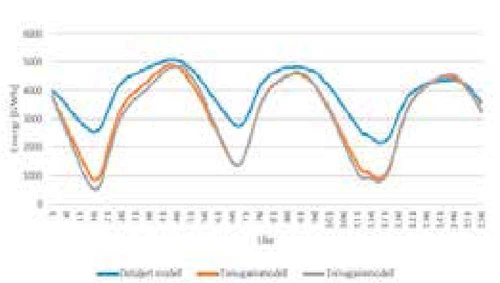
Background

Norway has in the recent decades utilized hydro as an energy resource, and the EMPS model has long been used as a simulation tool of the power prices in the Nordic energy marked. The great number of hydro power plants and reservoirs in the Nordic power system contributes to an increased complexity in the model, and therefore an aggregated representation of the hydro system is used.

The main objective of this master thesis is to study the effects of aggregation models in a SDDP simulation program, named ProdRisk. Aggregation leads to fewer state variables in the SDDP, reduces the computation time drastically and simplifies the EMPS model. Representations of one, two or three reservoirs coupled in parallel and/or series are to be analyzed, together with a step-by-step aggregation method to find a «set-of-rule» system on how to aggregate a given river system.



Figur 1.1: Overgangen mellom et fysisk system til venstre og et aggregrert system til høyre



Figur 5.3: Reservoarnivå for modellene gjennom simuleringsperioden.

MASTER THESIS

Martin Berg-Leirvåg

Department of Electric Power Engineering

Spring 2017

Modelling of Aggregation and Disaggregation

Supervisor:
Magnus Korpås
Co-supervisor:
Birger Mo

NTNU

MASTER THESIS

Vegard Rosenvinge Johansen

Department of Electric Power Engineering

Spring 2017

FEM Calculation of Losses and Heating of the End-Region of the Stator in Large Hydropower Generators

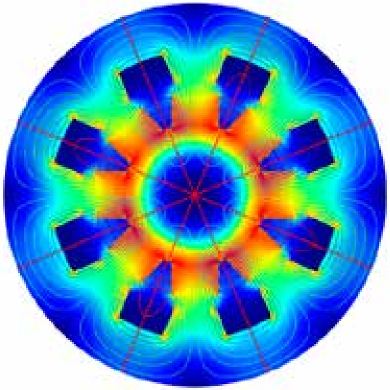
Supervisor:
Arne Nysveen
In cooperation with:
Statkraft and NVKS

NTNU

Background

During the last decades, the need for electrical power has increased in parallel with the rest of society. This demand have led to generators increasing in both size and ratings.

Larger generators are susceptible to an excessive heating in the end winding of the stator. This is due to the stray magnetic field from the rotor.



Objective

Study and research the designs of the synchronous generators that are currently in use in the Norwegian hydropower plants.

Conduct a FEM-Analysis of the generator during different scenarios and study the heat losses in the steel laminations in the end region of the stator.

Design an experimental setup and conduct heat measurements in order to validate the computer simulations.

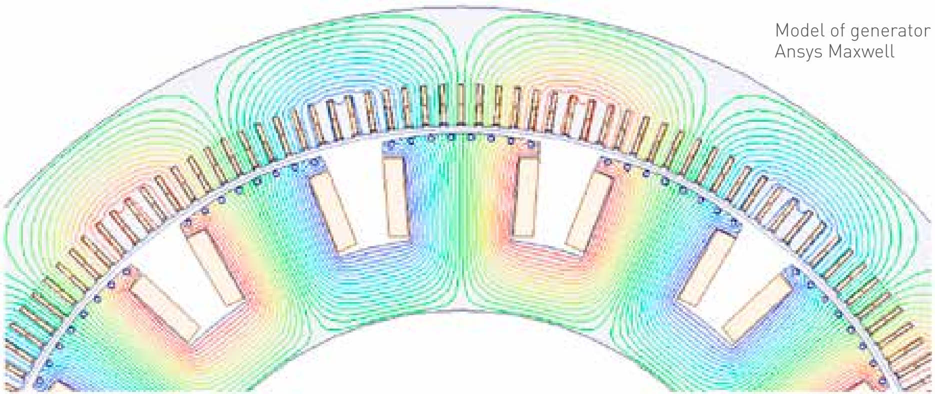
Background

The hydropower generator is a critical component in hydropower stations and is therefore subject to condition monitoring and preventive maintenance strategies to avoid failures of the generator components. In this master thesis short circuit faults in the rotor windings will be studied.

The project was started on the basis of Kalvdalen hydropower plant, where some short circuited windings were discovered in one of the rotor poles. As a result of investigations on the short circuited windings, questions arose about the possibility of on-line monitoring of short circuit faults in the rotor windings, to detect degradation and to get early warnings of potential faults.

Objective

The objective in this thesis is to develop a model of Kalvdalen hydropower generator in Ansys Maxwell and analyze different internal fault conditions in the rotor windings. Further the objective is to propose suitable methods and monitoring techniques for identifying these faults in operating generators.



Model of generator in Ansys Maxwell

MASTER THESIS

Kari Gjerde Jørstad

Department of Electric Power Engineering

Spring 2017

Modeling, Simulation and Detection of Rotor Faults in Hydrogenerators

Supervisor:
Arne Nysveen
Co-supervisor:
Mostafa Valavi

NTNU

MASTER THESIS

Anders Schjølberg

Department of Electric Power Engineering

Spring 2017

Analysis of Different Bidding Methods in the Spot Market

Supervisor:
Magnus Korpås, NTNU
Co-supervisor:
Tellef Larsen, Statkraft
In cooperation with:
Statkraft

NTNU

Background

The nordic power producers deliver plans of how much power they want to produce the next day, and at which price, to Nord Pool every day. These plans are sorted in bid matrices, with the bids as a function of the prices and the hours. This is done 12 to 36 hours before the operation hour. They therefore have to consider the uncertainty in price and inflow.

The simulations in this project are performed in the optimization tool SHOP, developed by Sintef. SHOP gives the opportunity to model river systems of all sizes and complexities. It has a time resolution of one hour, and flexible time horizon. The goal is to maximize the revenues or minimize costs related to fulfilment of load obliga tions. Parameters and restrictions of your plant operation can be the input, and SHOP computes detailed operation plans of both the plants and the reservoirs.

The goal of this project has been to investigate which bidding method that is most profitable. Profitability in this context could include robustness, complexity, simulation time and benefit. In the specialization project the area of analysis was limited to simulation of benefit.

In the master thesis the analysis of benefit will continue. We will also look at the possibility of investigating the impact of stochastic optimization.

Foto:Statkraft

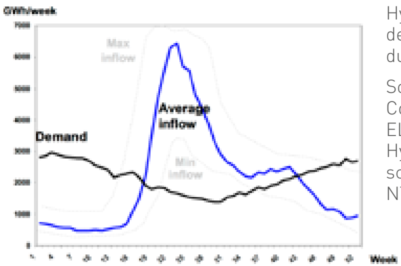
Background

An increase of generated power from intermittent renewable energy sources in Europe will result in a more unpredictable generation schedule and increase the need for reserve power. The master project concern reserve procurement costs and has as goal to extract data from simulations to analyse prices related to reserve requirements for a scenario of Norway 2050. The contribution of the master project will be to provide information for decision takers to utilize the Norwegian hydro resources for a future power system.

SINTEFs EMPS model will be used as simulation tool for the master project. The EMPS model is a power market simulation tool with the goal of maximizing the socioeconomic benefit of a power system based on the water value method.

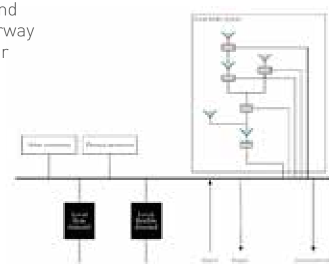
The model is designed for stochastic optimization of the Nordic power system, which includes stochastic handling of hydro inflow. The Norwegian power system connected to Europe will be represented in a simplified way. The data set for Norway is provided by SINTEF and projected towards 2050 by the student. Wind and solar series are added to represent the variation of intermittent generation during the year.

As the model of the power system is represented in a simplified way, more nodes and links can be added to make the model more representative for the real power system. A higher level of detail of the data set may be obtained by including wind and solar series specific for the geographical areas represented by the nodes in the extended model.



Hydro inflow and demand in Norway during one year

Source: Compendium ELK-15 Hydro power scheduling, NTNU



Local area model in the EMPS model

Source: Manual of the EMPS model, SINTEF Energy

MASTER THESIS

Tale Marie Astad Paulshus

Department of Electric Power Engineering

Spring 2017

Analyses of Reserve Procurement Costs Using the EMPS Model. Case Study Norway 2050.

Supervisor:
Hossein Farahmand
Co-supervisor:
Arild Helseth
In cooperation with:
SINTEF Energy

NTNU

MASTER THESIS

Vebjørn Vidarsson Haukaas

Department of Electric Power Engineering

Spring 2017

Dynamic Analysis by Integration of Small Hydro Power Plants

Supervisor:
Kjetil Uhlen
Co-supervisor:
Bjørn Erik Strand.
In cooperation with:
Siemens PTI and Voss Energi

NTNU

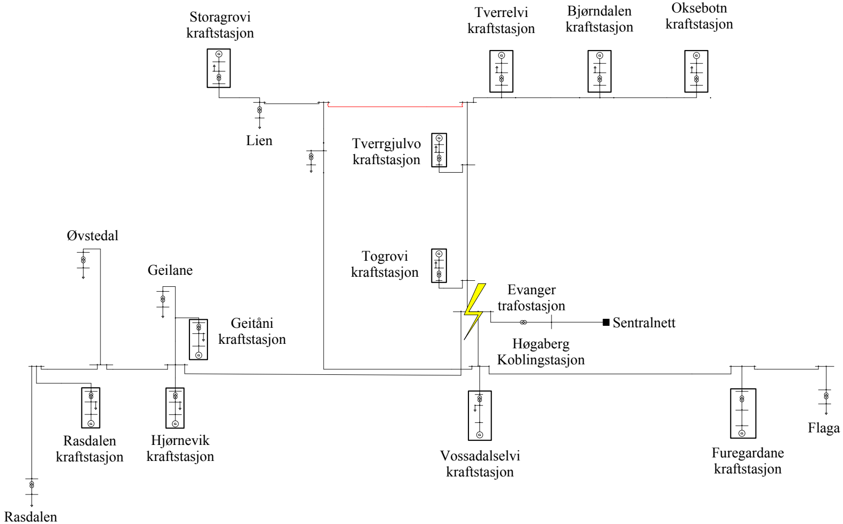
Background

A distribution system with a large amount of small hydro power production can cause stability issues. This thesis will investigate the stability in a distribution system in the municipality of Voss kommune.

As of now there are five hydro power plants connected to the 22 kV grid. In addition, six more power plants are either under planning/building or waiting for licences. My task is to propose requirements for the construction of the new synchronous generators to satisfy stability of the power grid.

The thesis is carried out in close cooperation with Siemens Power Technologies International (PTI) and Voss Energi.

The model of the system is modeled in the simulation tool PSS Sincal provided by Siemens PTI. Some calculations are done in PSS Netomac and Matlab.



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.

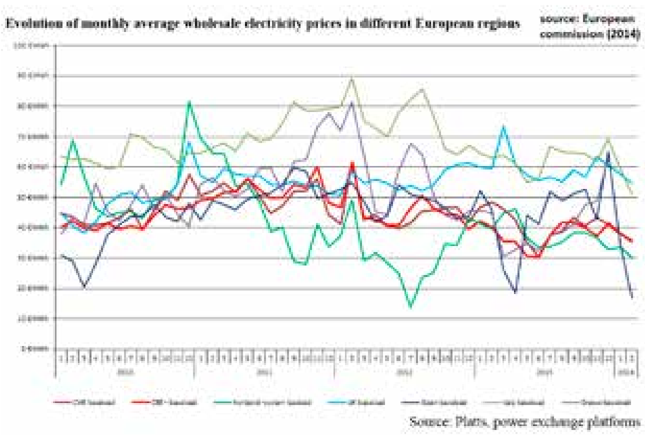
Those ancillary services are the current topic of the ongoing research in this PhD project. The current questions consist of – how do the different services interact; what potential and risk exists for prospective future services; how do market participants realize their goals through offering or calling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

Martin N. Hjelmeland

Department of Electric Power Engineering

2015-2018

Integrating Balancing Markets in Hydropower Scheduling Models

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

Background

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

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

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

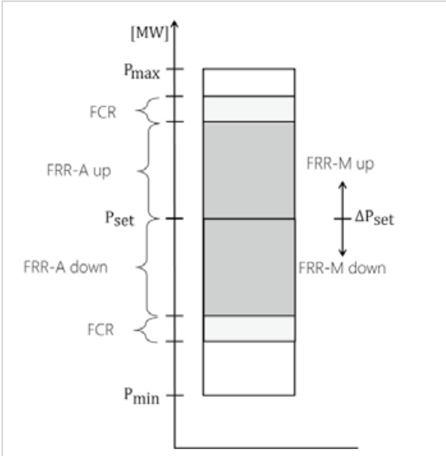


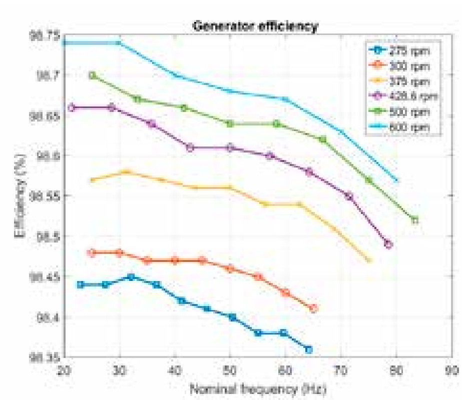
Illustration of different balancing reserves that could be provided from a hydropower station. FCR, FRR-A and FRR-M respectively refers to primary, secondary and tertiary balancing reserves

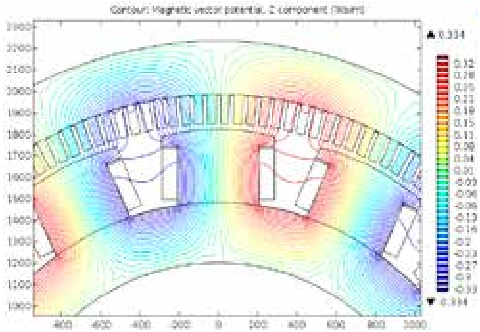
Background

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

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

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





Erlend L. Engevik

Department of electric power engineering

2014 - 2018

Design of Variable Speed Generators for Hydropower Applications

Supervisor:
Arne Nysveen
Co-supervisor:
Robert Nilssen

NTNU

PHD THESIS

Torstein Grav Aakre

Department of electric power engineering

2016-2019

PHD THESIS

Condition Assessment of Generator Insulation

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

NTNU

Background

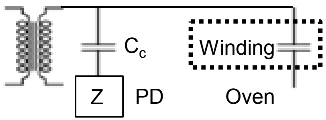
The majority of the Norwegian hydropower generators was installed between 1960 and 1990, and many of these will soon reach the expected lifetime and need refurbishment. One main root cause for failure in hydro generators is generally located to the groundwall insulation. It is therefore important to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



Background: Variable Speed Operation

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

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

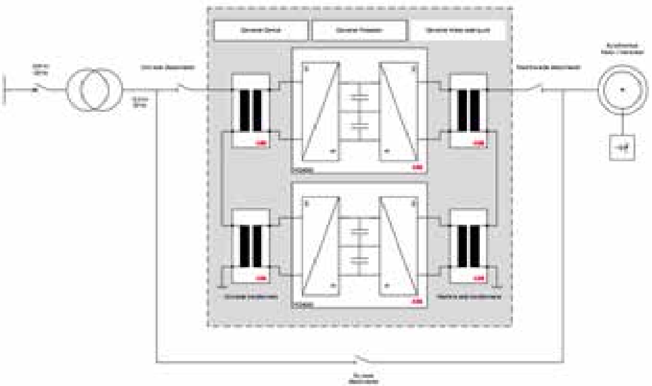
There are two energy conversion systems to realize the variable-speed operation of the hydro power plant: converter-fed synchronous machine (CFSM) and doubly-fed induction machine (DFIM). The focus of this research work is on the CFSM with full-rated converter which offers a higher degree of flexibility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

Background: Vibration Analysis

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

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

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



Mostafa Valavi

Department of Electric Power Engineering

2014-2017

Variable Speed Operation of Hydro Power Plants/ Vibration Analysis of Hydro Generators

Supervisor:
Arne Nysveen

NTNU

POST DOC.

HSN University College of Southeast Norway

MASTER THESIS

Kim Andre Aars

Department of Electrical Engineering, IT and Cybernetics

2015-2017

Simulation of Load and Fault Scenarios in a Hydropower System with Island Grid

Supervisor:
Dietmar Winkler

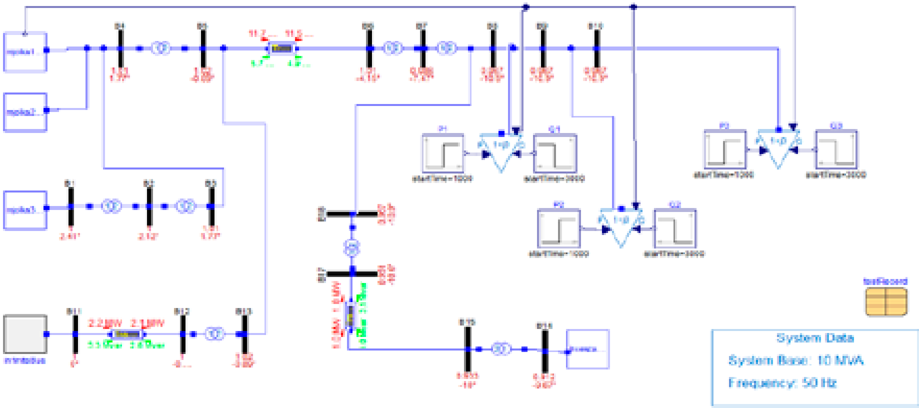
University College of Southeast Norway

Background

The Westfjords area of Iceland is connected to the national power grid with only one transmission line. Due to harsh weather conditions in the area, the reliability of the power supply is poor. The transmission lines have been refurbished, but this is insufficient. To improve the conditions, power production inside the area needs to be increased as the loads are larger than the production. The largest power station in the area is Mjólká; this power station consists of 3 generator units with a capacity of approximately 10 MW. It is therefore of interest to study the characteristics of the units during faults in the transmission line. Dynamic models of the Mjólká generator units and the Westfjords transmission system are implemented using the Modelica modelling language. The loads in the area are represented by three lumped loads.

Scenarios to investigate

- Which sequence of disconnection of the loads gives the quickest stabilization of the voltage and frequency in the islanded system,
- Is it possible to improve voltage and turbine regulation to keep system stable,
- What impact has additional production in the area.



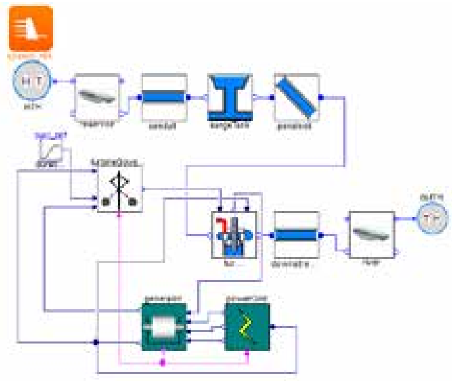
Background and objectives

Sustainable energy development implies meeting the energy needs of the future without jeopardizing the life quality of the planet. To achieve this, sustainable energy sources need to be renewable, and hydropower is one of the most important renewable energy sources.

A hydropower plant, including the water way, the energy transformation to electricity, and the distribution grid, constitutes a complex dynamic system which must be controlled to operate within constraints. A hydropower plant can be divided into subsystems where several of these subsystems are of the same type; hence an object oriented modeling language will greatly simplify the process of setting up a model. As an example, various conduits (intake race, penstock, etc.) essentially vary in geometry, slope, friction, etc. The advantage of an object oriented language is also obvious if we want to study a system of many power plants. The equation based modeling language Modelica supports differential algebraic equations, and is a good choice for modeling hydro power systems. OpenModelica is one of several free simulation tools based on Modelica; Dymola is an example of a commercial tool. Commercial hydropower libraries are available for Dymola, but a simple, free library is also under development for OpenModelica (see Ph.D. study of Liubomyr Vytvytskyi).

Main objectives of this work

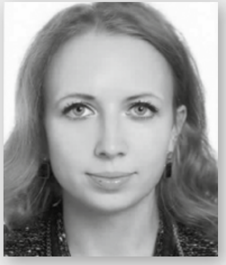
- Overview of hydropower system component
- Development of simple models for each component of the system
- Particular emphasis on mechanistic turbine models (Euler-equations) vs. efficiency look-up tables
- Implementation of standard control system for hydropower system
- Composition of a complete hydropower model
- Collecting hydropower case studies
- Testing complete model (with, without surge tank, mechanistic vs. table-look up turbine model, etc.) for case studies



Screenshot of hydroelectric power system using the commercial Hydro Power Library from Modelon

MASTER THESIS

Valentyna Splavska



Department of Electrical Engineering, IT and Cybernetics

2015 – 2017

Simulation and Control of Hydro Power Plant

Supervisor:
Bernt Lie

University College
of Southeast Norway

MASTER THESIS

Kristian Dønheim Kvam

Department of Electrical Engineering, IT and Cybernetics

2015 – 2017

Improved Flood Management of Lake Toke

Supervisor:
Bernt Lie
Co-supervisor:
Nils-Olav Skeie

HSN University College of Southeast Norway

Background

Operation of hydro power plants according to concession requirements under flooding is challenging. Previous work (Lake Toke) indicated the importance of handling data in a rigorous way, while also using efficient algorithms to solve the constrained optimization problem of finding optimal flood-gate openings. This thesis deals with storing data in a database, refitting parts of the model, integrating the database approach in the controller, and making it possible with simultaneous off-line what-if simulations.

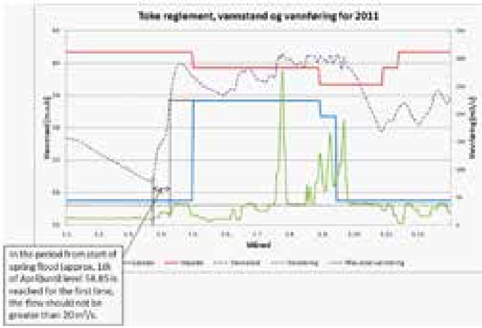


Figure 1- Levels in Lake Toke during 2011. Due to B. Furenes, Skagerak Kraft

The main steps in this work are:

- Development and implementation of a database for storing measurements and on-line computed controller results,
- Refitting/modifying model of Lake Toke to logged data, including data from a major flood in the fall of 2015,
- Integrate the database approach to data storage (as opposed to temporary storage in MATLAB arrays) with advanced flood control algorithm.
- Develop approaches to off-line what-if simulation studies using the database information, which can be carried out while the system is in on-line control where the controller is connected to the same database.
- If there is time, refine the advanced flood controller, and develop a GUI for running the combined on-line control and off-line what-if routines.

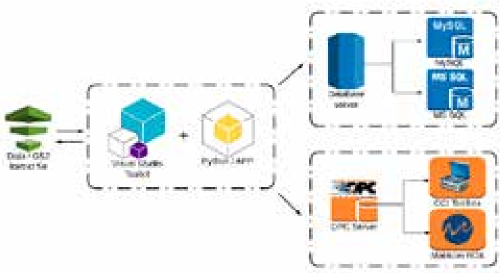
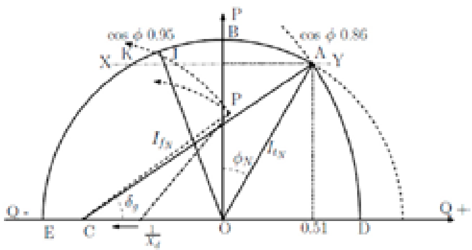


Figure 2 - Diagram of the system

Background and objectives

The Norwegian Network Code FIKS from the Norwegian Transmission System Operator (TSO) Statnett, states that synchronous generators ≥ 1 MVA must connect to the grid with a cosφ ≤0.85 capacitive and ≤ 0.95 inductive. Reactive power can be used to compensate for voltage drops in a power system, but must be provided closer to the demands than real power needs due to transportation limitations of reactive power through the grid. Flexible power factor control on large synchronous generators located close to points of high demand could enhance the voltage stability of a power system Model Predictive Control for voltage control through field excitation of hydroelectric generating units is investigated.



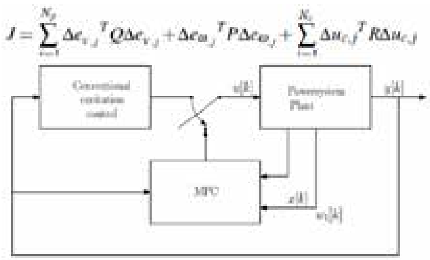
Capabillity diagram of a synchronous generator.

Typical objective criteria:

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

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

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



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

Thomas Øyvang

Process, Energy and Automation Engineering

2014-2018

Improved Functionality of Power Systems Using Model Predictive Control

Supervisor:
Bernt Lie
Co-supervisor:
Gunne Hegglid

HSN University College of Southeast Norway

PHD THESIS

PHD THESIS

Liubomyr Vytvytskyi

Process, Energy and Automation Engineering

2016 – 2019

Dynamics and Control of Integrated Energy Systems

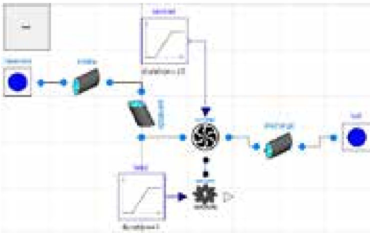
Supervisor:
Bernt Lie
Co-supervisor:
Roshan Sharma

University College of Southeast Norway

Background and objectives

A transition towards more renewable energy sources is currently happening in Europe and all over the world, which 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 energy. In the study of dynamics and control of integrated energy systems, the research focus will be within hydropower systems, but in such a way that the developed methods and tools are relevant for other energy systems, too.

The study aims at developing a set of models relevant for hydropower production from precipitation, via transport through the catchment to dams or rivers (hydrology) , as well as flow in rivers and/or pressure shafts to the turbine, including turbine, various pressure shock damping devices, and possibly including generator. The models will be encoded in a

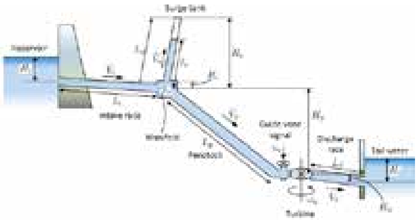


Screen dump of the library components combined in the hydro power system

Modelica library (using OpenModelica as an open-source Modelica-based modelling and simulation environment), and should be able to interact with other libraries "downstream" from the generator, e.g., including transmission, and consumption.

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

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



Schematic of a hydro power system

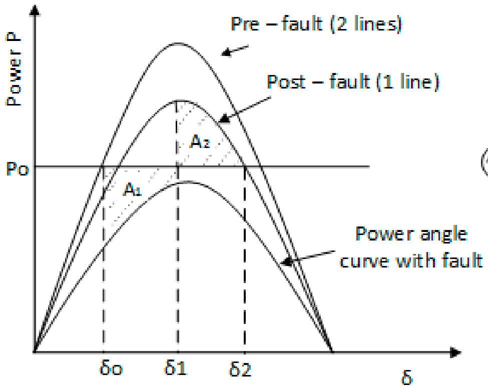
Background and objectives

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

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

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

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



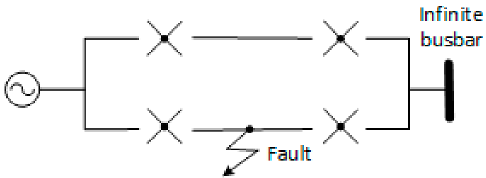


Figure: Fault on oneline of two lines i parallel. Equal-area criterion. Resistance neglected. 1 is critical clearing angle for input power Po (Reference: B. M. Weedy, B. J. Cory, N. Jenkins, J. B. Ekanayeka, G. Strbac, Electrical Power Systems, Fifth edition, 2012, page 289)

Manjula Edirisinghe

Process, Energy and Automation Engineering

2016 – 2020

Transient Stability in High Voltage Power Systems

Supervisor:
Gunne Hegglid
Co-supervisor:
Svein Thore Hagen

University College of Southeast Norway

PHD THESIS

Jonas Kristiansen Nøland

Department of Microsystems

2014– 2018

Remote Controlled Fast-Response Brushless Rotating Exciters for Improved Performance of Hydrogenerators

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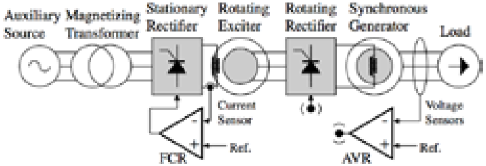
Background

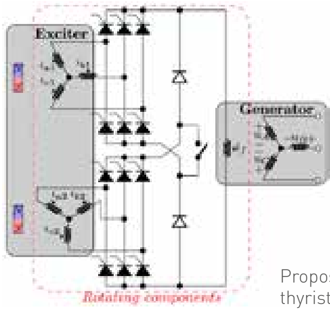
The grid code, FIKS, from the Norwegian Transmission System Operator (TSO), Statnett, states that synchronous generators ≥ 25 MVA, must have a static excitation system. However, an improved brushless excitation system is in operation on some commercial power plants (36MVA, 93.75rpm & 52 MVA, 167.67rpm)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

Preliminary outcomes of the project

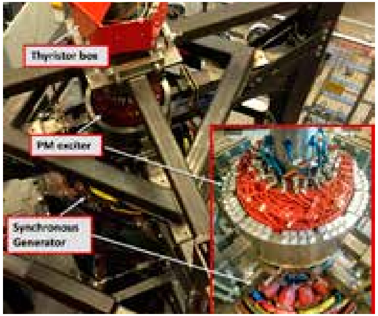
- A new era for large brushless hydro-generators is expected. If remote control is not allowed, a control signal through brushes should be employed instead.
- A six-phase exciter design with a hybrid-mode thyristor interface leads to improved redundancy, better controllability, minimized torque pulsations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



Schematics of commercial brushless system (Voith)



Proposed hydbrid-mode thyristor based interface



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

Objectives of the future work

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

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