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Fakultet for ingeniørvitskap og teknologi
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Referanse HYDROPEAK/ÅK

Hydro power development for peaking and load balancing in a European system with increasing use of non-regulated renewables (HYDROPEAK)

1. Objective

A new operational regime characterized by increasing amounts of non-regulated renewables like wind power (onshore/offshore) and unregulated hydropower, will increase the need for well regulated (balancing) hydropower both for peaking and as backup during periods of low wind or low unregulated inflow. This could have consequences both for the operation of existing hydropower plants, for planning of upgrading/refurbishment of existing plants and for the design new hydropower plants.

The objective of this project is to study how the hydropower system can be used to support increasing amounts of non-regulated renewables and assess what type of adaptions that are needed both in the existing and in the future hydropower system. Some specific project aims are:

i) to identify the changes in load characteristics in the hydro system in the new load scenario
ii) to identify related technical and environmental problems in the hydropower system
iii) to develop methods for mitigating or reducing negative effects
iv) to develop improved methods for optimizing operation of the hydropower system
v) to develop knowledge and methods for planning of upgrading/refurbishment to meet the new demands on the hydropower system
vi) to identify needs for new hydropower development in a new operational regime
vii) to build capacity within selected areas (MSc and PhD students)
viii) to disseminate information and project results in Norway and internationally

2. Frontiers of Knowledge and Technology

The present hydropower system in Norway (and in the Nordic and European hydropower system) has mainly been developed for supply of base load and energy. The Norwegian hydropower system has substantial capacity for producing more peaking power but there are limitations both of technical, legal and environmental type.

With the introduction of large scale, non-regulated renewable energy, e.g. offshore wind parks, it is expected that hydropower will have to provide much more balancing power. Hydropower peaking, and hence rapid variations in flow and reservoir levels, means new challenges to the operation of the hydropower system, and may have adverse effects on machinery, hydraulic structures, dams and tunnels, and also in rivers and reservoirs. Increased demands on hydropower for load balancing in the Nordic and European power system can be met by i) Changed operation of existing system, ii)

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Upgrading and refurbishment of existing system and iii) developing new hydropower with reservoirs and/or pumping capacity

In order to meet the future demands and challenges in a necessary to establish a research program where the various technological challenges (and opportunities) are identified and studied. It is important to have a broad perspective and a balanced approach between the many different topics of importance. Some of the most important tasks have been identified and included in this project proposal. The project proposal is divided into 7 main sub-projects or work-packages, identified as WP1 to WP7.

3. Research tasks

WP1: Scenarios and dissemination

This work-package will contain a number of activities related to the internal and external coordination and dissemination of results. Three main stages can be defined:

i) In the initial phase a series of meetings/workshops will be used to collect and analyze information and generate scenarios for future development of the renewable capacity and its impact on the hydropower system in Norway. Technical, economical and social premises for a 'hydropeaking' regime/market and important benefits and drawbacks will be discussed. The scenarios will be a framework for discussion and coordination in the project. In this stage both national and international experts will be invited to contribute. A report will be produced and presented containing main scenarios and recommendations (9 months).

ii) During the next 2 ½ years the main activity will be to ensure coordination between different work-packages and to maintain contact externally through regular (annual) presentations of progress and results. Cooperation with users through EBL for dissemination of results.

iii) Towards the end of the project a conference will be arranged where main results and findings will be presented for an international audience.

A group of interested users and scientists will participate in the scenario formulations and later meet at regular intervals to contribute by advice and recommendations during the project.

WP2: Hydrology

Anticipating increased demands from non-regulated energy production, management of hydropower reservoirs for peaking or load balancing will require improved inflow prognosis tools for both long term management and short term peaking operation, including flood management. Emphasis is set on improving these tools for short time step simulation and updating from observation data. Important topics will be:

1. Development of algorithms to improve the hourly forecast accuracy, including gridded runoff response simulation. A core approach is to explicitly separate channel hydraulic attenuation from terrain drainage processes, utilizing all available geographic information. Changed climatic conditions will be addressed with particular attention on high winter flows.

2. Analysis of hourly inflow data quality with respect to calibrating and updating gridded response units from hourly data measured at catchment scale. The updating techniques must be improved to utilize locally and remotely measured data, accounting for the data quality.

Future inflow scenarios will be provided for several other work packages, specifically the modelling of power system s in WP 3 and the river ice effects in WP 8.

WP3: Impact of Short Term Effects on Long Term Hydro Scheduling

The increased variability of hydro power caused by the developments described in the initial parts of this proposal is not well represented in the long term scheduling models EOPS (Vansimtap) and EMPS (Samkjøringsmodellen). These models are essential for the long term strategic use of the reservoirs. The limited modelling of short term effects in these models may increasingly lead to incorrect water values and a non-optimal long term use of the reservoirs. With respect to the EMPS model, an upgrade in this respect is already included in another KMB project proposal. Focus is on the representation of short term issues in long term models to ensure better long term decisions. This work package is targeted on the EOPS model, because the actual short term physical issues are primarily of interest for the operators of specific river systems. The basis for this work package will be a version of EOPS (“Simtap-effekt”) that has a daily time step, and which includes an LP-model for the intra-week optimization. Activities in this work package include: i) Taking into account the turbine related costs of rapid variations ii) A better representation of time delays, also for discharge and bypass constraints iii) The representation of new types of environmentally based and more dynamic constraints and iv) Reserve markets

WP4: Pumped storage plants

Reversible pump turbines (RPT) are well suited for load governing and also for grid support regarding frequency and voltage governing. In Norway there are quite a few pump storage plants in operation. They were initially built to store energy from season to season. The change in the marked situation with increasingly difference in price night and day, they are already more active in utilizing both turbine and pump mode of operation. At the European continent, there are several reversible pump turbine plants which operates mainly for grid support, hence helping to stabilize both frequency and voltage. With increased amount of non-governing power will result in an a major change in operation of the Norwegian RPT-plants. Todays RPT plants are not able to meet the challenge of changing between pump- turbine and condenser mode fast enough to meet the demands on the grid. Topics to be investigated are i) Evaluate the demands for change in modes of operations ii) System dynamic evaluation of existing RPT-plants iii) Develop effective systems for altering between pumping and turbining. There are strong links to WP5, WP6 and WP7. Technical consequences and related additional costs of frequent start/stop of hydropower plants, and operation outside optimum (design) levels are studied in the BIP/EBL project 'Verdiskapende vedlikehold innen vannkraft' (Value adding maintenance in power production). A link between HYDROPEAK and the BIP project will be established.

WP5: Frequency and load governing

A more varying power marked as well as a more dominating element of non-governing power, will challenge the existing governing and control systems. The governing stability is initially robust with good stability margins. Wind power will not contribute positive and result in reduced stability margins. The water power system will be exposed to more rapid and more frequent load changes which will result in pressure surges in penstocks and conduit system. Already there have been incidents causing higher loads on equipment and increased sand erosion. In a quite a few occasions, mass oscillations have been the cause for emptying sand traps through the machinery. Topics to be investigated are: i) Evaluate the original dimensional criteria regarding governing stability ii) define new demands under changed operational regime iii) Develop governing and control systems to meet the new challenge iv) System dynamic modelling, pressure transients, mass oscillations and governor stability. There are strong links to WP4, WP6 and WP7.

WP6: Effects of load fluctuation on tunnels and associated hydraulic structures

Transients may destabilize the tunnel roadway and scour deposits from sand traps, resulting in sand transport and turbine damage, and also destabilize entrapped air pockets resulting in blow outs. Pore pressure variations may destabilize the rock mass and trigger rock falls.

Hydropower intakes and tunnels are poorly instrumented and monitored, and hence reliable

data on loss of water, friction losses, air and sediment problems are virtually non-existent. In order to study the hydraulics of tunnel systems it is also necessary to develop reliable monitoring methods. This project will address the following topics:

1. Develop scenarios for hydraulic fluctuations at selected sites. (Closely linked to WP5.)
2. Develop experimental reaches for field monitoring and testing.
3. Analyze the effects of fluctuating loads tunnels and structures.
4. Develop tools for predicting short and long term effects.
5. Develop guidelines and propose mitigation measures.

WP7: Physical effects of load fluctuations in rivers and reservoirs

Fluctuating water levels may destabilize banks along lakes and rivers and trigger slides. Frequent flood waves may increase scouring. In total this may lead to increased sediment and nutrient transport. Also, hydraulic structures like dams, weirs, bridges and revetments etc. will be subjected to frequent fluctuations in hydraulic loadings which may have a destabilizing effect. A general increase in river flow and more frequent floods due to climate change is likely to intensify these problems. The following steps will be carried out:

1. Develop scenarios for hydraulic fluctuations at selected sites. (Closely linked to WP5.)
2. Develop experimental reaches for field monitoring and testing.
3. Analyze the effects of fluctuating loads on bed, banks and structures.
4. Develop tools for predicting short and long term effects on scour and sediment transport.
5. Develop guidelines and propose mitigation measures.

WP8: Ice problems in rivers

Winter conditions in northern rivers can usually be divided into an ice formation period in late autumn/early winter, a stable ice period during the winter months and breakup in spring. Releases of warmer water from reservoirs due to hydro power production will influence the downstream ice regime, usually by reducing static ice formation (stable ice cover) and by increasing dynamic ice formation (frazil and anchor ice). The length of the influenced reach will be dependent on geomorphology, discharge and climate conditions within the river system. A more fluctuating production schedule could have adverse impacts on ice conditions, particularly if periods with low production permits an ice cover to form which is subsequently broken when releases are increased (mechanical ice-breakup). Also, predicted climate change towards a warmer winter climate is expected to create more frequent changes between ice forming periods and mild periods with increased river flow resulting in ice break up and ice-runs, also in unregulated rivers. This could lead to more frequent ice runs which will have negative impacts both on the environment and on technical installation in the river, for example hydro intakes, bridges and revetments.

To cope with these challenges, the following sub-projects are proposed:

i) Analyze ice formation at several regulated study sites with rapid variation in hydro power production over the winter season. Develop models and tools for the assessment of ice formation, ice volume and ice breakup. ii) Study the impacts of ice runs and increased ice production at intakes and downstream of the hydropower outlet, identify critical areas and damage potential iii) Propose mitigation measures to handle adverse ice conditions at intakes and in downstream reaches.

There are strong links to WP2 and WP7.

4. Research approaches, methods

The research will be organized in a number of separate but coordinated projects (Work-packages). In most of the work-packages we will set up a team consisting of one senior researcher at SINTEF, one Professor from NTNU, one PhD student and a number of MSc students. In addition funds are allocated international cooperation, guest researchers, student exchange and participation in international conferences. In this way we ensure both the development of new knowledge/methods and the capacity building which is a key element in a KMB project. The MSc students can give valuable contributions to each work-package within selected areas, and it will also introduce the students to new challenging topics, thereby increasing recruiting to the industry.

Most of the work-packages will be aimed at developing models or methods that can be directly used for planning of operation or for upgrading and further development of the hydropower system. One of the work-packages (WP1) will be used specifically to ensure project coordination internally (between different work-packages) and externally (national/international cooperation).

WP1: Scenarios and dissemination

Coordinated by Eivind Solvang (SINTEF). The main activities planned are: i) An initial series of meetings to collect and analyze information and generate scenarios ii) Report with summary of scenario studies iii) Establishing an international reference group for the project iv) Internal information/coordination meetings (between work-packages) v) Annual dissemination meetings with users (EBL) vi) Final international conference vii) Contributing to teaching (MSc) at NTNU and to continuing education courses (NTNU/ICH)

WP2: Hydrology

Coordinated by Sjur Kolberg(SINTEF). It will support one PhD combined with complementary research activity at SINTEF. PhD supervisor is Knut Alfredsen at NTNU. This activity is closely linked to hydrological modelling activities at SINTEF, to ensure that this project will fit in with ongoing and planned hydrological projects.

WP3: Impact of short term effects on long term hydro scheduling

Coordinated by Gerard Doorman (NTNU). It will support one PhD combined with complementary research activity at SINTEF. PhD. This activity will be closely linked to other modelling projects including other planned KMB projects at SINTEF.

SINTEF Energy Research intends to apply for a BIP within the same area in the autumn of 2008. If this materializes there will be a fruitful synergy between the projects.

WP4: Pumped storage

Coordinated by Torbjørn Nielsen (NTNU). It will support one PhD combined with complementary research at the Hydropower Laboratory (“Vannkraftlaboratoriet”) at NTNU. This activity will be closely linked to other projects at the laboratory, this coordination is ensured since Nielsen is Head of the laboratory.

WP5: Frequency and load governing

Coordinated by Torbjørn Nielsen (NTNU). It will support one PhD combined with complementary research at the Hydropower Laboratory (“Vannkraftlaboratoriet”) at NTNU. This activity is closely linked to other projects at the laboratory, this coordination is ensured since Nielsen is Head of the laboratory.

WP6: Hydraulics in tunnels and water conduits

It will be run as a PhD project at the Norwegian Hydraulic Laboratory (“Vassdragslaboratoriet”) at IVM, NTNU. PhD supervisor is Associate Professor Lars Jenssen at NTNU. The activity will be closely linked to other projects at the laboratory, the coordination is ensured since Jenssen is also Head of the laboratory. This WP will also have contribution from HydroLab, Nepal.

WP7: Hydraulics in rivers and reservoirs

It will be run as a PhD project at the Norwegian Hydraulic Laboratory (“Vassdragslaboratoriet”) at IVM, NTNU. Project leader is Associate Professor Lars Jenssen at NTNU. This activity is closely linked to other projects at the laboratory, the coordination is ensured since Jenssen is also Head of the laboratory. This WP will also have contribution from KTH, Sweden.

WP8: Ice problems in rivers

Coordinated by Knut Alfredsen (NTNU). It will support one PhD combined with complimentary research done at SINTEF. Another PhD student financed from other sources will also be linked to this project. Lars Jenssen is supervisor for the second PhD. This WP will also have contribution from scientists in Canada.

5. Project organization and management

Project manager for the KMB project: Professor Ånund Killingtveit, NTNU
Project leader for each work-package:
WP1: Senior Research Scientist Eivind Solvang, SINTEF Energy Research
WP2: Research Scientist Sjur Kolberg, SINTEF Energy Research
WP3: Professor Gerard Doorman, NTNU Department of Electric Power Engineering
WP4: Professor Torbjørn Nielsen, NTNU Department of Energy and Process Engineering
WP5: Professor Torbjørn Nielsen, NTNU Department of Energy and Process Engineering
WP6: Associate Professor Lars Jenssen, NTNU Department of Hydraulic and Environmental Eng.
WP7: Associate Professor Lars Jenssen, NTNU Department of Hydraulic and Env. Eng.
WP8: Associate Professor Knut Alfredsen, NTNU Department of Hydraulic and Env. Eng.

6. International co-operation

International cooperation will be organized both within each WP and for the total project.
The following international partners have been identified to contribute in the project

Professor Anders Wörman, KTH, Sweden (WP1, WP7,)
Professor Kristjo Daskalov, University of Sofia, Bulgaria (WP1, WP6, WP7,)
Head of Laboratory Meg Biswakarma, HydroLab, Nepal (WP6, WP7)
Professor Terry Prowse, University of Victoria Canada (WP8)
Research Scientist Edward W. Kampema, University of Wyoming, Laramie, USA (WP8)

Contact has been established with the following European power companies:
Verbund, Austria
ENDESA, Spain

Due to time constraint no formal documents regarding cooperation have been produced, but both companies have expressed interest in participating in WP1 for the strategic discussions and for scenario development.

7. Progress plan – milestones

The following general milestones can be identified. More detailed plans and milestones in WPs.

Project acceptance	Dec 2008	Report Scenarios from WP1	Oct 2009
PhD recruiting	Oct 2008	→ Jan 2009	
Start WP1	Jan 2009 ;	Start WP2 – WP8	Jan 2009
First dissemination seminar	Mar 2010;	Second dissemination seminar	Mar 2011
Third dissemination seminar	Mar 2012;	PhD's finished	Dec 2012
International conference	Dec 2012		

8. Cost incurred by each research performing partner

		Sum	2009	2010	2011	2012
SINTEF	Energy research	**8990**	**2723**	**2410**	**2073**	**1785**
	Personal		2200	1800	1500	1400
	Andre kostnader		523	610	573	385
NTNU	Hydraulic and env. Engineering	**12374**	**2426**	**3863**	**3813**	**2271**
	Personal		1610	2572	2572	1610
	Andre kostnader		816	1292	1242	661
	Electric Power Engineering	**2518**	**451**	**803**	**815**	**449**
	Personal		434	754	754	434
	Andre kostnader		18	49	61	15
	Energy and process Engineering	**5086**	**877**	**1656**	**1656**	**897**
	Personal		867	1508	1508	867
	Andre kostnader		10	148	148	30
Other	Intnl. cooperation	**2958**	665	764	764	764
	Sum	**31926**	7142	9497	9122	6166

9. Financial contribution by partners

RENERGI	6 mill NOK pr year
Statkraft	1.5 mill NOK pr year (Confirmed)
Hydro	0.2 mill NOK pr year (Confirmed)
Agder Energi	0.15 mill NOK pr year (confirmed)
Other funding	(0.15 mill NOK/yr) is pending and will be announced later
Sum	**8.0 mill NOK pr year**

PART 2: Exploitation of results

10. Relevance for knowledge-building areas

The projects main objective is to develop new knowledge and increased capacity within topics that are known to be of critical importance for the future development of the energy system in Norway. The project will be of high relevance for the main knowledge-building areas Energy and Petroleum ("*Kompetansefeltets energidel favner kunnskapsområder innen produksjon, transport, handel/omsetning og bruk av energi samt fremstilling av utstyr*") and Civil and Environmental Engineering ("*Utfordringene i kompetanse-feltet er knyttet opp mot bærekraftig planlegging, bygging og drift av samfunnets fysiske infrastruktur, som bygg til alle formål, veianlegg, havner, kraftverk, vannforsyning og avløp, baner, flyplasser og offshore konstruksjoner*").

11. Importance to Norwegian industry

The Norwegian hydropower industry recognizes the importance of adapting the hydropower system to new challenges. The main topics and structure of this proposal has been presented to a number of large companies, including Statkraft, and it has received positive approval and promise of support. This shows that the industry agrees on the relevance and importance of the proposed research.

In addition, this project aims to meet the strong demand for capacity building. The hydropower industry has during the last years repeatedly argued for the need of recruiting more specialists within all the three important sectors of hydropower engineering, civil, electrical and mechanical. This project will help to create more human capacity both as researchers (7 PhDs planned) and MSc in Engineering. A large project like this will give excellent opportunities to improve the recruitment of more students to the hydropower industry.

12. Relevance for call for proposals and programmes

This proposal meets directly the call for proposal where it asks for projects with focus on hydropower and:

- *"Teknisk optimale løsninger for samkjøring av regulerbar og ikke regulerbar kraftproduksjon"*
- *"Driftsmessige og miljømessige konsekvenser av alternativ regulering av kraftproduksjonen"*

All work-packages comply fully with this specification. (We assume that an English translation of the Call for proposals will be provided for the external referees by the Research Council)

13. Environmental impacts

The research project has no environmental impacts, but it will contribute to the development of more environmentally friendly power production by enabling an optimal co-generation between renewables with and without regulation capacity. This KMB will maintain strong links with KMB1 where environmental effects is the main topic. There are a number of sub-projects especially within WP2, WP7 and WP8 which are of interest for both KMB1 and KMB2. The project managers will see that the proper coordination is done.

14. Information and dissemination of results

The project management will have strong focus on information and dissemination of results. The overall information strategy will be developed in WP1. In addition each of the other work-packages will provide dissemination of results through the usual scientific system, by publishing in journals, presentations on conferences and through participation in MSc courses and continuing education courses arranged by NTNU. The scientific publishing in each PhD project will typically consist of one Thesis, 2-4 peer reviewed papers in international journals, and 2-4 publications on scientific conferences. Detailed plans for what and where to publish must be set up in each PhD-project. It can also be expected that each PhD project will attract 2-3 MSc students, often more. Based on this preliminary plan the information and dissemination plan for the project can be summarized to:

8	PhD theses
16-32	Peer-reviewed papers
16-32	Presentations at international conferences
16-24	MSc theses
Several reports	From Scenario studies, from SINTEF research, Data collection reports etc
1	International conference
4	National workshops/seminars
12	Internal (coordination) workshops between WP’s and other KMBs