International Conference on Hydropower for Sustainable Development
Feb 05-07, 2015, Dehradun

HYDROPOWER FOR ENERGY STORAGE AND BALANCING RENEWABLES

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ABSTRACT

Hydropower with reservoirs is the only form of large-scale renewable energy storage in wide commercial use today. Pumped storage hydropower plants (PSP) are designed to lift water to a reservoir at higher elevation when the electricity demand is low or when prices are low, and turbine water to produce electricity when the demand is high and/or prices are high. PSP are often designed with a relative high capacity to operate in turbine or pumping mode only for some hours each. They often use artificial reservoirs with limited capacity of storing water. Environmental impacts of hydropower and pumped storage plants are related to impacts of flooding land to create a reservoir, the barrier effect disturbing the connectivity in the river and impacts on the flow regime and related ecosystem downstream from the dam.

The world-wide installed PSH capacity today adds up to around 130 GW. About 24 GW is added since 2005, and projections indicates installation of as much as 500-600 GW more PSH until 2050.

As of today, Norway has 1250 hydropower stations with in total 30.14 GW of installed capacity, a yearly production of 130 TWh and a storage potential of 84 TWh, which makes up 50 % of the total storage capacity in Europe. In future, the large storage potential existing in Norway could be used to balance fluctuations in power generation of intermittent renewable energy sources in the European power grid. The intention is to extend existing hydropower stations for the use of pumped storage without constructing new dams or reservoirs. These pumped storage hydropower facilities could be used to back-up the electricity production in times with little generation from wind and solar power, and to absorb energy and pump back water when wind and solar power production is high.

This presentation will mainly a case study on large-scale energy storage and balancing services from Norwegian hydropower to Europe, showing the technical potential to develop 20 000 MW of new hydro where about 10 000 MW includes pumping.

INTRODUCTION

Many European countries are increasing the proportion of wind and solar power generation in their electricity supply. This increases the need for energy storage to compensate for the difference between production and consumption, known as balance power. Hydropower with reservoirs is the only form of renewable energy storage in wide commercial use today.

Existing Norwegian hydropower reservoirs have considerable storage capacity that can be exploited for balancing services within the current regulations regarding highest (HRWL) and lowest (LRWL) regulated water levels.

The balance power capacity of Norwegian hydroelectric power stations can be increased by installing larger turbines and generators in some power stations, and by installing (reversible) pump turbines to pump water between two reservoirs. It will be necessary to build new tunnels in parallel to existing ones as well as new power stations in association with existing facilities.

The balance power capacity of hydroelectric power stations depends on how much power can be supplied during periods of shortage and how much power can be absorbed in periods of overproduction. Power can be absorbed if a power station can pump water up to a higher reservoir. In many power stations the capacity of the downstream reservoir will limit the amount of power which can be generated. Pumping at times of the day when the power demand is lowest (e.g. at night) will reduce the capacity restriction effect of the downstream reservoir. Such pumping will also increase the capacity of the upstream reservoir and the periods of power generation can be extended by pumping water back during the part of the day in which the power demand is lowest, to be used at the time when the demand is highest.

Implications for the operational schemes of the affected reservoirs when balancing wind power from the North Sea area are analysed. Based on time series of stage and live storage volume of the upper and lower reservoirs, balancing power on daily basis was simulated on top of the current operation of three existing power plants (Figure 1). The objectives were to compare the current patterns of water level fluctuations to the simulated patterns (season, frequency, rate of change) and to analyse which factors determine how much power can actually be balanced compared to how much is required to be balanced (turbine capacity, free reservoir volumes).This analysis is based on the results from a preliminary case study on large-scale balancing services from Norwegian hydropower (Solvang, Harby & Killingtveit 2012), showing the technical potential to develop 20,000 MW of new hydro where about 10,000 MW includes pumping.

The social acceptance of using Norwegian hydropower reservoirs for large-scale balancing services for Europe are analysed according to how these are expressed by key Norwegian stakeholders. Does this use of Norwegian hydropower have legitimacy, what are the drivers supporting this idea, what are the barriers, and what approaches are necessary to overcome important barriers, are the questions that is addressed. The analysis draws on an analysis of interviews with 22 informants, representing four interest groups, as well as the public authorities concerned. These interests include; energy companies, environmental NGOs, recreational NGOs, as well as the host communities. The interviews performed with the stakeholders focused on the how the idea of Norway as a provider of large-scale balancing services was considered by the different stakeholders in general, and not in relation to concrete projects.

The issue of social acceptance may be understood in several ways. In this report we have chosen to use a broad interpretation which includes environmental and economic aspects, questions of involvement, as well as reflections on the current national framework's ability to take key stakeholder considerations into account. The question of social acceptance is therefore treated as a question of societal acceptance.

The main drivers and barriers for large-scale exploitation of Norwegian hydropower for balancing services for Europe as expressed by the informants are presented according to each stakeholder group.

The timeframe in the current study is set to 2030 and beyond. At the same time it is necessary to pinpoint that the timeframe relevant for several of the key stakeholders is somewhat different. When reflecting upon the question of potential concerning the stakeholders' interests it is important to take into consideration that the question of time should be divided in to short, middle and a long term perspective. On the one hand the NGOs for example address the question of potential by directly referring to the political targets (2020 and 2050). On the other hand the companies (except Statnett who has 2030 as their timeframe) reflect upon the current political uncertainties – both nationally and internationally speaking – concerning political support for further investments in the national and international grid development, as well as for instance the unpredictability related to what is perceived as a time consuming concession process.

This introduction and the following results are taken from the report from a pilot study by Solvang et al (2015).

RESULTS

Existing Norwegian hydropower reservoirs have a large balance power potential. This is illustrated in a preliminary study (Solvang, Harby & Killingtveit 2012) relating to increasing the power output of existing hydroelectric reservoir plants in southern Norway, subject to the constraints of current regulations relating to maximum and minimum regulated water levels (HRWL and LRWL). The main scenario involves twelve new power stations with a combined power output of 11,200 MW. It is envisaged that these power stations would be constructed with new tunnels to an upstream reservoir and to the downstream outflow into a reservoir or to the sea. The power generation outputs in the scenario were chosen mainly so that the water level change in the upper and lower reservoirs does not exceed 13 cm/hour. According to research into the stranding of salmon in rivers, the water level should not sink by more than 13 cm/hour (Harby et al. 2004). Although this is not directly applicable to lakes, this was used as a rule of thumb for acceptable water level reduction in reservoirs.

The output of the 12 power stations in the main scenario can be increased to 18,200 MW without the water level changes in the upper and lower reservoirs exceeding 13 cm/hour. How long the power stations are able to deliver this power output will depend among other things on the current regulations regarding highest and lowest regulated water levels (HRWL and LRWL), as well as what strategies are adopted with regard to pumping in the case of pumped storage power stations (Figure 2). By including more cases in southern Norway in addition to some in northern Norway, it will be possible to increase the output of existing hydroelectric reservoirs by a further 1,800 MW to give a total of 20,000 MW for the whole country.

Drivers for large-scale exploitation of Norwegian hydropower for balancing services for Europe are:

- EU-20-20-20-targets and Roadmap 2050 (European Climate Foundation) – promotion of further development of renewables.
- Balancing services: A way of contributing to a more climate friendly energy system.
- A possibility if biodiversity commitments are taken into account.
- A business and development opportunity is the host municipalities and NGOs are involved at an early stage.
- A possibility if benefits are shared between producers, distributors and host municipalities.

Implications for the operational schemes of the affected reservoirs when balancing wind power from the North Sea area are analysed. Based on time series of stage and live storage volume of the upper and lower reservoirs, balancing power on daily basis was simulated on top of the current operation of three existing power plants. This was assumed to be realised by installing reversible turbines in addition to the existing ones. The objectives were to compare the current patterns of water level fluctuations to the simulated patterns (season, frequency, rate of change) and to analyse which factors determine how much power can actually be balanced compared to how much is required to be balanced (turbine capacity, free reservoir volumes). The characteristics of these patterns may be important when studying environmental consequences of providing balancing power and could serve as parameters related to impacts on the ecosystem.

Two balancing power scenarios were defined; the 7Days-Avg scenario and the Dev-Avg scenario. The 7Days-Avg scenario is based on the 7 day moving average of wind power production assuming that hydropower will compensate short-term fluctuations up to one week. The Dev-Avg scenario assumes that hydropower balances the large fluctuations in wind power production where the number of consecutive days with generation or pumping required, last typically 1 to 2 weeks.

The analysis of the three power plants (reservoir pairs) shows to which extent the current patterns of fluctuations in water volume, water level and surface area in the reservoirs are modified when introducing balancing power operation. In case of the 7Days-Avg scenario these changes affect both the seasonal pattern of the storage volume in the upper and lower reservoirs and introduce short-term fluctuations. The average rates of change in water level are obviously higher than during the current operation (Figure 3), but they are still below the range of critical rates as defined by Halleraker (2003) and Saltveit (2001). The simulation results of the Dev-Avg scenario show the same tendency in terms of water level variations. However, the short-term fluctuations are less frequent and have slightly lower magnitude. The factors limiting the provision of balancing power most are the turbine capacities and the live storage volume of the lower reservoirs.

The analysis shows that water level fluctuations are site-specific. Hence, for the purpose of detailed planning, each case should be studied individually. Water level variations depend on the load, the characteristics of each reservoir pair (live storage volume, steep/gentle bank slope, size of lower reservoir compared to upper one) and the installed capacity. The storage volumes available in the reservoirs are not entirely used for energy storage, since simulation results show that the reservoirs are not often completely filled or emptied in these three cases. Therefore, it would be interesting to analyse scenarios with larger demand for balancing power, i.e. simulate scenarios with more focus on energy storage and balancing than on the current operational regime.

The societal aspects of using Norwegian hydropower reservoirs for large-scale balancing services for Europe are analyzed according to how these are expressed by key Norwegian stakeholders. Does this use of Norwegian hydropower have legitimacy, what are the drivers supporting this idea, what are the barriers, and what approaches are necessary to overcome important barriers, are the questions that is addressed.

Interviews with 22 informants, representing four interest groups, as well as the public authorities concerned were carried out. These interests include; energy companies, environmental NGOs, recreational NGOs, as well as the host communities. The interviews performed with the stakeholders focused on the how the idea of Norway as a provider of large-scale balancing services was considered by the different stakeholders in general, and not in relation to concrete projects. In summary, the interviews showed that:

- All stakeholders supported the idea that Norway could play a role in reducing climate change by offering balancing services from hydropower.
- At the same time there is widespread doubt that this is realistic – at least within the timeframe of 2020, because a range of political clarifications and regulatory frameworks that are considered crucial to proceed with planning for balancing services are presently lacking.
- Despite the overall support of considering Norwegian hydropower as balancing services in a European context, stakeholders agree that the likely contribution will be minor, because of limitations set by environmental values, as well as commercial and financial constraints or uncertainty.
- Even if the barriers concerning environmental, economic and social interest in Norway are possible to overcome, all the stakeholders considered the extent of the Norwegian contribution to cover the need for balancing services in Europe as rather limited.
- Among some of the energy companies, there exist uncertainty about the commercial basis for pumped storage as this depend on that energy prices continue to vary significantly. Some companies question if this will last, especially if the European grid is developed further.
- The most concrete barrier within the 2020 timeframe is the existing grid policy. Statnett's current mandate focuses on national services and currently not on contributing to grids that make it possible for large scale transmission of balancing services to Europe.
- The existing grid policy is also seen as insufficient regarding the distribution of benefits and costs from new cables.

- Representatives from the environmental NGOs stress that Norway must contribute to reduce climate change but at the same time live up to biodiversity commitments.
- Better involvement of stakeholders and local communities is seen as crucial in further planning of balancing services but there are different views on how and who should be responsible for better involvement.
- There is general agreement that host communities must get their share of benefits from production of balancing services, and that the current legislation must be changed to take this into account.
- Balancing services should avoid sites where rivers or smaller downstream reservoirs are affected. Nearby transmission cables is also seen as a prerequisite in choosing suitable projects.

Despite the fact that exploitation of Norwegian hydropower for large-scale balancing services has legitimacy among the stakeholders due to the hope that deliverances of balance power will increase the renewable share of energy production in Europe, this analysis has shown that the barriers identified are several, especially if the timeframe is set within 2020. The main barriers have political, economic, and environmental implications, as for example:

- Lack of political support regarding the future development of hydropower at the national level.
- Perceived risks and uncertainties that such an investment pose, both economically and politically.
- Uncertainty about the commercial basis for pumped storage as this depends on that energy prices continue to vary significantly.
- Uncertainty about further grid development, including the strengthening of the national grid, as well as interconnectors to Europe.
- A barrier if biodiversity commitments are taken into account.
- A barrier if a benefit sharing system is not designed
- A barrier if early involvement does not take place (host municipalities and NGOs).

The risks the stakeholders identify are not just seen as environmental, economic and social concerns per se. In order to overcome the barriers, the stakeholders in unison call for a national political clarifications regarding the energy policy. Despite their different roles and goals, they all agree that Norway lack an updated and integrated energy policy. It is considered as a national political responsibility to decide whether or not Norway de facto should become a large provider of balance power for Europe, and if so, the regulatory framework needs to be adjusted accordingly. Thus, it is important for the Norwegian political decision makers – government and parliament, to clarify whether and on what premises Norway should contribute to the promotion of renewable electricity development in the EU countries. As part of this, a clarification is called for regarding the grid development towards Europe (Statnett's mandate, on how to finance the cables needed, as well as benefit sharing on revenue generated and so forth), as lack of grid capacity is one of the most concrete and immediate barriers to the idea of Norwegian hydropower as a large provider of balance power for Europe.

This article is showing results of a large pilot study, using relatively simple modeling tools and analysis to assess challenges and opportunities for large-scale balancing and energy storage from Norwegian hydropower. For all the studies conducted, there are more advanced options of modeling and analysis using more comprehensive input data and parameters available. A comprehensive use of models and analysis is not possible in a pilot study, but should be part of a research project. The CEDREN research project "HydroBalance" will focus on many of these aspects and some others, bringing more knowledge and a broader perspective around challenges and opportunities for large-scale balancing and energy storage from Norwegian hydropower.

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FIGURES

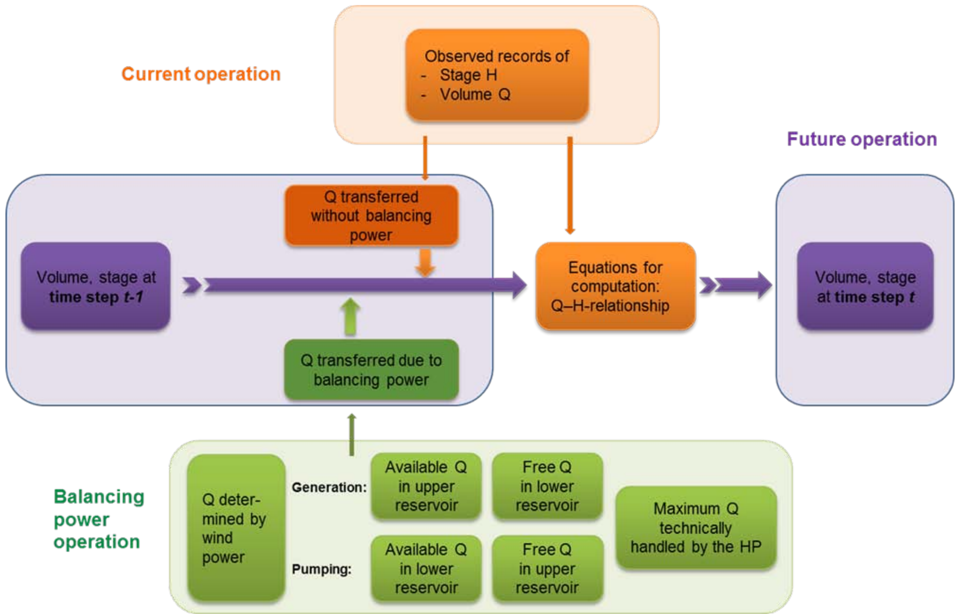

Fig. 1. Schematic model of how the future operation of hydropower plants with increased capacity was calculated

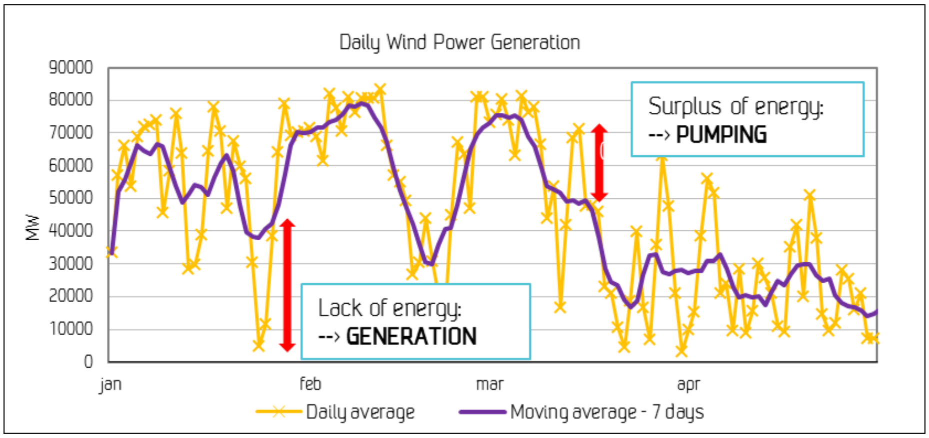

Fig. 2: Example of a period with both surplus and deficit of wind power that leads to pumping and production modes

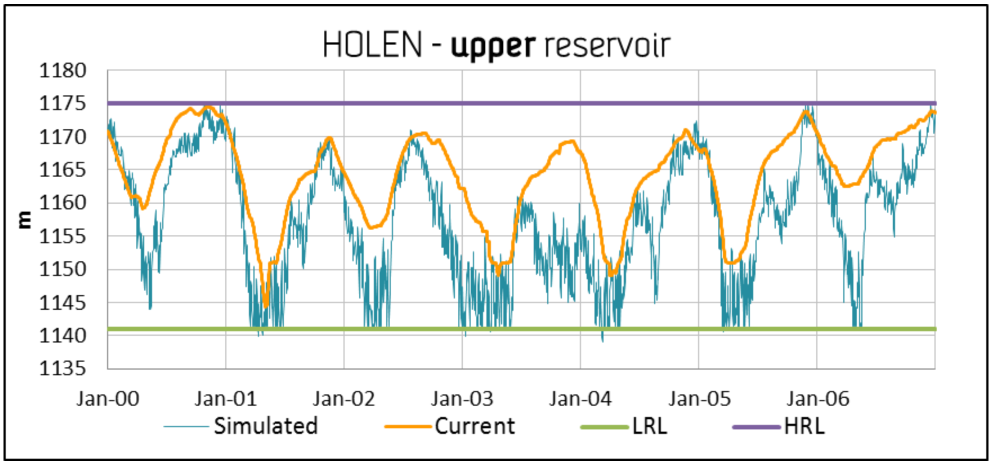

Figure3. An example of water level variations in the upper reservoir for Holen power plant with current (observed) pattern (yellow) and simulated with balancing power with the 7Days-Avg scenarios for the years 2000-2006