Optimization down to the smallest detail: the actual potential of run-of-river hydroelectric power plants

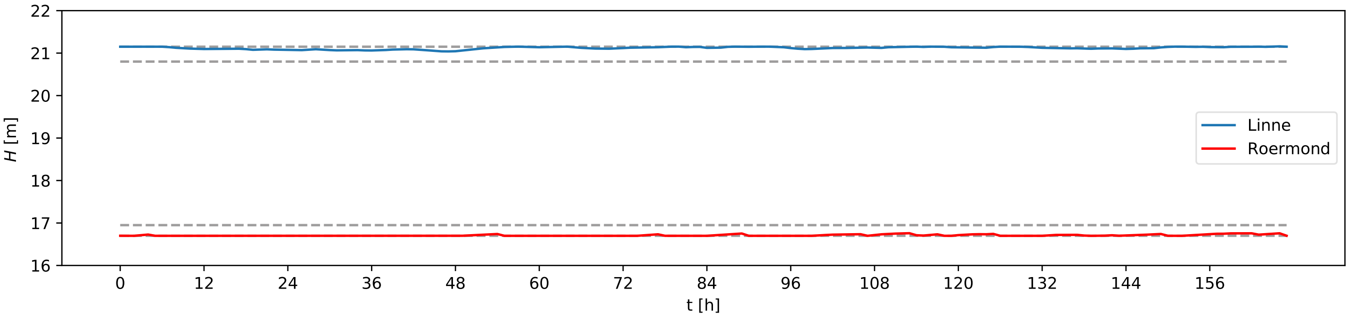
Many run-of-river hydroelectric power plants generate energy only as a byproduct of the water flow when regulating the water level. Often there are only a few centimeters of leeway in this process due to the water level requirements defined by the authorities. For this reason, it has been generally assumed that these few centimeters of variation in the water level are rather pointless in terms of energy generation. Now, in a study conducted at an RWE hydroelectric power station in the Netherlands, KISTERS has demonstrated just how much potential these few centimeters have to generate energy in a sustainable manner for use in the energy market while also achieving ecological benefits for the water used: A new mathematical optimization algorithm offers promising results.

The idea: using water level flexibility to make hydropower a controllable and sustainable source of energy

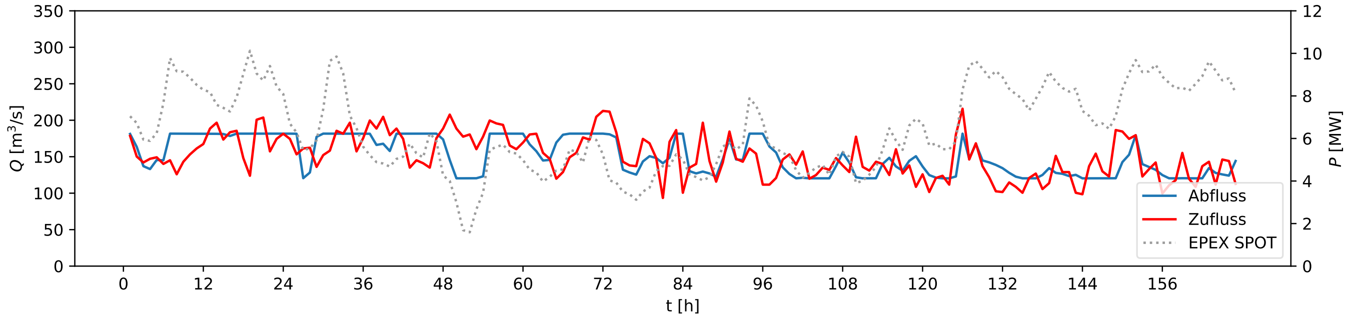
The Linne complex of RWE near the German-Dutch border is designed to regulate the water level of the Meuse river and keep it within a range of 35 cm. This is the stipulation of the Rijkswaterstaat (acting authority of the Dutch Ministry of Infrastructure and Environment), which is responsible for the management of major waterways, including the Meuse, in the Netherlands. The Linne complex consists of a hydropower plant with Kaplan turbines (14 MW capacity) and weirs with up to 4.1 m of head pressure. To minimize harm to the fish in the water that flows through the power plant, the turbines are switched off at low flow and all water is guided via the weirs.

Energy generated by the control of relatively small hydropower stations is generally considered as a byproduct of the water flow and not included in the operational management and planning by water management authorities. The amount of water that flows through the turbines when the water level is regulated by a few centimeters appears insignificantly low. Hydropower, with its excellent storability and controllability, can be used to compensate for bottlenecks and fluctuations in the energy supply when volatile energies such as solar and wind are not readily available or in overabundance. This potential often remains unused. In particular, river sections or basins separated by weirs are an ideal form of controllable energy storage. And the few centimeters allowed in the water level

The Linne complex of RWE near the German-Dutch border



Water level at the weirs in Linne and Roermond over the course of one week



Flow through the weir and the turbine in Linne over one week, energy price (gray-dotted curve) at the EPEX SPOT

fluctuation of a river are calculated for ten or fifteen kilometers of river length, which is a lot of water that can be used for sustainable energy production.

With this in mind KISTERS, the software solution provider for water management and hydrology, came with the following project idea: Can the water level variation of a river be used to make a useful contribution to the green energy transition in terms of sustainability, supply security and grid stability under the given constraints (ecology, water quality, navigability ...) with hydropower plants? Thinking one step further, the question arises whether it would be profitable to sell the energy stored in the backwaters of the upper reaches of the river on the energy market by controlling the hydropower plant so that it generates energy primarily at peak price times. At the beginning of the study, the assumption that there would be a significant amount of storage potential proved somewhat risky as it called into question the general understanding and long-standing practice in the operation of hydropower plants. Nevertheless, no idea should be left unturned when it comes to generating sustainable electricity and creating an effective green energy mix of sun, wind and water. Naturally this goal must not be at the expense of the waters in question, but should at best have a positive effect on ecology, plant management, etc.

Objective and solution: optimization of energy production in harmony with the environment

After initial calculations clearly demonstrated that smaller hydropower stations could be used to generate larger amounts of energy in a controlled manner, the following objectives were defined for the project:

1. Increasing energy production by increasing the difference in upstream and downstream water levels so that turbines generate more energy from the same amount of water
2. Generating energy when it is most needed – when there is no sun or wind - by storing water when energy is not needed. This bridges supply bottlenecks and contributes to grid stability
3. Improve and control conditions for the river ecology by reducing fluctuations in water level and flow

Whether Objectives 1 and 2 (focus on energy generation) and Objective 3 (focus on environment/ecology) are as contradictory as they initially appear should be studied over the course of the project. To this end KISTERS chose to bring suitable partners on board: the Dutch modeling experts from Deltares and the energy company RWE, which provides data from the Linne complex for test purposes.

“After doing the first calculations we were surprised at how many MWh you can potentially gain by changing the water level a few centimeters. That is why we explored the subject in greater detail, calculated many different scenarios and developed a new mathematical optimization algorithm as part of a master’s thesis,” says Dr. Dirk Schwanenberg, Head of Business Unit Water at KISTERS. One important finding: ecology and energy production can go hand in hand. The “maximize energy production” and “improve river ecology” objectives can both be achieved at the same time by carefully merging and/or postponing fluctuations in the river inflow. Using a detailed mathematical optimization algorithm that takes every centimeter of water level variation into account, it is possible to reduce fluctuations while also achieving a higher energy yield. The newly developed optimization algorithm considers both water management constraints such as minimum and maximum water levels, fish migration times and requirements for water temperature and maximum rate of change in river outflow as well as energy economy parameters such as energy prices and energy production forecasts. This generally leads to a very dynamic optimization result that depends on numerous factors. Due to its high accuracy and attention to the smallest changes in the upper reaches of the river, the algorithm can determine exactly how the power plant must be operated to achieve an optimal result both for the environment and for energy generation in observation of all given constraints. The calculation result for the hydropower plant in Linne: by skillfully merging shorter fluctuations in the inflow into longer fluctuations in the outflow and by temporally shifting the fluctuations, two results can be achieved simultaneously (!):

- Fluctuations in the outflow can be reduced by 50 % compared to the inflow, i.e. outflow varies by only half as much.
- At the same time, it is possible to increase energy production by 10-20 % at average flow rates (and in some cases even up to 70 %). This would lead to an approximately 15 % increase in profit if the energy is effectively marketed, generated primarily when prices are high and stored as potential energy in the water when prices are low.

The new algorithm is already integrated into optimization software that is linked with the comprehensive KISTERS Water Software Suite. This means, for example, that the optimization algorithm always works with plausible, quantitatively sufficient and accurate values, because the KISTERS Water Software validates all measurement data from the hydropower plant and the overall system algorithmically before they go through the optimization process. When errors are reported during validation, the software notifies the system operator and activates mechanisms that generate substitute values. The software also visualizes the optimization results in a web browser using clear web-based graphics.

Conclusion & outlook: detailed optimization can benefit both ecology and energy production at the same time

The calculations and results from the pilot study in the Netherlands can be transferred to hydropower plants in Germany and around the world that generate energy as a by-product of regulating flow and water level. Storing energy in the form of backwater and generating energy at favorable times can significantly increase the amount of energy produced and potentially lead to profit gains in the energy market. Just a few centimeters of variation in the water level can be decisive to achieving effective and sustainable energy production. At the same time river ecology can be positively affected by reducing fluctuations in the water level and flow. Factors such as which constraints apply in specific cases, how much leeway exists regarding the water level and what issues need to be observed in terms of ecology and operational management of a body of water must be clarified with the relevant water management authorities.

A detailed and sophisticated mathematical optimization algorithm like the one used in the pilot study can incorporate all of these factors. As a result, the interests of the authorities and those of the power plant operators can be combined with the goal of encouraging a positive outcome for all concerned. The more data that can be incorporated regarding water management, ecological and energy economy constraints and forecasts, the higher the accuracy in planning scenarios and determining probable results and effects. Under favorable conditions, the amount of energy generated from hydropower can be increased by about 10 %. Dr. Schwanenberg sums up the next step: “Together with Deltares, we will continue to refine the algorithm and test it over longer periods of time and at other power plants. We are excited to see the results.” There is also a plan to implement a power plant control system that will automatically optimize hydropower plant operation based on the optimization results.

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