INTERDEPENDENCIES BETWEEN HYDRO STORAGE SYSTEMS AND THE ALLOCATION OF BALANCING RESERVES –
MODEL DEVELPMENT AND APPLICATION TO SWITZERLAND

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Overview

The European electricity system is currently changing at a significant rate. This applies not only to developments in generation capacity and networks but also to arrangements for operating the system on a European level. The planned integration of markets for electricity and ancillary services could lead to overall cost decreases but also to distribution effects (Lorenz and Gerbaulet, 2014). These are caused by heterogeneous generation capacity and renewable expansion. This is especially true for the Alpine region as it represents a central node with large hydro capacities in the European electricity grid.
Due to the large scale of optimization models often used in electricity sector analysis, hydro storage plants are often depicted without interconnections between reservoirs of any kind, implying that hydro storage plants act independent from each other. This assumption reduces the model complexity greatly but because hydro storage plants often consist of many cascaded reservoirs it also induces possible inaccuracies.
The question arises what influence this assumption has on the result of the allocation of balancing power, especially if the studied region is so heavily defined by hydro generation as Switzerland (Schlecht and Weigt, 2014). Additionally hydro storage plants are generally excellent providers of balancing power because of their inherent flexibility (Førsund, 2007).
The aim of this paper is to create an elaborate model of a hydro based electricity sector to take a close look on how the implementation of connections between hydro storages impacts the resulting allocation of balancing reserve as well as computational time. In a second step, the model is applied to Switzerland, which is a particularly complex hydroelectric system.

Method

We develop a bottom-up mixed integer unit-commitment model, including cascaded hydro reservoirs and endogenous allocation of balancing reserve. The ability of a power plant to provide balancing power highly depends on its flexibility. Therefore this model not only include flexibility constrains for conventional power plants but also an elaborate representation of generation states of hydro storage plants, distinguished by turbine/pump technologies. The interconnection of hydro storage plants leads to a more accurate represent of the flexibility of hydro storage generation.
The model considers positive and negative balancing power for secondary and tertiary control. The time frame for balancing power reservation depends on the balancing product which varies in Switzerland from four hours to one week (Swissgrid, 2013). Therefore, the model horizon is 168 hours to include all balancing products in the optimization. To prevent overuse of hydro storage generation due to the limited model horizon, a linearized version of the model is used, before the detailed calculation, to endogenously calculate the storage levels for whole year which are then used to fix start and end values for the reservoir levels in the 168 hour model run.
As inflows are crucial to the implementation of hydro storages, but data is generally not publicly available, they are calculated based on the annual generation and demand of plants of the corresponding reservoir (Balmer et al., 2006). The annual distribution is derived from pardé-coefficients, which are normally used to quantify runoff from precipitation and meltwater (Pfaundler and Zappa, 2006; Weingartner and Aschwanden, 1992) .
To quantify the influence of the addition constrains to the model by the depicted interdependencies between hydro storages the model was run in two scenarios, with and without connection between reservoirs.

Results

The results indicate, that neglecting hydro storage interconnections lead to an overestimation of storage generation and storage demand, as well as an underestimation of tertiary control reserved by hydro storages, while the differences in secondary reserve seem very small in comparison.
This is especially true for positive balancing power, as the capacity of storage plants is preferably used for spot market when independent from each other. The additional constrains, in the form of cascaded reservoirs, can cause them to rather reserve generation capacity rather than congest a lower level reservoir.
The effect on the allocation of negative balancing power is smaller, as hydro storages can use its capacity on the spot market while providing negative balancing power with and without cascaded reservoirs.
On the underlying topic of computational complexity of the formulation, the model presented in this paper runs more than twice as fast when neglecting storage interconnections. The additional computational cost can be enormous, particularly when extending the model to multiple regions or including a transmission grid.

Conclusion

The increasing importance of ancillary services in the European context make it necessary to increase the scope of electricity sector analysis in regard to balancing power. The inclusion of cascaded hydro storages are the next step to achieve an accurate representation in optimization models, especially if countries like Switzerland or Austria are part of that analysis. The results of this paper show that the inclusion of interdependencies of hydro storages can have large impacts on the allocation of balancing reserve as well as generation from hydro storages with the cost of additional computational complexity. The decision on considering cascaded storages should be based on how much the depicted system is defined by hydro storage and what kind of balancing products are included. Additionally, the presented results can give an indication on how results of large scale models are affected when cascaded hydro storages are ignored.

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