INTERACTION BETWEEN SHORT-TERM AND SEASONAL STORAGES IN A PREDOMINANTLY RENEWABLE POWER SYSTEM

Christoph GROISS
Salzburg Netz GmbH – Austria
christoph.groiss@salzburgnetz.at

Walter SCHAFFER
Salzburg Netz GmbH – Austria
walter.schaffer@salzburgnetz.at

Wolfgang GAWLIK
TU Wien - Austria
wolfgang.gawlik@tuwien.ac.at

ABSTRACT

This paper deals with a future power system with a high share of renewable generation. Volatile sources like wind and solar power require short term balancing as well as seasonal balancing to cover the electricity demand. The focus of this paper is the interaction between short term storages (like pumped storage hydroelectricity and battery storages) with long term storages (like seasonal hydro storage and power-to-gas alternatives). The results of an optimisation system are presented, which show that additional long term storages are no competitor to existing pumped hydro storages. Instead the operating hours of short term storages will increase.

INTRODUCTION

Currently the annual electricity consumption in Austria is about 70 TWh with a share of renewable generation of about 70% [3]. The annual amount of hydropower generation is about 40 TWh. The increasing amount of wind and photovoltaic currently accounts for more than 5 TWh annual generation. [3]

In [1] the scenario of a predominantly renewable electricity supply for Austria is covered. The goal in [1] is an optimization from a technical perspective of the future further expansion of renewable generation as well as operation strategies (for power plants, storages) to maximise the share of renewable power supply.

In this paper the question how storage systems will be operated in a nearly 100% renewable energy system is covered. In Austria the existing capacities of pumped-storage hydroelectricity (PSH), decentralized storage (like stationary battery storages, electric vehicles) as well as future long term storages like power-to-gas solutions are analysed. This paper focusses on the resulting operation strategies for decentralized short term storages.

OPTIMISATION MODEL

In [1] an optimisation model was built, with the goal to maximise the share of renewable generation to cover the demand of electricity. The linear model optimised the installed renewable generation power as well as the operation of the power plants, storages and curtailment with the constraint of covering the demand at all times and to stay within the limits of each asset (e.g. high voltage lines).

To calculate the fluctuating power infeed of the volatile sources like hydropower, wind power and photovoltaics, historic profiles of precipitation/runoff, wind speed and solar radiation are used. These profiles are available over a 15 year timespan (1994 to 2008) in a time resolution of 1 hour. [2]

The optimisation model ran for different scenarios and constraints (for example “development of consumption”, “grid expansion”, “use of curtailment”, “installed power of fossil generation”, “import/export with neighbouring countries”, etc.). In this paper only the reference scenario with different variants of installed storages is discussed. In this specific future scenario a 25% load increase is assumed as well as an expansion of hydropower to the existing potentials. Figure 1 shows the results of the optimisation model.

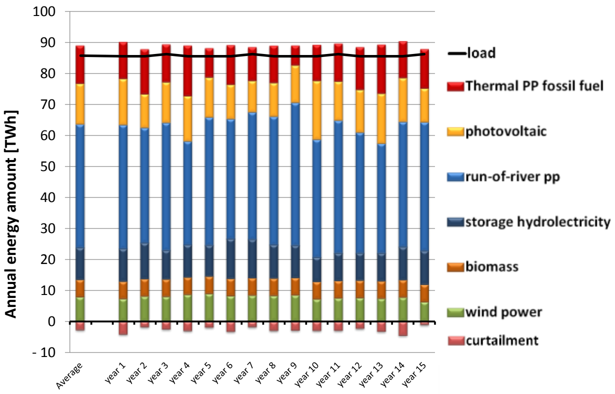

Figure 1: optimisation results - mix of generation to maximise the share of renewables [1]

The black line in Figure 1 shows the annual consumption which is covered by the different generation sources. The generation surplus is exactly the amount of curtailment (see negative y-axes). The red bar shows generation of thermal power plants using fossil fuels, which is minimised. The share of fossil generation is about 14% in average. [1]

In Figure 1 only the generation of storage hydroelectricity with natural inflow is shown. The operation of storages is not visible in this diagram because only primary generation and demand are shown. The operation of storages will be discussed in the next chapters.

PUMPED STORAGE HYDROELECTRICITY IN AUSTRIA

Within the optimisation model all existing and planned (pumped) storage hydroelectricity power plants in Austria are modelled. Figure 2 shows the sum of duration curves of these storages.

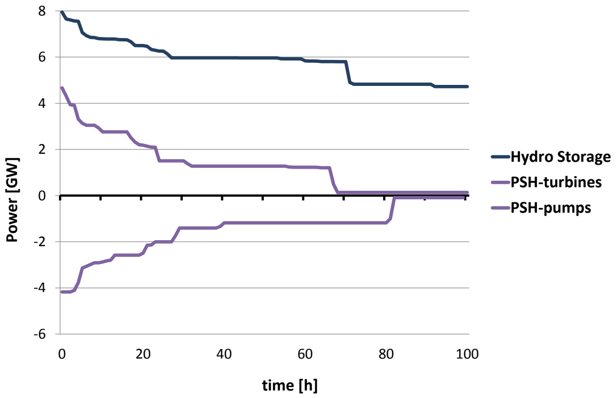

Figure 2: Duration curve of (pumped) storage hydroelectricity for pump- and turbine-operation

The lower curve on the negative y-axes shows the duration curve of the pumps of the hydroelectric storages. With the initial condition that all (upper) storage reservoirs are empty, the curve shows the power of the pumps until all reservoirs are full. The power decreases with time, when the first reservoirs are filled.

The upper curves show the duration curves of the turbine power. Here the initial condition is that all storage reservoirs are filled. The reversible operation is only given by the pumped storage hydroelectricity (PSH). In contrast the upper duration curve of the storage hydroelectricity power plants (SH) shows emptying of the storage reservoirs, which can only be filled by natural inflow.

Table 1: key figures of pumped-storage hydroelectricity (PSH) and storage hydroelectricity (SH) in Austria [1]

	PSH pumps	*PSH turbine*	*SH turbine*
Maximum power [GW_{el}]	4.17	4.66	7.95
Electrical energy [GWh_{el}]	238	190	3263
E / P_{max} [h]	57	41	410

Table 1 shows the data related to the duration curve of Figure 2. The maximum power is only available in the situation of completely filled / empty storage reservoirs. The electrical energy describes the area under the duration curve and shows what amount of energy can be stored with PSH and SH. The difference of PSH pumps und PSH turbine operation is explained by the modelled roundtrip efficiency of 80% of PSHs.

The stored energy in SHs (only natural inflow) compared to PSH is about 15 times bigger. Figure 1 shows that the annual generation of SHs is about 10 TWh. With a storage capacity of nearly 3263 GWh, this means that in average the SHs are filled about 3 times a year by natural inflow. [1]

OPERATION OF HYDRAULIC STORAGE

Figure 3 shows the results of the optimisation model for one year. The grey line shows the residual load, which is the normal demand not met by the volatile generation of run-of-river power plants, wind generation and photovoltaics. Instead, this residual load has to be covered by storages and controllable power plants to achieve the balance of demand and generation at every time step.

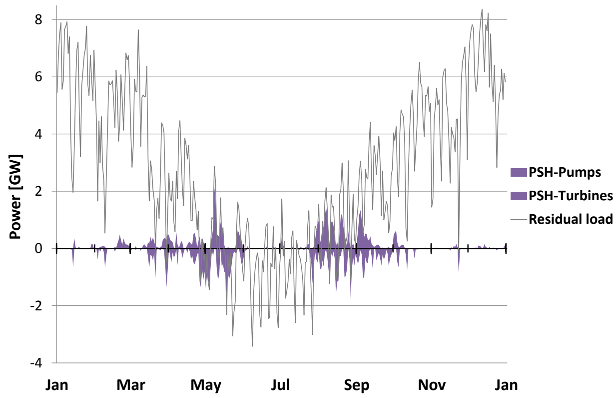

Figure 3: operation of short term storages (PSH) over one year

In purple, the operation of PSH can be seen. Negative values show the operation of pumps and positive values operation of turbines. As shown in Figure 3, the short term storages are only used in spring and autumn for day-night balance but not in summer-months were a bigger surplus of renewable generation is available.

The following example weeks in Figure 4 (winter), Figure 5 (spring) and Figure 6 (summer) show the reason for the resulting operation of short term storages. These figures are based on the results of the optimisation model with an installed power of 8 GW run-of-river power plants, 6 GW wind power and 13 GW photovoltaic (compare Figure 1 “future reference scenario - Austria”). The power infeed for this example week is calculated with the precipitation/runoff, wind speed and solar radiation of the year 2004, which is the most typical meteorological year of the timespan 1998 to 2008.

The black line shows the electricity demand which has to be covered. In winter the available generation of run of river power plants (light blue) is about 50% of the value for a summer week. Moreover, the photovoltaic generation is much lower in winter. In the shown winter week, there is no generation surplus of renewable generation. Therefore PSH are not in use because there is no energy which could be stored-in for day-night balance. Flexible generation of fossil power plants covers the remaining demand.

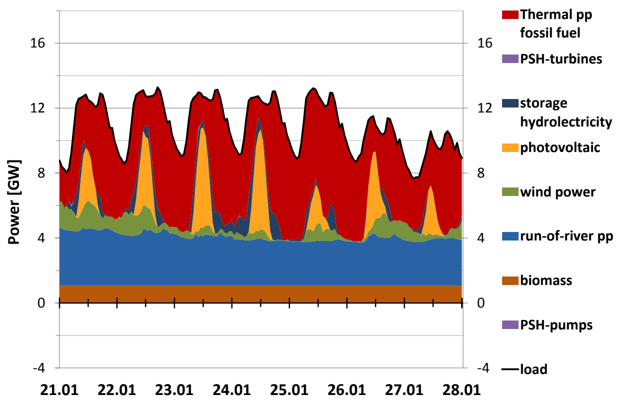

Figure 4: Example week – winter (future scenario)

In spring (see Figure 5) the transition is shown, where the annual potential of biomass generation is already fully used up. During the day, the renewable generation (here especially photovoltaics) exceeds the demand. This surplus is stored in PSH and is used in night times (in combination with SH). In this time of the year, most operation hours of PSH are achieved.

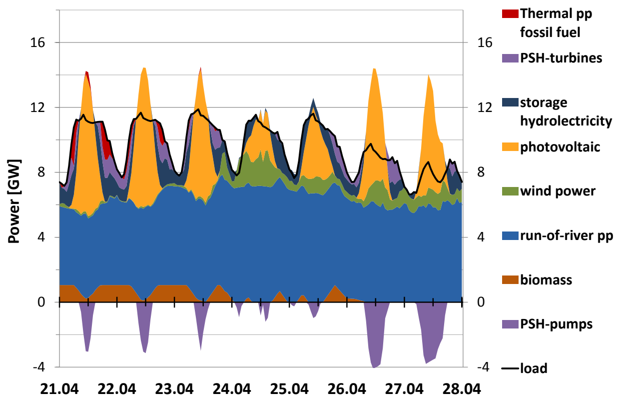

Figure 5: Example week – spring (future scenario)

Figure 6 shows a typical summer week. The area in light blue shows the generation of run-of-river power plants. Also storage hydroelectricity is used (dark blue) because many storage reservoirs are relatively small and only have a storage capacity of a few days for the natural inflow. Depending on the solar radiation the electricity demand during daytime is often exceeded (here by a factor of 2 on Sunday).

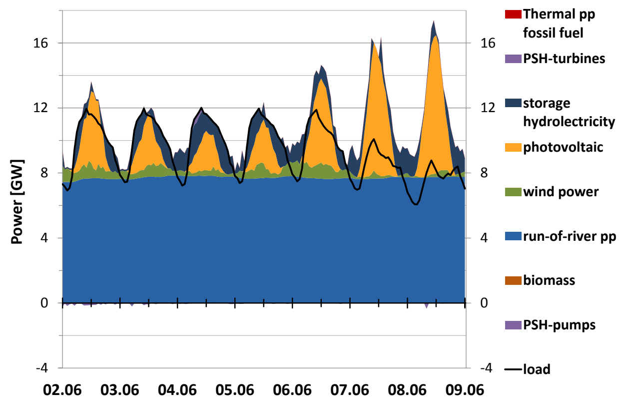

Figure 6: Example week – summer (future scenario)

Also during night-time the demand is covered by renewable generation. The lack of generation deficits is the reason why there is no useful possibility for short term storages to deliver energy. Therefore PSH are remaining constantly filled in summer time.

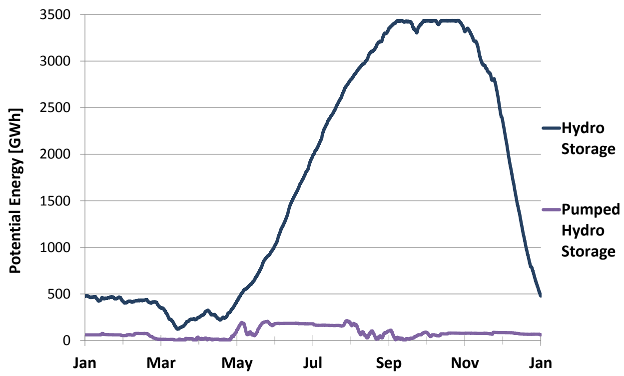

Figure 7: seasonal usage of Pumped hydro storages and hydro storages

This can also be seen in Figure 7, which shows the potential energy, which is stored in SH and PSH. The storage hydroelectricity power plants show the typical operation of seasonal balance. The short term storages (here PSH) are nearly completely empty during winter months and nearly completely full in summer.

ADDITIONAL SHORT TERM STORAGES

In [1] three scenarios with additional decentralized storage (e.g. electric vehicles and photovoltaic home storage systems) were modelled. A energy/power ratio of E/P = 0.4h is assumed. The scenario with 10 GW (see Table 2) relates to additional decentralized short term storages with a capacity of 4 GWh. This corresponds to about 200 000 electric vehicles with a useable capacity of 20 kWh each.

Table 2: Scenarios of additional decentralized storages [1]

Amount of decentralized storage	*0 GW*	*1 GW*	*4 GW*	*10 GW*
usage of pumped storage hydroelectricity [TWh/a]	1.75	1.69	1.55	1.34
usage of decentralised storage [TWh/a]	-	0.10	0.30	0.61
usage of short term storage [TWh/a]	1.75	1.79	1.85	1.95

Table 2 shows the usage of these additional storages as well as the existing PSH by the annual stored-in electrical energy. The total values of both storage types show a comparably small increase with adding additional short term storages. As shown in the previous chapter, the operation time of short term storages is limited by the lack of generation surpluses and generation deficits, which could be compensated by day-night balance. Therefore the optimisation goal of maximization of the renewable generation share only increases from 85.6% (reference scenario without additional storage) to 86.2% (scenario with 10 GW of additional storage). It has to be mentioned that local aspects of the distribution grid are not part of the optimisation models. Therefore decentralized storage could have a bigger impact in praxis when solving local constraints.

ADDITIONAL LONG TERM STORAGES

As described in the previous chapters, the big challenge to increase the share of renewables is the seasonal balance. Therefore in [1] additional seasonal storages were modelled to analyse the possible increase of the renewable generation share.

Power-to-gas solutions are typically limited by the installed power and not by the storage capacity. The available gas storages in Austria have a capacity of about 83 TWh and are therefore about 25 times as big as the sum of all hydroelectricity storages in Austria. [1]

In the optimisation model, the focus was to maximise the renewable share of the electricity system. Therefore the stored hydrogen and in a further conversion step methane, is used for electricity generation in gas power plants. Alternatively the produced hydrogen could be used for other purposes. But within this paper the focus is on the operation strategy of the power-to-gas system in combination with short term storages (here PHS).

Figure 8 shows the different duration curves for the reference scenario without power-to-gas systems. The black curve shows the overall electricity demand. The residual load is the consumption reduced by the volatile renewable generation. Hydroelectricity power plants (SH in dark blue and PSH in purple) are used to balance the volatile generation and the load as good as possible. This results in a duration curve which is exactly at zero for more than 2 months per year. The remaining deficit has to be covered by controllable generation (biofuels and fossil fuels) whereas the remaining generation surplus has to be curtailed to maintain a power balance.

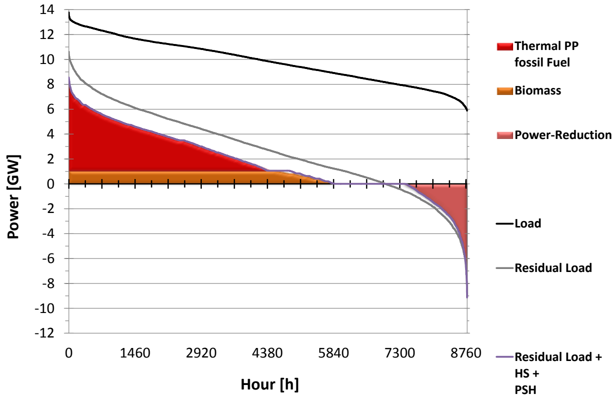

Figure 8: duration curve of controllable generation without a power to gas system for a full year

Figure 9 shows in comparison an electricity system with an additional 2 GW power-to-gas system. This results in the amount of curtailed energy being reduced from 2.77 TWh/a (reference scenario) to 0.43 TWh/a. This also leads to an increased renewable generation share from 85.6% to 88.8%. [1]

Figure 9 also shows that the power-to-gas system (orange area at the negative y-axes) is operated for about 2 months a year at the full installed power. The partial-load operation is a little bit less than 1 month. The power-to-gas system runs with 2000 full load hours per year.

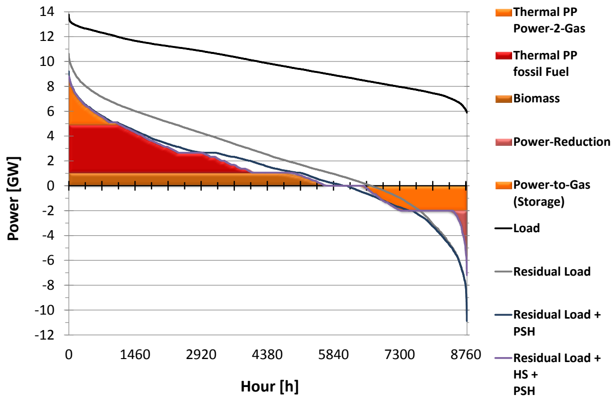

Figure 9: duration curve of controllable generation with an additional 2 GW power to gas system for a full year

Figure 10 shows an example week in summer with an installed power-to-gas system of 2 GW. In the reference scenario the PSH was not used in summer, because of the lack of generation deficits (compare Figure 6).

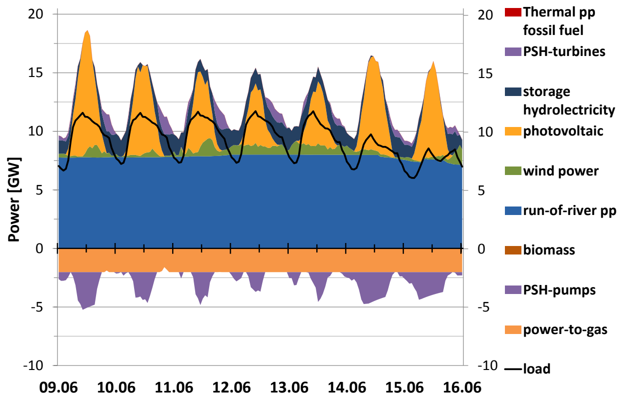

Figure 10: example week in summer with a 2 GW power-to-gas system

The power-to-gas system adds an additional load of 2 GW in summer. Now the short term storages (here PSH) are used for day-night balance. The volatile generation surplus is smoothed so that the power-to-gas system constantly operates at its rated power. The usage of (decentralized) short term storage is doubled, when adding a 2 GW power-to-gas system. [1]

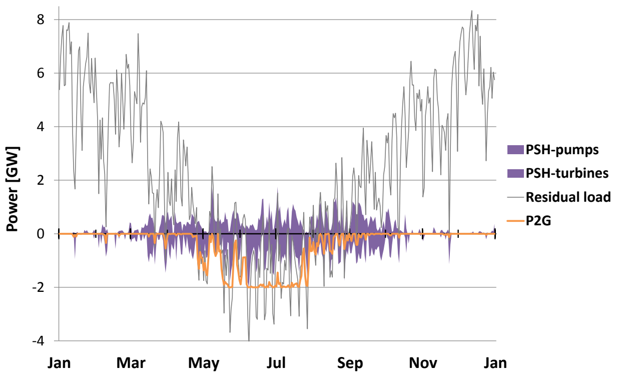

Figure 11: operation of short term storages (PSH) in combination with a 2 GW power-to-gas system over one year [1]

This behavior can also be seen in Figure 11. The power-to-gas system (orange line) is used especially in summer months to produce hydrogen at its maximum power. The existing short term storages are used in spring and autumn for the normal day-night-balance. Additionally in summer PSH have the task of providing a constant power for the long term storages.

CONCLUSION

Compared to the current share of renewable electricity generation in Austria of about 70 %, a substantial increase is possible by the expansion of renewable energy resources.

The main task is to cover the electricity demand during winter. Therefore from a technical perspective, the share of renewable generation is limited by the given resources of controllable renewable generation units and due to low seasonal storage capacities.

The additional seasonal storages (here P2G) add a further task for the short term storages. During summer months, they balance the generation surplus, so that the P2G systems are operated with a constant (maximal) power.

The usage of (decentralized) short term storage is doubled, when adding power-to-gas units to a highly renewable energy system. Therefore power-to-gas systems are no competitor to short term storages. In contrast the usage and demand of short storage rises.

REFERENCES

[1] C. Groiß, 2013, “Maximizing the renewable generation share of the Austrian electrical energy supply.”, *Dissertation (in German) at TU Vienna University*

[2] M. Boxleitner, C. Groiß, 2011, “Super4MicroGrid: Renewable energy supply under climate change conditions.”, *Final project report (in German) – Neue Energien 2020, 1. Ausschreibung, Klima- und Energiefonds*

[3] Energie-Control GmbH: Statistikbroschüre 2016