# KEY RESULTS OF THE PROJECT 'POWER-TO-HEAT IN SMART GRIDS'– A MULTI-OBJECTIVE APPROACH FOR A MAXIMIZED VALUE OF FLEXIBILITIES IN GRIDS

Christopher FUCHS
Westnetz GmbH –Germany
christopher.fuchs@westnetz.de

Dr. Stefan NYKAMP
Innogy SE – Germany
stefan.nykamp@innogy.com

## *ABSTRACT*

*Decentralized demand side response (DSR) applications are getting increasingly attractive for balancing and stabilizing the increasingly strained grids due to the increasing share of fluctuating renewables feed-in. One possible use case is to exploit DSR applications such as power-to-heat (PtH) assets as flexibility for grid usage to avoid/defer conventional grid reinforcements and to effectively integrate decentralized renewables and active prosumers in the future. The economics of the PtH asset operation can be improved substantially if a multi-use approach is realized. These approaches consider local grid-oriented usage in certain times of grid restrictions, e.g. due to fluctuating wind feed-in whereas system- or market-oriented usage could be applied in non-critical time periods. Real-world projects such as the R&D project 'Power-to-Heat in Smart Grids' are needed to show that multi-use approaches are technically feasible and impact the economics of the asset significantly. Besides results of an economic project study, the regulatory discussion highlighting possible future changes of the regulatory framework is also a main aspect of this paper.*

## INTRODUCTION

The increasing share of electrical energy generated from renewable energy sources (RES-E) leads to significant challenges for distribution system operators (DSO). Since 95% of the RES-E is connected to distribution instead of transmission grids, new grid design and operation strategies are needed for DSOs to avoid the increasing curtailment of 'climate neutral' electricity [1]. As an alternative to conventional grid reinforcements and feed-in management, flexible DSR applications such as PtH assets can be used effectively to stabilize the distribution grid, especially in times of high fluctuating RES-E feed-in [2]. In this context innogy SE and Westnetz GmbH have done a R&D project to evaluate the effect of a PtH asset to defer/avoid conventional grid reinforcements as well as to analyze the technical and economic effects of a multi-objective operation.

This paper focuses on the results of a study taking todays and possible future scenarios of the regulatory framework into account. Since the German regulatory framework currently does not incentivize DSOs to use grid-oriented flexibilities, a need for actions to enable a suitable usage of DSR potentials such as PtH assets is derived and options are discussed.

To provide a deeper understanding on the content of the paper, the next chapter will introduce and differentiate the value of flexibility. After describing the R&D project 'Power-to-Heat in Smart Grids' in more detail, the main chapters will deal with the economic and discussion of the regulatory dimension of the multi-objective approach.

## FLEXIBILITY IN GRIDS

Flexibility as an adaption of generation or demand behaviour by external signals may provide benefits for different stakeholders and use cases [3]. In the context of this project, three possible main use cases with a) market oriented usage (e.g. arbitrage at spot markets), b) system oriented usage (e.g. balancing frequency with secondary control power) and c) grid oriented usage are possible and described in [4]. The latter option is the focus of the grid operator and, however, only one of several alternatives to cope with the challenges in distribution grids. PtH assets may help to improve an efficient integration of renewable energy generation when adjusting demand considering local energy production.

Recent studies show that there is accordingly a huge potential [2]; an updated simulation for the reinforcement needs in German distribution grids showed additional grid reinforcements of up to 37 bn € by 2035. Note that the approach of peak curtailment is considered and otherwise, reinforcements need would even be 30% higher. Peak curtailment allows DSOs in Germany the curtailment of 3% of the energy of wind and photovoltaic generation which can be taken into account when planning and building the grids. This is an effective and efficient approach since such generation peaks are very seldom but high. Hence, curtailment is way cheaper in such situations than the costs for the integration of these peaks. This study focuses not only on the flexibility on the generation side but also on the demand side. Thus, demand peaks are supposed to be shaven as well, which is relevant especially with regard to the upcoming additional peaks in (sub-) urban grids due to the integration of e-mobility and further heat appliances. But demand can also be increased in case of a local generation surplus. This is considered in the simulation as well. In a nutshell, the additional costs for the integration of further generation and demand appliances can be decreased by 42% when grid operators are enabled to use all of these kinds of flexibility [2]. Hence, the potential for cost reductions is very high for the complete country. But every journey starts with a first step, so the R&D project 'Power-to-heat in smart grids' aims to get further insights in benefits, challenges and obstacles for using flexibility for grid purposes – in this case with a focus on increasing the demand when generations peaks will occur.

## PROJECT 'POWER-TO-HEAT IN SMART GRIDS' IN A NUTSHELL

The project is located in the city of Meisenheim along the southernmost point of the Westnetz grid area, a region with a comparatively high share of RES-E and especially wind power feed-in. Innogy SE and Westnetz, an innogy SE company and Germanys largest DSO, introduced a 600 kW PtH asset to test this technology with regard to technological and – especially – regulatory aspects taking the current unbundling regime into account. This multi-objective approach aims to relieve the transformer capacity in the local substation in times of high wind power feed-in. Connection and feed-in of another local wind farm will most likely shorten the time for a local bottleneck of the transformer capacity in 2020. Figure 1 shows a scheme of the local grid constellation including the technical integration of the PtH asset.

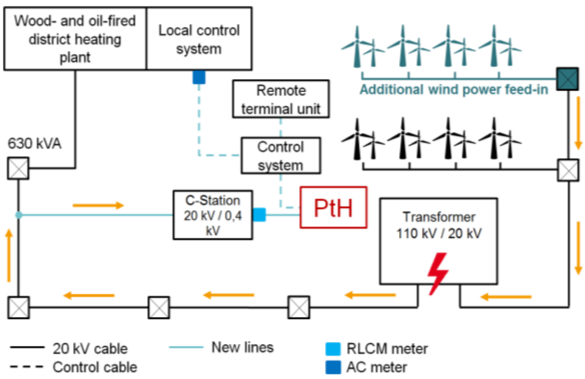


**Figure 1: Technical integration scheme of the PtH asset**

As stability of the complex infrastructure and the reliable electricity supply need to be ensured, the system control prioritizes grid-oriented operation of the PtH asset to relieve the transformer and – in the long run – to shift in time, reduce or in the best case completely avoid grid reinforcement. In case an algorithm does not forecast a critical grid situation, the PtH asset will be activated to offer flexibility for commercialization at balancing power markets (negative secondary control power) by the help of the innogy SE virtual power plant 'Smart Pool'. Obviously, grid- and system-oriented flexibility depends on the temporary heat sink of the local heating network as described in [4]. Note that the dimensioning of the asset can only contribute to a relief of the transformer but not completely avoid grid reinforcement in the high voltage grid level (110 kV). Hence, the curtailment of temporary wind peaks is the reasonable benchmark of the PtH asset.

In the set-up of the PtH-project of Meisenheim, the grid operator is only one of several possible stakeholders and demanders of the flexibility of the PtH asset. Hence, European unbundling rules are taken into account. It is ensured that grid operation is focused on grid tasks (e.g. by avoiding that the DSO is participating on system and market oriented flexibility usage) and the PtH asset is not part of the regulated asset base of the DSO. For an efficient and reliable operation, a main relevant aspect for such set-ups has been identified in finding proper contractual agreements for the prioritized steering of the DSO as well as for the relevance of accurate forecasts on both grid-load and weather profiles. Furthermore, the proper incentives have to be implemented for both the PtH operator and the DSO (see later).

Former results of the project have shown that a multi-use operation (grid- and system-oriented use) of the PtH asset is technically feasible. The asset was available for the third-party access (grid or system oriented usage) during the complete year and operation was proved in <1000 operating hours/a within the project [4]. Therefore an economic study was made in 2018 taking first project data into account. The study focusses on the analysis and evaluation of the PtH flexibility utilization based on the project. Hence, the usage of PtH in distribution grids is generally compared to alternative decentralized flexibility options. Relevant drivers of economic efficiency are identified to evaluate the influence on investment incentives. Furthermore the main constraints as well as additional requirements resulting from the current regulation design are highlighted. Detailed results are given in the next chapters.

## KEY RESULTS OF THE ECONOMIC ANALYSIS

Referring to a combined grid- and system-oriented operation and for heat production in low-price hours, four different scenarios of the regulatory framework for PtH asset operators and DSOs are considered within the study.

- The scenario 'status quo' is based on the current regulatory framework as well as today's electricity price tax and tariff structure (base case, see Figure 2) and thus represents the revenues that can already be achieved with the PtH asset today.

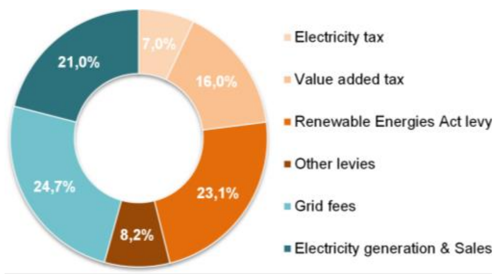


**Figure 2: Electricity price cost components (2018) [5]**

Although the PtH asset in Meisenheim is connected to the medium voltage level, the cost structure is typical for end customers, since 54.3% cost components (for heat and electricity) are state-induced taxes and levies as shown in Figure 2. Today, there is no time-variant end customer tariff system. Hence, the stock exchange price is not reflected in the end customer electricity price simultaneously. In conclusion, the structure of the end customer electricity prices (currently around 25 cent/kWh for electricity) along with taxation and state-induced levies as shown above play a decisive role for the economics of the PtH asset.

- The scenario 'sharing factor' assumes the introduction of a coordination model between grid operators and asset operators as part of an incentive regulation reform. Within this coordination model, costs and respectively saved costs due to a grid-oriented use of the PtH asset are equally shared between asset operator and DSO:
  - Costs of purchased electricity that is needed in case of a grid-oriented use activated by the DSO are assumed to be half of the DSOs costs that would incur for local curtailment in order to resolve the bottleneck.
  - If grid expansion can be avoided due to the PtH asset operation, it is assumed, that saved costs are shared equally between DSO and PtH asset operator. This case is of less relevance, as this is not a realistic scenario in the project.
- In the 'tariff structure' scenario, a tariff structure reform is assumed taking the expectation of increasing energy prices and network costs into account. Renewables Energies Act levies only incur to final consumption (here in terms of heat) and it is assumed, that future grid fees are charged more based on kW but remain neutral in total (see later). A further assumption of abolished kWh-based taxes and levies is equivalent to the impact of an amended regulatory framework in which the usage of surplus RES-E to generate (renewable) heat is not sustainably disadvantaged through high taxes and levies any longer.
- In the scenario 'tariff structure reform and sharing factor' an application of both, a coordination model between DSO and PtH asset operator and equally shared benefits of the operation, as well as a reform of the tariff structure as described above is taken into account.

The four scenarios have been calculated for existing PtH assets as well as for new PtH assets considering typical investment costs for an operating period of 20 years. Furthermore service-, maintenance and repair-costs have been taken into account, based on the practical experiences of the project. The results refer to the 'multi-use case', i.e. a combined operation of the PtH asset for grid- and system-oriented use as well as for pure heat production in low-price hours. The results of the economic evaluation are shown in Figure 3.

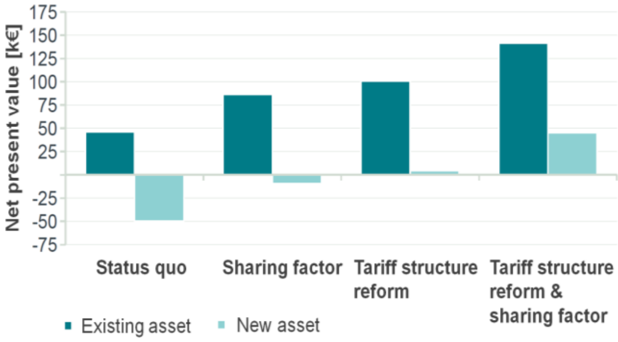


**Figure 3: Value of PtH flexibility in different multi-objective scenarios within an operating period of 20 years**

It is shown that the net present value (NPV) for the 'base case' (today's regulatory framework) is only positive in case the investment costs are neglected. The PtH asset generates a surplus of approx. 46 k € before tax based on a 20-year operational period after all fixed and variable costs have been covered. The NPV increases significantly in the scenarios 'sharing factor' and 'tariff structure reform' as a result of the assumed regulatory or tariff structure reforms. An implementation of the tariff structure reform and the coordination model (scenario 'tariff structure reform and sharing factor') results in the highest value of the PtH asset of approx. 150 k €.

More realistic assumptions take the investment costs into account. In the base case as well as the introduction of a coordination model between DSO and PtH operator cover all ongoing operating costs, but fail to reach the economic viability threshold (NPV of zero), As soon as a tariff structure reform is assumed, the NPV is slightly positive. A combined implementation of the reforms results in the highest NPV of approx. 28 k €.

In conclusion, an investment in a PtH asset would be economically unreasonable under today's conditions – even in case of a multi-use operation of the PtH asset in the specific project environment.

To evaluate overall economic aspects, a welfare economic analysis is useful. In this context, state induced electricity price components such as taxes and levies are neglected as they are not offset by any cost position caused by PtH asset operation. Grid fees only apply as far as they are caused by the use of the PtH asset (usually low). Thus, only the occurring costs are compared since tariff structures or regulatory incentives are irrelevant. The main differences in the evaluation of the PtH asset compared to above shown business valuation are:

- In case of a grid-oriented operation, costs of purchased electricity are zero (or negative), since otherwise RES-E would be curtailed and the attributable investment costs for wind turbines world be sunk costs. Hence, the overall economic benefit is generated by the heat production for a grid-oriented asset operation. Benefits based on avoided grid reinforcement are not considered in this case. Due to the individual jump functions of grid reinforcement costs, this position is very difficult to quantify and highly dependent on the individual grid constellation.

- In case of a system-oriented operation, PtH systems can also draw energy off the system on a short-term, in this context to provide negative secondary control power for the TSO. From a welfare point of view there is no difference, since revenues of a system-oriented use correspond to the overall economic benefit.
- In case of a market-oriented operation, the PtH asset operation can contribute to safe cost for heat production. In case electricity prices on the spot market are very low (or negative) and fall below the cost of alternative fuels for heat production due to a high power supply availability, PtH assets can replace fossil fuels for heat production. However, local conditions at the PtH site need to be taken into account to decide whether fossil fuels such as natural gas, oil or wood are likely to be substituted. In this context, electricity costs for heat generation are free of levies and taxes and considered costs only consist of the wholesale price and grid fees. As a result, the PtH asset is mainly used for heat generation.

The economic benefits are offset by investment and operating costs. Figure 4 shows the overall economic benefits and costs over time as a result of the analysis of the 'base case'.

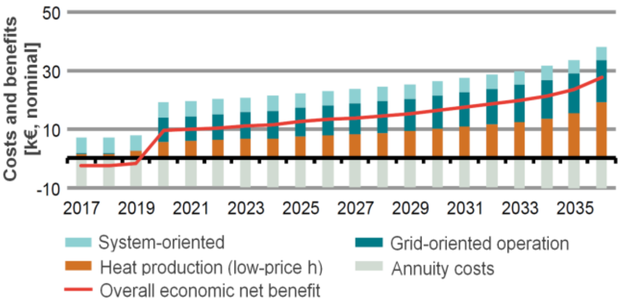


**Figure 4: Results of the overall economic cost-benefit analysis from a welfare point of view**

In the overall economic perspective, the grid-oriented operation of the PtH asset leads to a significantly higher benefit since the costs for purchased electricity in case of grid-oriented operation are zero. Heat generation in low-price hours is also significantly higher, as levies and taxes are not relevant. Note that the step of the overall economic net benefit in the year 2020 is a result of the connection and feed-in of another local wind farm leading to an increasing curtailment of wind peaks and potentially increasing operation hours of the PtH asset. The overall economic analysis reveals a large difference to the business valuation of the PtH asset, since the overall economic benefit is significantly higher than reflected in the (negative) investment incentive. Hence, there is a need for action in order to create investment incentives for grid-oriented PtH usage. A reform of the tariff structure or the regulatory framework is needed in order to generate investment incentives and to push PtH assets as a technically feasible sector coupling solution with decreased CO2-emissions forward. Further details on reform proposals are provided in the following chapter.

## REGULATORY DISCUSSION

An 'optimal and implementable' regulatory and legislative framework has to consider the existing (national) laws, transformation paths, implementation/ transaction costs, redistributive effects, acceptance, etc. Furthermore, a target vision is crucial and not necessarily time-consistent. This being said, the further elaborations on possible amendments focus on the results of the project taking the overall economical perspective into account. Nonetheless, the suggestions require further analysis to e.g. evaluate the redistributive effects and transaction costs. The main scope in this chapter is on grid costs (in the context of grid fees). Note that other cost components as described in the previous chapter may have similar or even higher effects for the flexibility provider (e.g. the levies in Germany).

First, the kWh-based allocation of grid costs is quite pronounced in German low/medium voltage grids and disadvantageous for such sector-coupling assets as shown in the project. On the other hand an only kW-based grid fee system may provide disincentives for an efficient usage of energy and could also increase costs for users if the additional power peak goes along with the peak of the normal demand. This effect is reasonable if the resulting peak leads to additional grid reinforcement needs (e.g. in case of system- or market-oriented flexibility usage). However, if the resulting peaks leads to relieved stress on grid assets (or even on reduced reinforcement needs), an additional costs component for the flexibility provide is unfavorable. Possible solutions are the increase of the annual 'basic price' for the connection of the customer to the grid going along with decreased prices for kWh and kW. Note that no basic price has been introduced in Germany on voltage levels higher than low voltage and that kW-based price schemes or not given for low voltage customers. Another option is the decrease of overall grid based cost components for the flexibility provider if an increase/decrease of power demand/injection is possible for the grid operator using suitable steering signals. Furthermore, compensation schemes are possible without even affecting the grid fees. In this scenario, flexibility products are demanded and being paid by the grid operator without reducing the kWh/kW/basic prices. For this, the incentive schemes and regulation for the grid operator have to be considered, since this product payment goes along with a compensation of the flexibility provider and operational expenditures (opex) for the grid operator.

Hence and as a second dimension, the incentives for the grid operator play a crucial role. In Germany, a revenue cap regulation system has been implemented and different ways of cost remuneration are given for the options of a) conventional grid reinforcement, b) curtailment of RES-E and c) expenditures for the compensation of flexibility providers for increasing their demand. More precisely, for option c) no concrete remuneration method has been established. For all of these options, the Averch-Johnson-effect and the impact on the efficiency value of the specific DSO need to be taken into account as described in [4]. Thus, under current regulation for the DSO, the conventional reinforcement is likely to remain the preferred solution although possibly inducing more costs than the alternatives (see [2]). More research is required in this context to determine appropriate regulatory adjusting screws.

Third, assuming that incentives for the flexibility provider AND the grid operator are given to use grid oriented flexibility options (when inducing less costs on both sides than the alternatives), some coordination issues need to be addressed. For an efficient usage of flexibility, the grid operators should activate the options with the lowest costs. For this, the competition of flexibility providers should be possible as long as the price is not regulated. Note that with non-regulated prices further challenges such as the possible occurrence of gaming might be possible, especially in areas with little liquidity and market power of (only a few) flexibility providers. In both cases of regulated and market-based prices, a coordination of flexibility offers to the grid operators (access grid operator, possibly upstream grid operator, transmission system operator) needs to be ensured. This coordination should be done beforehand and preferably not in real-time to address requirements from the accounting grid management. Such coordination mechanisms are subject to several R&D projects and required further efforts to be implemented in the future (see e.g. the SINTEG projects in Germany [6] or the Flex-Router approach focusing on a coordination scheme in higher voltage levels [7]).

## SUMMARY

As an alternative to conventional grid reinforcements and feed-in management, innovative flexible DSR applications such as PtH can be used. Particularly if certain site constraints such as overlapping surplus RES-E and an equivalent local heat sink as well as low frequencies of local bottlenecks are met, PtH usage can be economical in a multi-use operation. High local costs of alternative conventional heat generation can further foster the usage of PtH. The evaluated approach seems to be ecologically and welfare economically promising, since (peak) curtailment of RES-E could be reduced as surplus energy is transformed into 'green heat'.

In order to realize all the advantages of a PtH asset multi-use operation such as in Meisenheim, there is a need for regulatory action to provide suitable incentives both on flexibility provider and DSO side and to implement appropriate coordination schemes. For this, first ideas are presented as well in this paper.

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