The Added Value of Heat Pumps for Grid Stability via Demand Response

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As a consequence of the energy transition, the share of electricity generated from variable, intermittent (and hence less manageable) renewable energy sources (RES) is rising considerably. In order to still guarantee the required quasi-instantaneous balance between supply and demand, there is a clear need for demand side flexibility. One interesting application field offering a great potential for demand side flexibility is the residential heating sector, with heat pumps (HP) coupled to thermal energy storage (TES) as one of the key technologies. This article aims at illustrating what can be done in terms of demand response (DR) with heat pumps, by discussing results from research, demonstration projects, and even commercial cases.

Our energy system is transforming...

Efforts to mitigate climate change are leading to major transformations of our energy system. In the past, at the supply side, large fossil-fired and nuclear power plants produced electricity. At the demand side, passive end-users were simply paying the electricity bill. Nowadays, there is a strong push for renewable energy sources and local production (prosumers) on the one hand, and a transition towards more sustainable and conscious energy use – for example by using energy-efficient electric heat pumps or decarbonized electric vehicles – on the other hand. In other words, the electricity production becomes more variable, unpredictable, and local, and the electricity demand is rising.

... leading to some important challenges

These trends give rise to some important challenges. Firstly, it becomes harder to balance the rising electricity consumption with the unmanageable production. Secondly, the electrification and the resulting peak demand and supply can lead to increasing congestion or voltage issues in the distribution grid.

How can we cope with this?

In the past, balancing supply and demand was fairly easy, because of the dispatchable electricity generation. Due to the emergence of variable, uncontrollable RES, this is not possible anymore. However, the rising electricity demand, provoked by the energy transition, can offer a solution. Rather than letting supply follow demand, balancing can now be performed the other way around, by exploiting demand side flexibility. This flexibility can stem from two different sources, being demand response and energy storage.

Figure 1 shows in an illustrative way how demand side flexibility can solve the balancing problem. The left side shows the current problematic situation. When focusing for instance on electricity generation by photovoltaic panels (PV), the supply profile shows a clear peak around noon, when solar radiation is maximal. The traditional demand profile, on the other hand, is concentrated around the morning and evening period. Consequently, supply and demand don't match, an imbalance that cannot be tolerated by the grid.

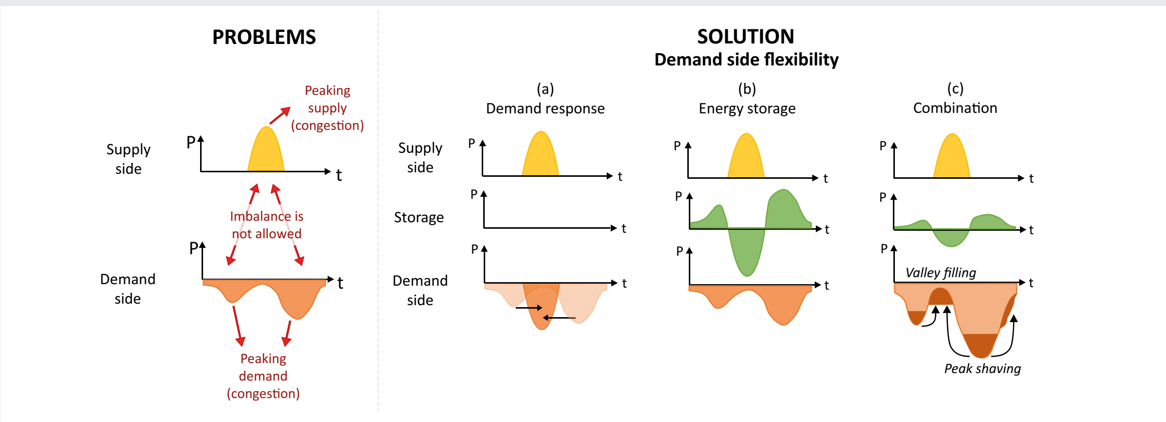

Fig. 1: Solving balancing and congestion problems via (a) demand response, (b) energy storage, or (c) a combination of both.

One possible solution to this problem is the curtailment of the renewable electricity production, and the use of traditional dispatchable power plants to cover the demand. However, this option is highly unsustainable. A more favourable solution is the application of DR. The demand profile is then changed to better match the available supply. For the considered case, the electricity consumption is shifted towards noon, in order to instantly consume the electricity generated by PV. Another possibility is the implementation of energy storage, such as a battery system. Note that in this case the traditional demand profile does not have to be changed, since storage allows for a decoupling of demand and supply.

Also the second challenge, i.e., the demand and supply peaks and related congestion, can be tackled by relying on demand side flexibility, as also shown in figure 1 (c). Combining DR and energy storage can bring about a desirable shift of the consumption from the peak periods towards the valley at noon (coinciding with the peaking PV generation), thereby flattening the demand profile.

DR with heat pumps

What can be done in terms of DR with heat pumps? Currently, the application of DR and the participation in the spot market is mostly limited to large, industrial consumers. Due to the energy transition, however, a new market is emerging, namely the small-scale flexibility of residential consumers. Heat pumps are particularly suited for DR, because of their significant share in electricity consumption and because heat demand is not that time critical, thanks to the available thermal storage in the building mass. This allows for a shift (advance) of the electricity consumption needed to generate heat, as an anticipation towards for example rising electricity prices, without jeopardizing thermal comfort, as shown in figure 2.

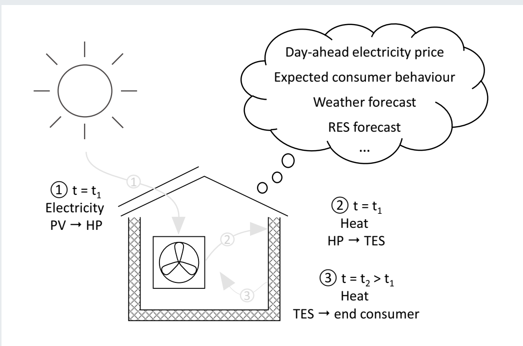

Fig. 2: Demand response with heat pumps.

A lot of work has already been done proving what is possible in terms of DR with heat pumps, ranging from research to demonstration projects, and even commercial cases.

Proof-of-concept in research

Patteeuw has done some valuable simulation studies showing the expected impact of a large-scale implementation of heat pumps participating in DR programmes [1-5]. Some interesting results of his work are shown in figure 3.

In a methodological, illustrative case study, Patteeuw showed the general trends and impacts of implementing heat pumps and using them for DR [1]. This is done for a fictitious energy system. The considered generation mix is very diverse, and the demand side is characterised by a large number of heat pumps, with an electricity demand equal to one fourth of the total demand. The impact of DR can be seen at two different levels: at the building level, as experienced by the consumers, and at the system level, as experienced by society.

Figure 3 shows the profile of the indoor air temperature and the electricity consumption by the heat pump without (top) versus with (bottom) DR for one single building. The application of DR results in a shift of the heat pump operation towards periods characterised by low electricity prices. Hence, the heat pump already starts to preheat the room prior to the instance where heat is really required to ensure thermal comfort. Consequently, a slightly higher final energy use is obtained, due to higher operating temperatures and related storage losses, but at a lower cost. Note that the electricity price profile changes when the share of heat pumps participating in DR increases. This is due to the fact that large-scale application of demand response can impact the generation mix, and thus the resulting electricity prices, as will be discussed further.

When looking at the system level, rather than at the building level, the most important impact of DR is the influence on the overall demand profile and the generation mix needed to cover this demand, as can be seen in figure 4. By applying DR, the combined effect of peak shaving and valley filling leads to a flattened demand profile. Consequently, the need for expensive peak power plants disappears, and also the curtailment of RES is reduced.

These research results demonstrate the expected advantages related to the application of DR, which benefits both end consumers and society. However, demonstration projects are needed to prove that these advantages also can be realised in practice.

Demonstration project

If we shift from theory to practice, an inspiring demonstration project is the smart grid project ‘Energy Frontiers’, implemented in the neighbourhood Heerhugowaard in the Netherlands [6]. The main research question is how decentralized flexibility can be used in a flexibility market to support the energy system. 203 households participated, with different types of smart appliances, from heat pumps to electric boilers and fuel cells. All houses had a smart meter and a smart thermostat, and all appliances were automatically controlled. At the end of the first phase of the project (2015-2016), some very promising results were obtained. Thanks to the flexible smart appliances, 15 power outages were avoided. Figure 5 shows the impact of exploiting flexibility in more detail. The height and duration of (the majority of) the power peaks could be reduced, shifting

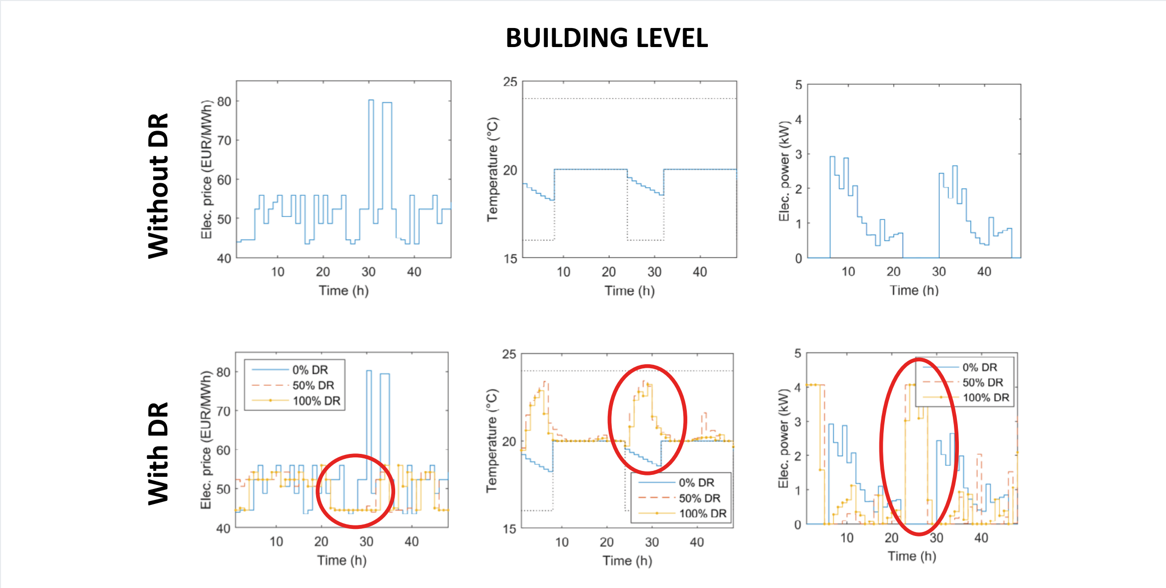

Fig. 3: The impact of DR on building level [1].

from the upper right corner, the area of power outage or damage, to the lower left corner, the safe area.

Commercial case

In addition to demonstration projects, commercial cases can be found. One commercial success story is TIKO in Switzerland. TIKO is one of the few initiatives already commercially exploiting the value of DR with heat pumps [7,8]. It is a kind of virtual energy storage network, that already in 2017 connected more than 10 000 electric heating devices, both from residential and industrial buildings, of which more than 5 000 devices were heat pumps. Today, the total connected capacity amounts to more than 100 MW. The aggregated flexibility is used to provide services to the Swiss balancing market. All connected devices are controlled in an On-Off manner whenever flexibility is – or is not – needed. The commercial success of this project, applying a rather simple control strategy, is very promising regarding implementation of demand response in practice.

Conclusion

Existing research projects, demonstrations and commercial success stories indicate that demand response with heat pumps offers interesting (and indispensable) possibilities to tackle the challenges of the future energy system – think about the balancing and the grid congestion – but also to exploit the opportunities of that same future energy system – think about the reduced curtailment of renewables. Consequently, it is expected that heat pumps will have a crucial role to play in the future.
However, if we come back to here and now, the number

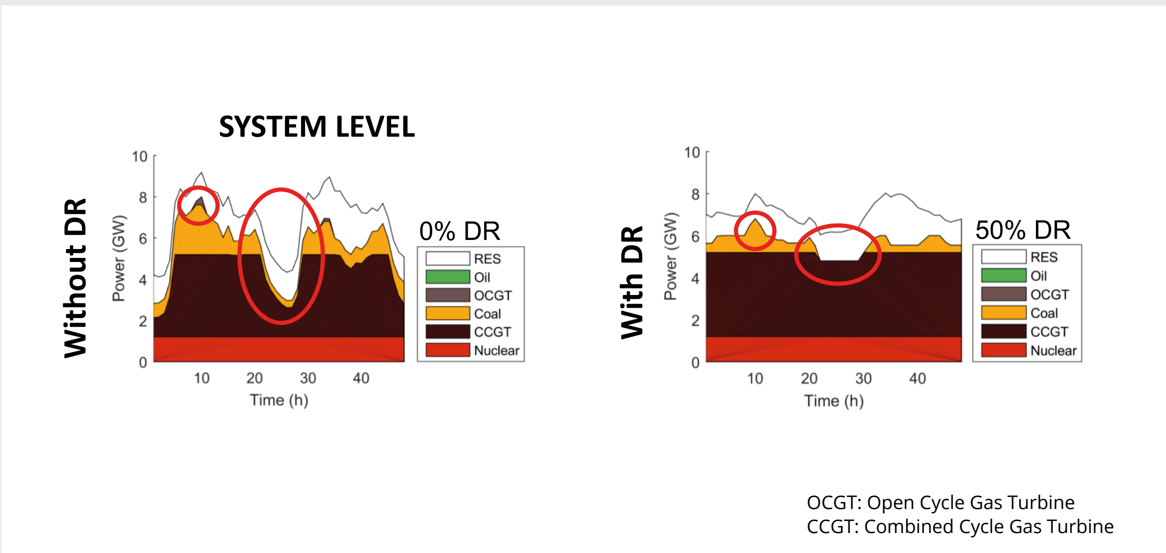

Fig. 4: The impact of DR at system level [1].

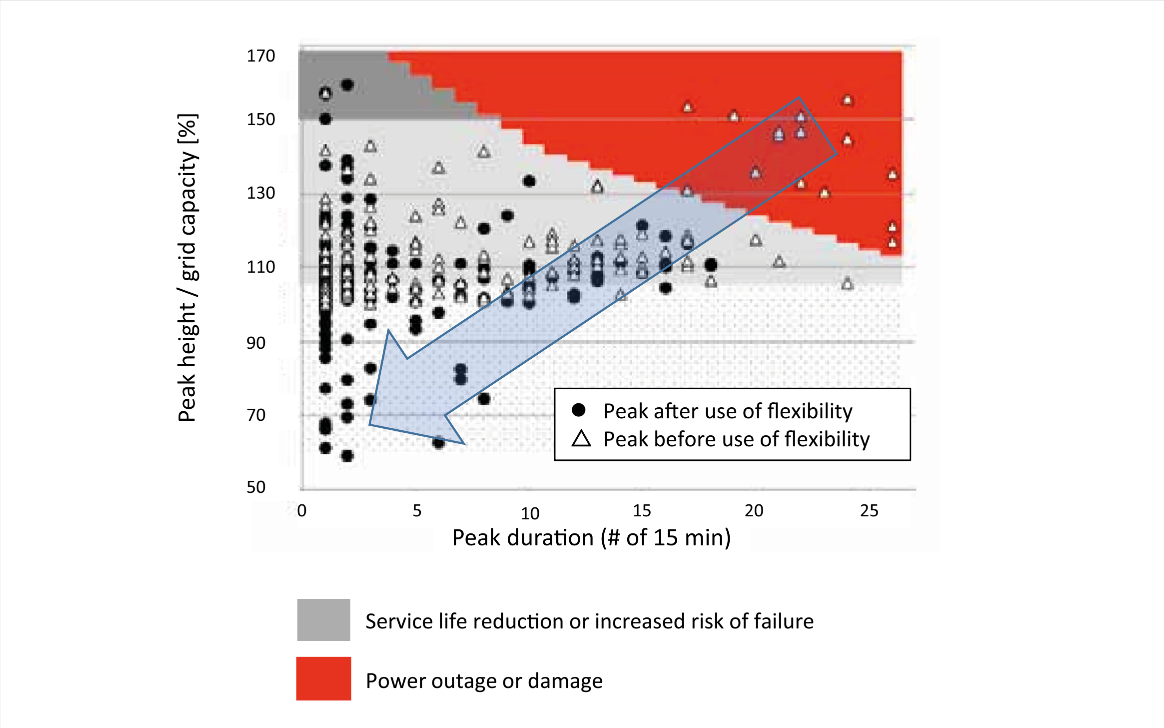

Fig.5: The impact of DR on building level [6].

of houses equipped with a heat pump is still very limited, let alone that households are engaging to offer their flexibility. There is still a long way to go... A challenge we all have to take!

Acknowledgements

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