Pooling of smart heat pumps provides flexibility to the electricity market and grids

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Smart heat pumps can offer their flexibility to the future energy system. They can be pooled together to become an active player on the electricity markets. Energy costs can be saved by using temporarily low energy prices to fill their storages and avoid operating at high price peaks. Furthermore, offering negative balancing services can be a profitable business case for the customer, if the IT costs can be held sufficiently low. However, if operated unfavourably, the thereby increased simultaneity might pose problems to the local distribution grid.

Introduction

The share of heat pumps in the distribution network has increased significantly during the last years, which may lead to the need for grid reinforcements in the future. On the other hand, smart heat pumps can be operated in a so-called "pool" and their operation can be optimized for the electricity market. However, this pooling leads to more simultaneity in the operation of heat pumps and could thereby cause additional grid problems.

This article analyses the potential future role of the heat pumps in the energy systems; it shows the possibly conflicting interests of the local grid and the electricity markets regarding optimal heat pump operation. It is accompanied by the results from a simulation case study conducted for the Austrian electricity market and three simulated local grids.

Heat pumps in electricity markets

Heat pumps - especially modulating ones - have very fast reaction times and can change their electric consumption within seconds. Heating systems often have a thermal buffer storage as well as a storage for hot water, and the building itself can act as a thermal storage. This makes the heating times quite flexible: after being heated up the system can usually run without power for several hours, since the buffer storage and the building have enough thermal capacity to still keep the air warm enough. If necessary, the heat pump can switch on very fast and consume electricity. This flexible behaviour can be used to optimize the electric consumption of the heat pump towards cheap prices on the short-term electricity markets, like the day-ahead and intraday spot market. The heat pump can be controlled so that it is turned on during low price times and switched off during high price times.

Another option is to use the flexibility to support the transmission system operator by providing balancing services. When the system needs positive capacity, the heat pump can switch off temporarily and when negative capacity is needed it can increase its consumption. Especially the second case can be a very interesting business case, since it (usually) means that the heat pump operator gets paid to consume energy. However, to participate in the balancing market, certain prerequisites must be fulfilled, such as market structures and prequalification criteria, which vary between countries. There is usually a minimum bid size of, for instance, 1 MW; this means that a single residential heat pump cannot participate in the market on its own. However, if several hundred heat pumps are aggregated and controlled together as one "pool" they can offer enough flexibility to participate in the market.

The flexibility influences the operation of the heat pump (e.g. operation cycles), hence a techno-economic assessment between flexibility and a possible increase of shut off/on times as well as the consideration of dead times is important. Moreover, the impact of flexibility on the comfort of heating and hot water supply has to be limited.

Heat pumps in electricity grids

The share of heat pumps in the residential sector has been rising continuously during the last few years, which leads to an increasing demand in the low voltage distribution grid [1]. This electrification of the heating sector, and the resulting increased consumption, may make grid reinforcements necessary in the future. However, with the above-mentioned pooling of the heat-pumps, the resulting simultaneity effect poses an additional threat: if several heat pumps in the same local grid area belong to one pool and react to the same market signal, they are prone to be switched on and off synchronously. This simultaneity could lead to grid congestions (thermal overload of assets or voltage limit violations) of typically between 94 and 106 % [2].

One method practiced by Austrian grid operators are so-called "interruptible tariffs". Then the heat pump owners allow the grid operator to switch them off during some time of each day ("blocking times"). In exchange they get a lower grid tariff. Another option would be the consideration of the heat pump locations: when sending a market activation signal, the aggregator could distribute it between heat pumps of different grids and activate heat pumps within one grid region slightly after each other. Thus the simultaneity could be reduced as the activation would be more evenly spread out by the variation of location and timing.

Operating strategies

As shown in Figure 1, heat pumps can follow different operating strategies. During conventional operation, the heat pump just takes the desired temperature levels in the building and the storage tanks into account. When adding a controller with a communication interface (see Figure 1), it can also react to external signals. In market-driven operation, those signals could indicate cheap prices on the spot market or required balancing services for the transmission grid operator. When following a grid-friendly operation strategy, the signal could come from the local grid operator to avoid congestion.

There are two general operating approaches that can be distinguished: central and decentral. In central operation there is one central intelligent controller, which is usually part of an aggregator. The aggregator receives the different external signals (grid, market, balancing services) and distributes them to the customers in the pool. However, in this case the aggregator needs information about the heating system (current temperatures, desired comfort levels). This means that a large amount of information will be exchanged. In the decentral approach, the controller and the information remain locally. Therefore, it is not guaranteed that heat pumps actually react to incoming signals, since the current status of the customer's system is not known exactly and needs to be predicted. This could lead to problems for the aggregator if the contracted flexibility cannot be provided.

An Austrian case study

The potentially opposing interests of the grid friendly operation and market optimization were analysed for a case study in Austria. With a group of heat pumps for single-family homes, potential revenues for the customers were calculated (Table 1). A model-based portfolio optimization was used for cost minimization on the day-ahead spot market as well as revenue maximization by providing manual frequency restoration reserve. This balancing service is used by the transmission grid operator, when longer imbalances occur between electricity supply and demand. Furthermore, the influence on three rural distribution grids for both existing and future heat pump penetration scenarios were analysed. Thus, electrical power flow simulations were used to compare the different heat pump operation strategies and their impacts on the electrical grid, namely: thermal overload of assets (lines, transformers), grid voltages (levels and unbalance) and heat pump coincidence factors.

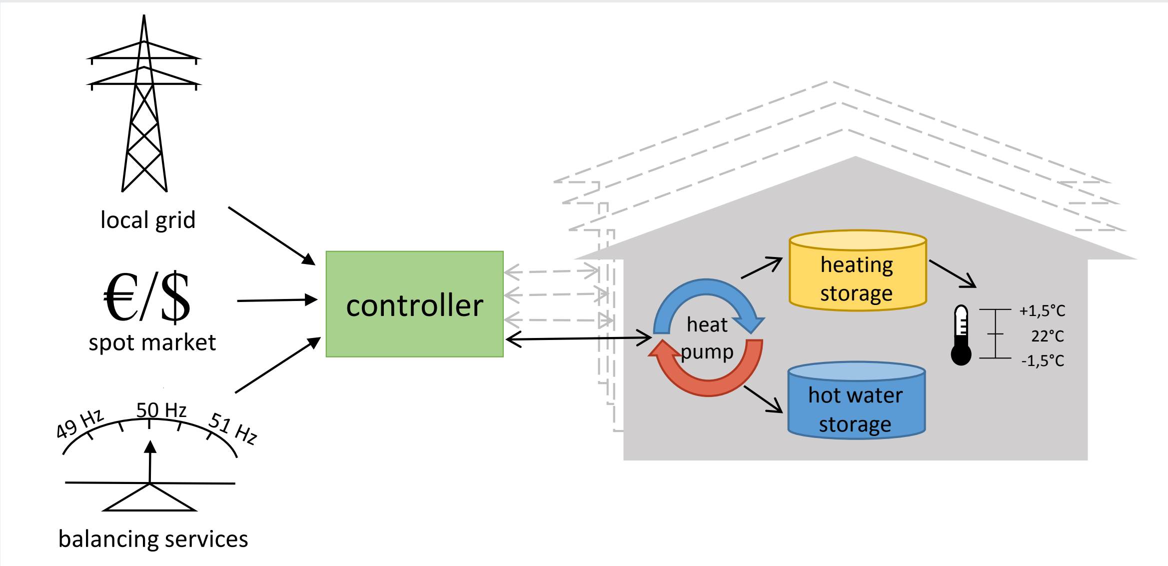

Figure 1: Schematic of different heat pump operation scenarios: grid friendly, spot market and balancing market.

	Passive house	Low energy building A	Low energy building B	Existing building	Renovated building
Heating demand	15 kWh/m²a	45 kWh/m²a	45 kWh/m²a	100 kWh/m²a	75 kWh/m²a
Heating system	Floor heating	Floor heating	Floor heating	Radiators	Radiators
Heat pump	Air-water	Air-water	Brine-water	Brine-water	Air-water
Thermal/ electrical power	3 kW/1 kW	5 kW/1.5 kW	5 kW/1.2 kW	12 kW/4 kW	7 kW/2.7 kW
Storage	DHW: 300 l	DHW: 300 l SH: 300 l	DHW: 300 l	DHW: 300 l SH: 500 l	DHW: 300 l SH: 500 l

Table 1: Analysed building types for the Austrian case study. The colors for the different types are the same as in Figure 2. [1]. (SH – System Heating, DHW – Domestic Hot Water)

Economic analysis

The economic analysis showed that a business case especially for the tertiary balancing market can be interesting, if integration cost for information and communications technology (ICT) are low [1]. Moreover, a combination of use cases, such as for example the combination with the increase of PV self-consumption, improves the business case. In 2016, the additional revenues for the participation in the tertiary balancing market were 18 – 73 € (20 - 79 USD)[1] per heat pump and per year. The heat pump pool participates more in the negative balancing products (the pool is paid to consume energy). With the optimization on the spot market, electricity cost reductions of 23 – 35 % (11 – 53 € / 12 - 58 USD) were possible for the year 2016.

The analysis shows that the flexibility potential of the building highly influence the results. In contrast to older and less efficient buildings, the passive house has a high potential for pre-heating, but has lower cost reduction potential due to lower energy consumption as well as lower power to offer on the balancing markets. The highest revenues could be gained with the existing buildings, since they have the highest heat demand. The season highly influences the flexibility potential; the pool has a higher potential during winter times.

Technical analysis and impact on grid

Grid simulation is performed in one minute time resolution with measured household load and PV in-feed profiles and heat pump simulations with realistic domestic hot water (DHW) and space heating (SH) demand profiles. A simplified heat pump model is implemented in the grid simulation application. The conventional operation is compared to grid friendly and market participation via arbitrage. In the grid friendly operation, the above mentioned blocking times are used, during which the heat pumps can be switched off by the grid operator. In a second improved grid-friendly strategy, the so-called "pre-charging", the thermal storages are filled before the off-period to avoid a high power demand after the blocking time.

The case studies of the three Austrian low voltage grids show that the impact of heat pump installations on the grid is lower than expected, see Figure 3, which shows the simulation results for one of the grids. The left-hand figure shows the variation of the lowest grid voltage while the right-hand figure shows the variation of the highest line loading, for the different scenarios. Even in the most extreme future grid penetration scenario, with more than 50 % of all buildings equipped with heat pumps (hp50), the median of the lowest voltage does not decrease significantly (left figure). Although grid constraints are violated in the shown grid, this grid is very close to its capacity limits even without heat pumps (scenario hp00). In addition, the median of the highest loading of the lines only increases by up to 10 %, as can be seen in the right figure.

Simulations showed that the blocking hours do not significantly relieve the grid, concerning the lowest grid voltage. The introduced pre-charging of the storages tends to bring some improvements. Furthermore, dynamic setting of blocking hours according to the actual grid loading in combination with a decentral control could further improve the situation for the grid.

[1] 1 € = 1.086 $ (January 1, 2016)

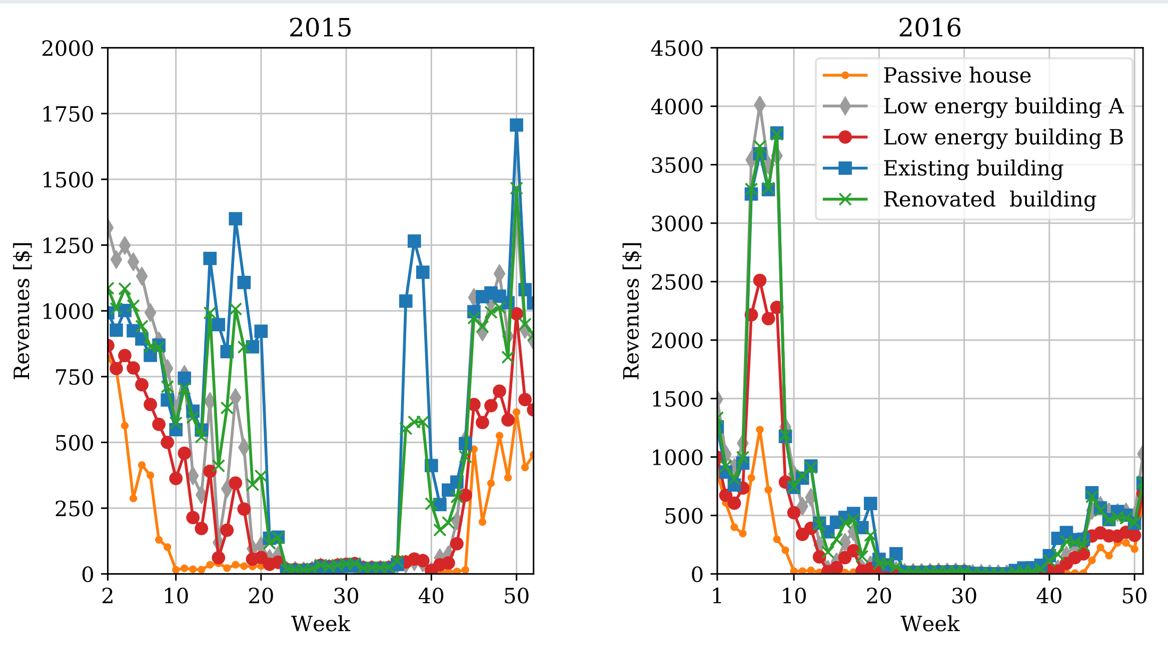

Figure 2: Possible weekly revenues for the customers, of a pool of 400 heat pumps with different building types, providing manual frequency restoration reserve (i.e. supporting the electricity grid during imbalances), for the years 2015 and 2016.

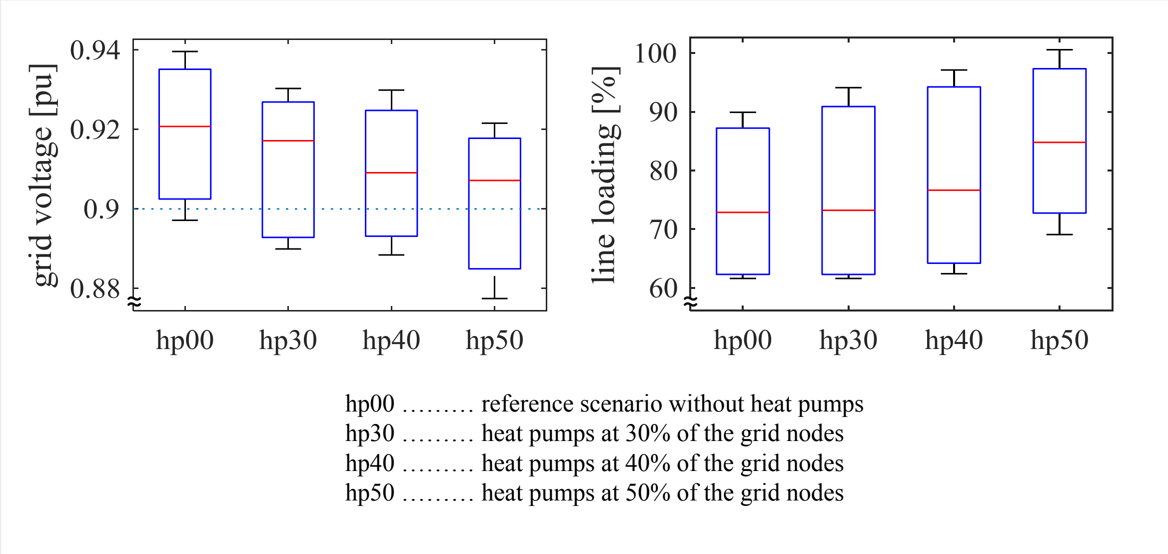

Figure 3: Variation of the lowest grid voltage (left) and the highest line loading (right) for the investigated heat pump penetration scenarios in one of the simulated grids. The dotted line in the left figure shows the minimum allowed voltage in the grid. The box plots indicate the median values (red lines) as well as the lower and upper quartiles (boxes) and the minimum and maximum values (whiskers). [2]

Conclusions

It has been shown that heat pumps potentially can earn revenues on the short-term electricity markets. Especially the negative balancing market can be an interesting business case if the ICT costs are sufficiently low. It will be important to also consider the heat pump characteristics and their efficiency to find the overall optimum. In the analysed case study, the impact of the heat pump pool on the distribution grid was not very large. However, in countries with weak distribution grids, this may still pose a problem in the future. Particularly the combination with other electrification trends, e.g., electric vehicles, can put further stress on the grids.

References

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[2] R. Schwalbe, M. Häusler, M. Stifter, T. Esterl, Market driven vs. grid supporting heat pump operation in low voltage distribution grids with high heat pump penetration – an Austrian case study, 12th IEA Heat Pump Conference 2017, Rotterdam 2017.

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