TECHNO-ECONOMIC ANALYSIS OF FLEXIBLE HEAT PUMP CONTROLS

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Overview

There exists a gap between flexibility needed within the German energy system and flexibility being actually provided. The flexibility gap is currently being expanded by two effects: First, big thermal power plants that used to provide flexible power supply are shut-down according to the list of closure notifications (BNetzA, 2017). Second, installed capacities of fluctuating renewable energy power plants are growing as they are planned to account for 50 % of German electricity production by 2030 and more than 80 % by 2050 according to section 1 (2) EEG.
In principle, there are different approaches to increase the amount of flexible loads in the system and thereby mitigate negative effects of less flexible energy supply (Lund, Lindgren, et al., 2015): strengthen grid flexibility by expansion, install storage capacities, implement local smart grids, and couple sectors to use synergies. Additionally, load shedding measures can be applied (Praktiknjo, 2016). Especially coupling the electricity and the heat sector has been proven to increase the possible share of renewable energies within the system in several studies (see e.g. Kiviluoma and Meibom, 2010; Niemi et al., 2012; Lund, Mikkola, et al., 2015). As the share of energy required for space heating amounts to almost 30 % of Germany's final energy consumption (AGEB, 2017), electric heating devices have huge potential to shift loads.
Based on increasing market shares, high efficiencies, and advancing communication technologies, Fischer and Madani (2017) conclude that heat pumps (HPs) can be seen to be the core technology to connect the heat and the electricity sector. We contribute to the scientific discussion by conducting a simulation of different *realistic and easily applicable* HP control methods in order to assess both their efficiency effects and their economic potentials.
To reflect realistic circumstances, easy and rule-based control algorithms are implemented that are wether state-of-the-art or likely to be applied in near future and can be realized with current HP control systems. No MILP formulation to minimize overall system costs or complex model predictive controls for whole building systems are implemented, because these complex approaches are only applicable to pilot trials and not for large-scale implementation, as of now. The guiding research questions within our manuscript are as follows: *Are currently applicable HP control methods that provide flexibility profitable from an efficiency and cost perspective? Does the ecological and economical profitability change for a more advanced HP control method for flexibility provision in the year 2030?*

Methods

We apply three different predictive rule-based algorithms to a validated MODELICA simulation model of a HP and compare the energy use (i.e. efficiency) and electricity costs to a reference case, where regular temperature control is applied: time of use (TOU) based control, spot market price based control (day-ahead prices), and residual load based control for future scenarios in 2030. All control schemes are implemented by varying the set temperature of a buffer storage according to price signals. Within our techno-economic analysis, we focus on a ground source heat pump (GSHP), which is connected to the electric grid of Germany. In order to assess financial consequences of the different control methods, three market models are applied:

(1) For TOU control, current market structures and tariffs are used. Nowadays, HP owners in Germany can often choose between a usual single tariff structure and dual tariff structures that differentiate between high tariff and low tariff times. In order to investigate financial consequences of their choice, actual tariffs being currently offered serve as source of data.

(2) For day-ahead price based control, current spot market data is used. *PHELIX* spot market prices of the heating season 2014/15 (EPEX Spot, 2016) were leveraged on domestic price level.

(3) For residual load based control, a market model of the future German electricity market is derived. The model is needed to assess economic consequences of residual load based control methods in 2030. Its derivation is based on the assumption of perfect competition and consists of two steps: First, the residual load curve needs to be set up.

Second, prices need to be associated to the residual load in order to be able to assess financial consequences for the HP owner. Due to the uncertainty of future developments, six different scenarios are analysed based on Trieb (2006).

Results

For the investigation of TOU tariffs, two main results are indicated: First, easy applicable control methods that are already used nowadays are able to reduce peak load consumption. Second, due to efficiency losses and current tariff structures, no financial gains can be achieved for the HP operator.

The analysis of day-ahead price based control reveales similar results: It is possible to make the electricity consumption of geothermal HP units follow day-ahead prices by applying easy, rule-based algorithms that can be implemented in current controlers. However, high efficiency losses prevent financial gains.

By studying a residual load based control method for GSHPs, we reveal very high efficiency losses of up to 70 % in comparison to reference control. Furthermore, our results show that the magnitude of these losses depends on the future development of the German power plant park: the more fluctuating the residual load curve emerges, the higher effifiency losses are caused by a flexible control method. Based on our market model, we show that financial gains through residual load based control methods are only to be expected in an ecological worst-case scenario.

Conclusions

We conducted a techno-economic analysis of three different HP control methods to provide flexibility. To do so, we used a validated MODELICA simulation model. Our findings imply that easily applicable control schemes can shift electricity consumption and thereby provide flexibility. However, high efficiency losses and cost increases need to be considered. As more efficient control algorithms to provide flexibility are too complex for large-scale implementation as of now, a new market design for flexibility provision can be claimed necessary to ensure incentives for flexible operation. Given current market conditions, there are no financial incentives for HP owners to shift loads. Nevertheless, TOU based controls are often implemented in practice. This behaviour can be explained by insufficient information on efficiency losses caused by such a tariff based mode of operation. For future research, we recommend to investigate, if efficiency gains for the whole energy system through flexibility provision by HPs are high enough to compensate for the units' efficiency losses. If so, the willignesses to pay for flexibility of different actors within the energy system need to be derived and business cases for HP owners need to be identified.

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