Impact of different control strategies on the flexibility of power-to-heat-systems

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Overview

Flexible electric loads are essential to overcome the challenges caused by the increasing share of volatile renewable energy sources in the European power system. Flexibilities of power-to-heat-systems in residential areas offer a promising option to react to the changing electricity supply as shifting their operation in time can be done without affecting the thermal comfort of the inhabitants in a negative way. Existing hot water tanks in combination with heat pumps or electric heating elements serve as the heat storage. The heating of the tank can be done whenever there is a surplus of electricity generated by wind turbines or photovoltaic systems. This flexibility, however, heavily depends on the control strategies of the heating devices as well as the technical endowment and heat usage-patterns. Currently, most often a conventional control strategy is used in which the heating device starts to heat the water when the lower temperature-limit is reached and terminates this heating process after the water reaches the predefined upper limit. In this study, we investigate the impacts of three different control strategies (*Small Upper Control*, *Small Lower Control* and *Middle Control*) on the thermal load flexibility of a single building equipped with a heat pump and a hot water tank. In the *Small Upper Control* strategy, the temperature in the hot water tank is as close as possible to the upper thermal limit of the tank. The consideration of minimal running times and minimal standby times, botch caused by technical limitations, ensures that the electric heating device is not permanently switched on and off. The *Small Lower Control* strategy is similar to the *Small Upper Control* strategy but in this case, the temperature is as close as possible to the lower thermal limit. The *Middle Control* strategy aims to have the temperature of the hot water tank around the middle of the upper and lower thermal limit while ensuring minimal running times and minimal standby times of the heating device. We compare the results of these strategies with the ones of the conventional control strategy.

Methods

Nuytten et al. used the concept of delayed and forced flexibility of thermal heating systems to quantify the flexibility of thermal energy storage for district heating [1]. Six et al. calculated the delayed and forced flexibility of a residential heat pump for one household [2]. The delayed flexibility (negative flexibility) measures the maximal amount of time a thermal storage can be cooled down without violating the lower temperature limit of the storage whereas the forced flexibility (positive flexibility) quantifies the time a thermal storage can be heated up without violating the upper temperature limit. We calculate those two measures for every timeslot of a day for each of the three strategies as well as for the conventional strategy. A heat pump with an electric power of 2500 W and a constant coefficient of performance of 4 is chosen for the analysis. The minimal running times and standby times are 15 minutes. We choose three different volumes for the hot water tank (300 litres, 400 litres, 500 litres) and analyse their impact on the temporal flexibilities. The upper thermal limit is 40 °C and the lower limit is 30 °C. We use heat demand data generated by the tool *synPRO* that has been developed by *Fraunhofer Institute for Solar Energy Systems (ISE)*. The resulting heat demand data was successfully validated against measured data of German single-family houses [3]. For our analysis we choose a typical German single family house with four inhabitants that was built after the year 2001 and whose energy efficiency level is high. A tool that requires the technical parameters and the heat demand of a day as inputs was implemented in JAVA to simulate and compare the different control strategies with a time resolution of 1 minute.

Figure 1 illustrates the temperature profiles of the three alternative control strategies for one day. By using the *Small Upper Control* strategy the positive flexibility is maximized whereas the use of the *Small Lower Control* strategy maximizes the negative flexibility. The goal of the *Middle Control* strategy is to balance the positive and the negative flexibility. We choose a uniform temperature model for the hot water tank. This means that the temperature is homogeneous within the tank and there is no temperature stratification. To calculate the temperature changes we use an energetic difference equation similar to [4].

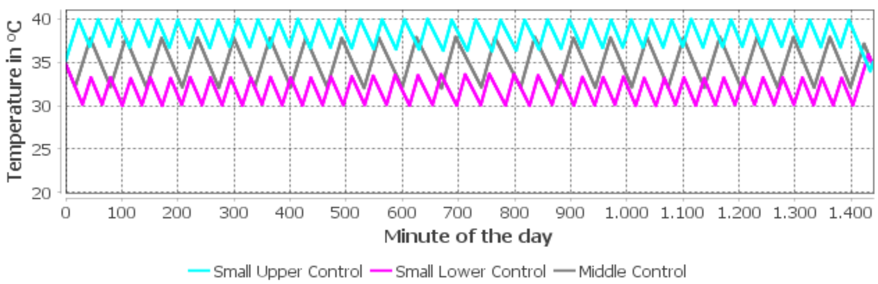

Figure 1: Temperature of the hot water tank for the three control strategies

Results

The average temporal flexibilities of the three alternative control strategies and the conventional control strategy are shown in figure 2. The *Small Upper Control* strategy leads to the lowest average positive flexibility and the highest average negative flexibility. As expected, the highest average positive flexibility can be achieved by using the *Small Lower Control* strategy but using this strategy leads to the lowest average negative flexibility. The values for the conventional control strategy and the *Middle Control* strategy are almost identical but the standard deviations s of the flexibilities of the Middle Control strategy are smaller (conventional control: $s_{Positive} = 13.3$, $s_{Negative} = 19.7$; *Middle Control*: $s_{Positive} = 8.1$, $s_{Negative} = 12.1$).

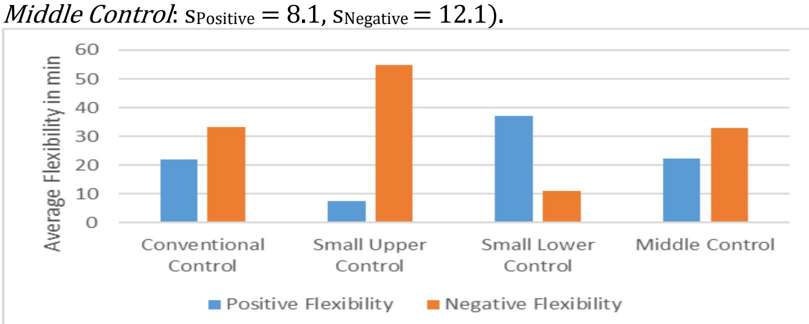

Figure 2: Average temporal flexibilities of the control strategies for one day

Conclusions

The usage of a hot water tank in combination with power-to-heat-systems offers load flexibility potentials that can help balancing supply and demand in future electricity grids with high shares of volatile renewable energies. In this study, we analysed different operational control strategies of electrical heating systems. These different control strategies can be used when strong intra-daily fluctuations of the supply are expected. The results show that there are significant changes with regard to the flexibilities between the *Small Upper Control* strategy, the *Small Lower Control* strategy and the conventional control strategy. The *Small Upper Control* strategy offers the highest average negative flexibility and the *Small Lower Control* strategy leads to the highest average positive flexibility. The *Middle Control* strategy and the conventional control strategy lead to relatively balanced flexibilities. We intend to investigate the impact of the outside temperature and the size of the thermal storage on the flexibilities.

References

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