Smart integration of heat pumps by predictive controls

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The integration of heat pumps into a PV and battery system faces the challenge of sharing the available PV power among the actors. In order to coordinate this competition, a suitable energy concept, as well as the control, must match. In a cluster of eight terraced houses, an energy system has been implemented, which should represent a smart integration of heat pumps. To coordinate the interaction of the components, model predictive controls are used. The simulation shows very good results for the predictive controls, but the results cannot be replicated in total practice.

The cluster of eight terraced houses is located in Herzogenaurach (Germany) in the new district of Herzo Base and was built in 2017. The buildings were designed as "all-electric buildings", which means that the core source of energy is electricity. A PV-system (88 kWp) on the roofs delivers an annual surplus of energy. The terraced houses share a central heat pump system of two modulating heat pumps (MHPs) of each 16 kWth, with a geothermal heat source as well as a battery system with a capacity of 40 kWhel. The supply of domestic hot water is decentralized in each terraced house by a domestic hot water-HP (Booster), which uses the heating buffer storage units as a heat source. The energy system is illustrated in Figure 1. All 8 terraced houses are equipped with floor heating and decentralized ventilation devices.

The idea of small neighbourhoods creating an energy community and sharing energy systems enables a higher potential to increase the PV self-consumption. Furthermore, synergies between different electrical loads lead to a more even electrical profile and reduces electrical load peaks. To tap this potential, smart integration of heat pumps into the energy system is necessary. Predictive control strategies, in particular, can contribute to an objective-oriented response to fluctuating PV generation. They enable efficient use of PV generation and increase the efficiency of the heat pumps. Similarly, available PV power can be targeted to heat pumps and storage systems to prevent competition for power [1].
Various controls were developed and tested in the terraced houses to evaluate their potential to increase PV use, efficiency, and operating costs. Besides two rule-based controls, a Model Predictive Control (MPC) and a simplified predictive control (SPC) are implemented. Monitoring has been carried out since April 2018 to evaluate the control strategies and the energy system.

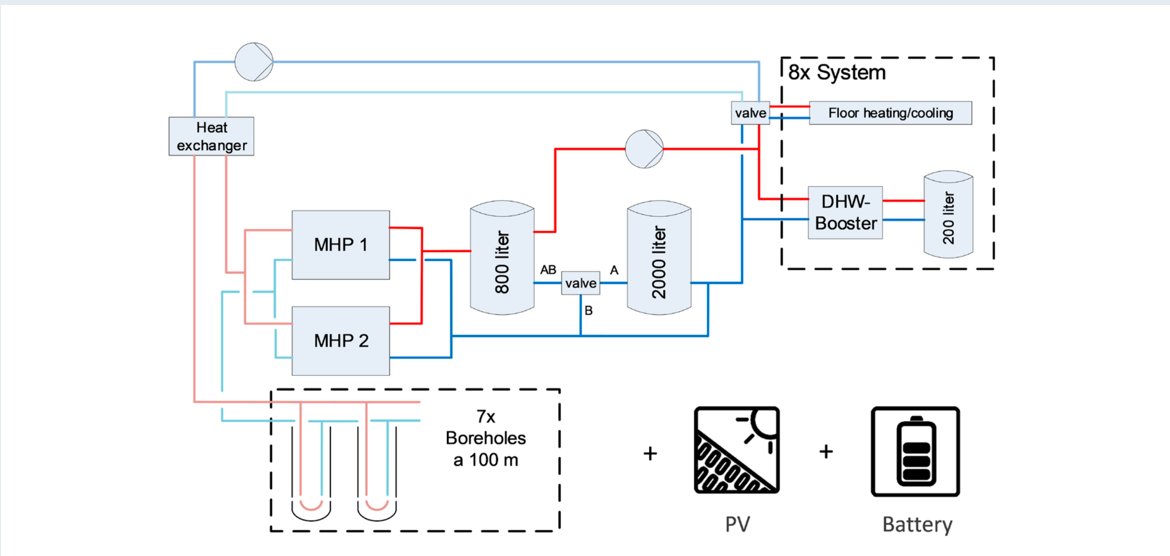

Figure 1. Energy system

Simulation and real operation

The standard operation in the energy system of the terraced houses is a PV-optimized control (PVC), which charges the thermal storage units up to a higher temperature level during PV generation. The PVC was fully commissioned in the second monitoring year in 2019. Thus, in the first monitoring year, the heat pumps were operated by a heat-controlled (HC) operation. In the monitoring years, PV generation has slightly decreased, and consumption has increased (see Figure 2). The increase is mainly due to household electricity and e-vehicles. Direct PV consumption and battery discharge have also increased and, most recently, by 16% compared to the 1st monitoring year. The increase in the 2nd monitoring year was quite high at 13% and remained the same in the 3rd monitoring year. This increase is partly due to the general increase in consumption but also due to the implementation of the PVC at the end of the 1st monitoring year. The simulation of the energy system with the PVC was implemented in TRNSYS and simulated with measured values from 2019. The simulation results show a higher load cover factor (LCF) of 68% and a supply cover factor (SCF) of 42%, which mainly results from a higher battery charge and discharge.

In order to introduce predictive control strategies, in the first step, a simulation study was carried out. In the second step, the control strategies were implemented in real in the terraced houses [2].

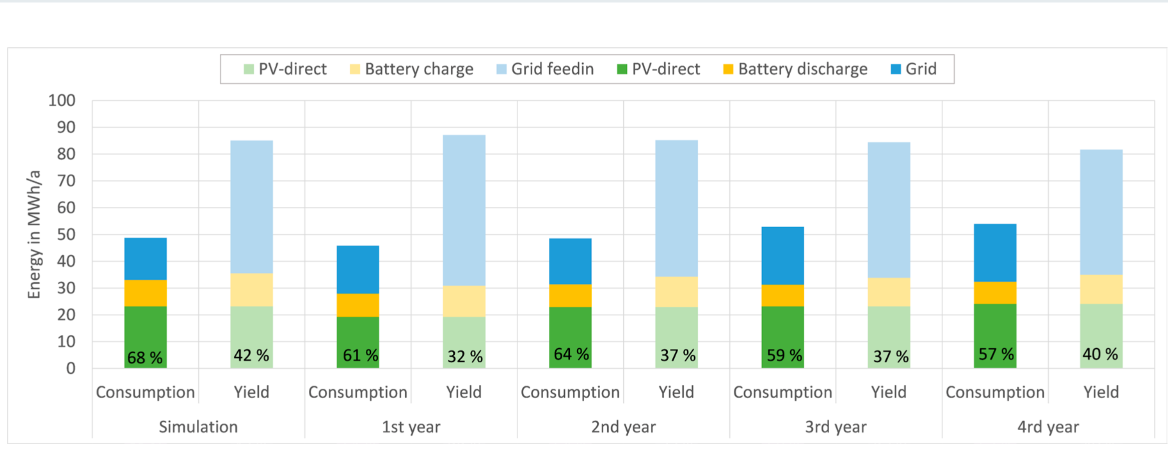

Figure 2. Results of simulation and monitoring years

For the simulation of the control strategies, measured data of the energy system of the terraced houses for the year 2020 is used. The simulation study was carried out in the MATLAB software. The rule-based approaches include the HC and the PVC. For the use of the predictive controls, MPC and SPC, forecasting models, which were realized by artificial neural networks (ANN) in Python with the library Tensorflow, are used to generate the thermal and electrical load forecast. The MPC approach is realized by a mixed-integer linear programming (MILP). All energy models are based on energy flows coupled in an energy node to receive linear models. The SPC uses the forecasting models as well as energy balancing to determine the heat pump operation and the state of charge of thermal storage units throughout the day.

The results of the simulation study are shown in Figure 3. The simulation of the control strategies shows that due to the large PV production, a very high PV self-consumption is already achieved in HC operation. Advanced control strategies, like MPC, increase the load cover factor by only 2% to 3% percentage points. Energy cost savings can be achieved, especially by MPC, by up to 34% compared to an HC operation. Even though PVC and SPC have slightly higher energy consumption, the operating costs are less due to the use of PV. Although the differences between PVC and SPC are small, favourable results are shown for the predictive approach. In addition to operation at PV production, efficient operation with high COP at partial load is crucial for energy cost savings.

To test the control strategies in real operation, the MPC and SPC are implemented in the real energy system of the terraced houses. Since December 2020, the energy system has been operated with the MPC and SPC in sections over several weeks. The process of MPC and SPC differs from PVC because an operating plan is created, which is passed on to the heat pumps. The operating plan of the MPC is created every hour, while the operating plan of the SPC is created only once a day at 6 am. For the comparison, MPC operation was tested for 42 days, and SPC operation was tested for 20 days during the winter of 2021 and 2022.

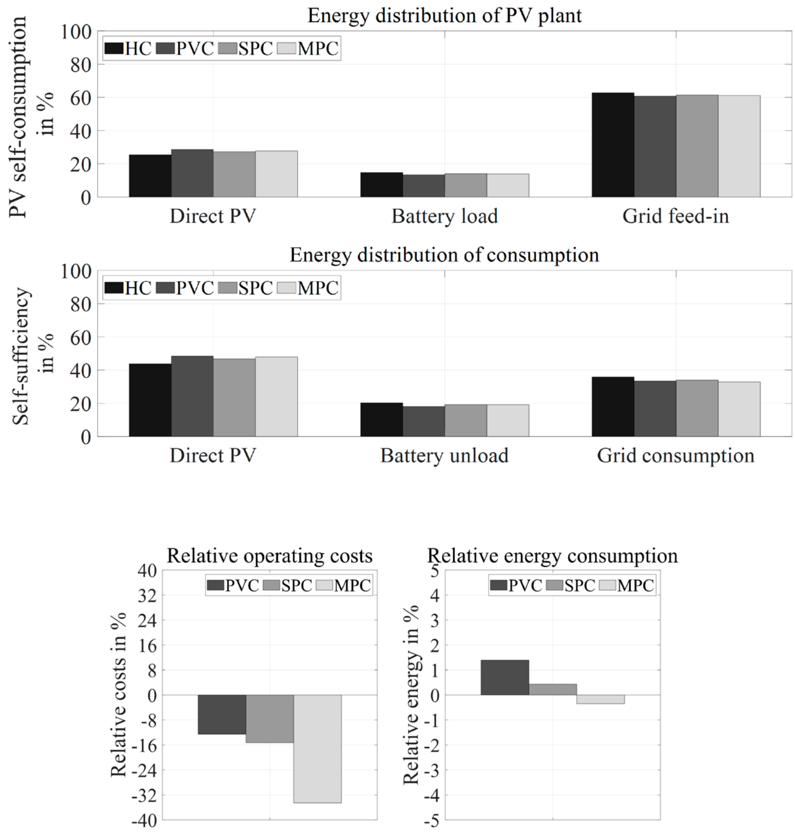

Figure 3. Energy shares regarding PV self-consumption and self-sufficiency (left) and relative operating costs and total energy consumption (right).

The real operation of the MPC and SPC shows that deviations in the prediction and modeling, as well as the interpretation of the setpoint from the online simulation, lead to different results in real operation. The operating costs of online simulation and measurement show deviations of – 64% and + 20% in the two predictive operating modes. In the case of MPC operation, the main deviations results from the PV prediction, which was 27% higher in the measurement, while energy consumption was only 15% higher. Thus, the feed-in bonus reduced the operating costs significantly.

Conclusions

The terraced houses present a smart integration of heat pumps into an energy system with PV and battery system. Due to the smart and predictive controls, the available PV generation is allocated to the components, and the competition between consumers and various storage units is coordinated.

The simulation shows very good results for the predictive controls, but the results cannot be replicated in practice. In the simulation, cost savings of up to 34 % can be achieved. In real operation, deviations of the operating costs up to - 64% can be seen compared to the result from the simulation.

In real operation, differences between offline/online simulation results and measured data become apparent. Since the setpoint specifications from the simulation can only be transferred to the real heat pumps in the form of setpoint temperatures, the operating plan cannot be fully implemented. To resolve this conflict, a more open control would be desirable in the future. As well, deviations in the prediction, especially the weather prediction, lead to different results. In order to get an overview of the full potential of the predictive controls, a long-term operation is planned.

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