The role of Heat Pump Control in Decentralized Energy Flexibility Exploitation

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Wide-scale adoption of heat pumps not only decarbonizes the heating and cooling sector but also increases the availability of energy flexible services. While new heat pump control strategies are investigated, the role of the implemented internal heat pump control by the manufacturer cannot be simply neglected, especially when third-parties want to directly control the heat pump. This article aims to summarize the effects of the internal heat pump control with the focus on energy flexibility provision while maintaining a system's perspective on the energy flexibility trading in a peer-to-peer manner.

In 2019, the combination of space heating/cooling (SH/SC) and domestic hot water (DHW) accounted for more than 75% of the final energy consumption within the European residential sector [1], while the residential heat pump (HP) market share was only 6% at the end of 2020 [2]. Fuel burner replacement by HP allows further decarbonization of the energy sector while increasing the renewable energy production allows a more sustainable energy provision as well. In such a scenario, HPs use a sustainable thermal source, while electrical energy comes from renewable resources as well. Though, the volatility of renewable energy resources puts additional constraints on energy security and requires supplementary energy flexibility. Due to their market potential, renewable character and coupling to the electricity grid, HPs are seen as one of the appropriate technologies for energy flexibility services. Usage of thermal energy storage or the thermal building mass allows energy shifting towards moments of renewable energy surplus. In this context, smart HP control strategies are investigated. Though, reaching an accurate short-term behavior control of HP is not straightforward as HP manufacturers already implement internal control strategies to ensure safety, reliability and satisfaction of the end-user comfort. The development of smart HP control strategies should already incorporate these internal control rules as these manufacturer constraints can generally not be bypassed and influence the short-term behavior. As grid users will be allowed to trade energy and flexibility services in the near future [3], an accurate estimation of the

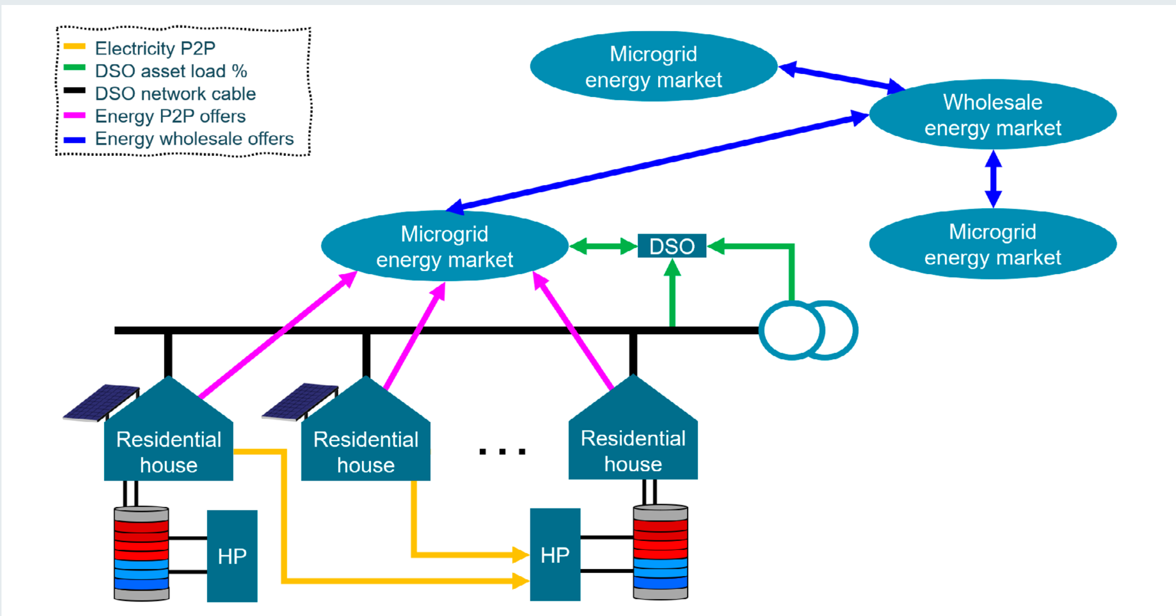

Figure 1. Microgrid energy trading.

real HP behavior is thus required. In this article, the role of HP control during energy trading will be summarized.

Microgrid energy trading

Figure 1 shows the transition towards distributed energy production with flexibility services. The distributed nature allows small groups of grid users, e.g. all users fed by a single distribution transformer, to join forces and introduce the concept of microgrids with peer-to-peer (P2P) energy trading. Within microgrids, users with energy excess (e.g. due to solar energy production) set a minimum selling price and energy level, while users with an energy shortage (e.g. due to a HP) determine a maximum buying price and energy level. After reaching an agreement, grid users directly trade energy among them. It allows to minimize grid losses and grid fees while local energy consumption is improved. Though, the coupling with the wholesale energy market is mainly kept for energy security and to allow users to buy/sell energy from/to energy retailers as well.

Considering a P2P market, the role of blockchain technology (BCT) is currently investigated as it allows transparent, secure and trustworthy transactions while excluding the full dependency on third parties. In contrast with public reading/writing access as in the domain of cryptocurrencies, energy trading via BCT has to meet more restrictive rules due to the grid infrastructure. In general, the goal of P2P energy trading is clear, while the system requirements, legal aspects, required grid parties, trading platforms and trading rules are still unclear.

Heat pump internal control strategies

Trading energy with HP is not straightforward as it requires an accurate knowledge of the actual HP behavior. Indeed, before submitting an energy bid, an estimation of the expected energy consumption is needed. Future energy trading within time slots of fifteen minutes is mainly expected due to the measuring frequency of smart meters, transmission system balancing processes, renewable energy volatility and due to the limited flexibility potential of residential appliances of a single user. Comparison of HP modeling approaches showed that an accurate energy performance representation is the main focus within the literature, while internal control strategies are mainly neglected. Figure 2 shows a general overview of the HP internal control strategies, including the coupling to an energy management system

In [4], Evens and Arteconi investigated the incorporation/neglection of these control strategies, both in the short- and long-term. While long-term effects were rather limited, short-term effects were clearly noticed and influenced the HP flexibility provision. By gradually increasing the modeling complexity and comparing annual short time step simulations, the duration curves of Figure 3 were constructed. Therein, the HP electricity consumption and HP outlet temperature of each modeling approach for each minute of the year were compared to a model closest to the expected HP behavior. It was shown that the HP operational schedule was not only time-shifted but also profile-modified due to the internal control. The HP model was built on a thorough understanding of the HP manufacturer manual.

To prove the validity of their model, a hardware-in-the-loop HP test bench was built. While the experimental campaign for the validation process showed the importance of the internal control strategies [5], a future work will include model calibration. Once a calibrated

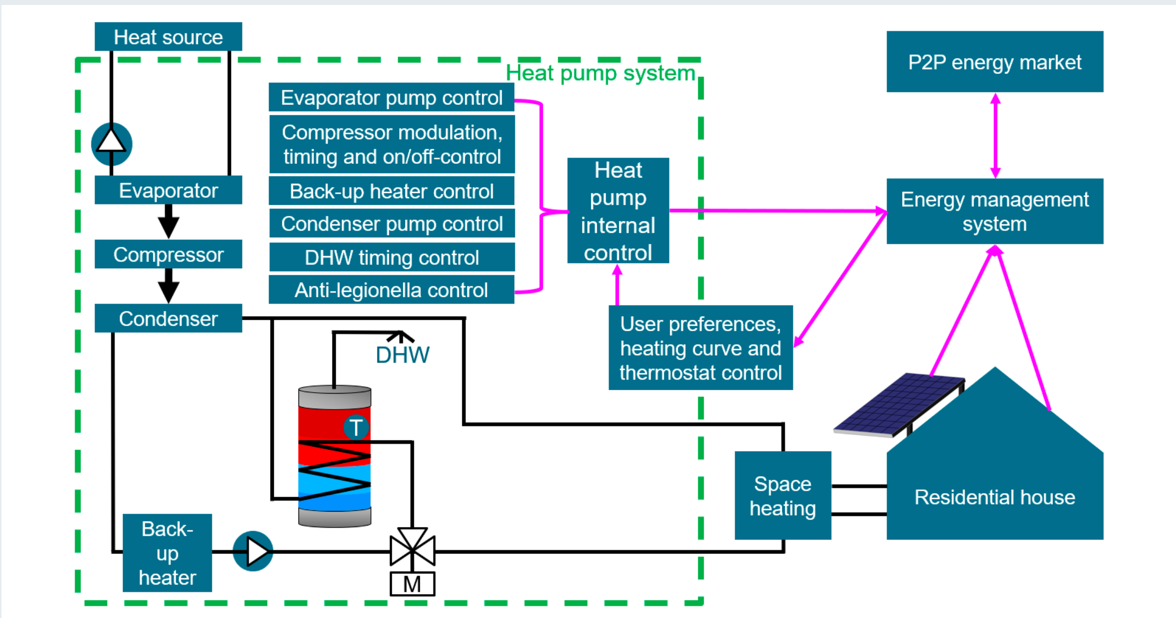

Figure 2. Overview of HP internal control strategies.

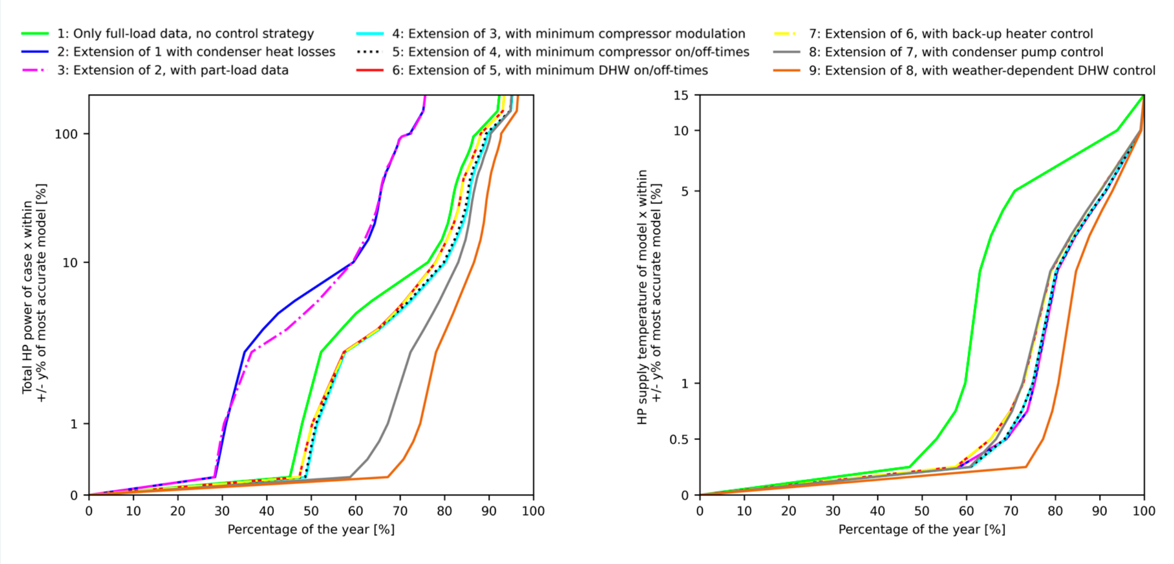

Figure 3. Duration curve HP modeling approaches [4].

HP model is obtained, it allows to accurately represent the actual HP behavior and to develop new strategies for energy flexibility.

Conclusions

The energy transition leads to the gradual replacement of fossil-fired appliances by heat pumps, while the volatility of renewable energy resources requires more energy flexibility. In this context, new heat pump control strategies for energy flexibility provision are investigated. A preliminary step is to obtain an accurate knowledge of the heat pump's internal control strategies, already implemented by the manufacturer, as these control rules can generally not be bypassed. Also, energy trading by end-users in microgrids requires an accurate estimation of the heat pump behavior and energy flexibility potential during the trading interval. Again, the internal control strategies change the operational behavior and can affect the estimated flexibility potential. Hence, developing smart heat pump control strategies requires an accurate knowledge of the real heat pump behavior.

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