Large-Scale Demand Response of Heat Pumps to Support the National Power System

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In a power system with an increased share of electricity from intermittent renewable sources, such as wind and solar, a more flexible electricity consumption will be needed. In this article, the possibilities and constraints to control residential heat pumps on a large scale are investigated. The goal is to support the electricity grid with demand response based on the heat pump manufacturers' already existing hardware and cloud solutions. The article discusses barriers related to technical constraints in the heat pumps and the electricity market, as well as potential communication standards and cybersecurity.

Introduction

We see a clear trend of intermittent electricity production from wind and solar increasing all over the world. In a power system with an increased share of electricity from intermittent renewable sources, a more flexible electricity consumption is most likely needed. Flexibility, also called demand response, can help reduce problems due to bottlenecks and shortage of capacity in the electricity grids, as well as avoid curtailment of renewable energy sources. Today, there is ongoing work to find affordable solutions to increase the robustness and flexibility of the power system.

The findings in the article are based on expert interviews with relevant stakeholders, literature review, and field tests carried out within the Swedish research project "Large scale Electrical Grid Flexibility Control of Heat Pumps", financed by the Swedish Energy Agency. The article focuses on Swedish conditions, but the results are likely relevant in several countries. Barriers related to technical constraints in heat pumps and the electricity market as well as communication standards and cybersecurity, are discussed for a concept where heat pumps are controlled on a large scale to support the electricity grid. The concept uses the heat pump manufacturers' existing hardware and cloud solutions to communicate the load control to the individual heat pumps.

Demand response of heat pumps

Controlling individual heat pumps for demand response via the manufacturers' already existing cloud and application programming interface (API) would enable rapid deployment of heat pumps as a flexibility resource. If no hardware changes are needed to get the flexibility solution up and running, the investment cost to use heat pumps as flexibility resources is lower compared to solutions where new hardware is needed.

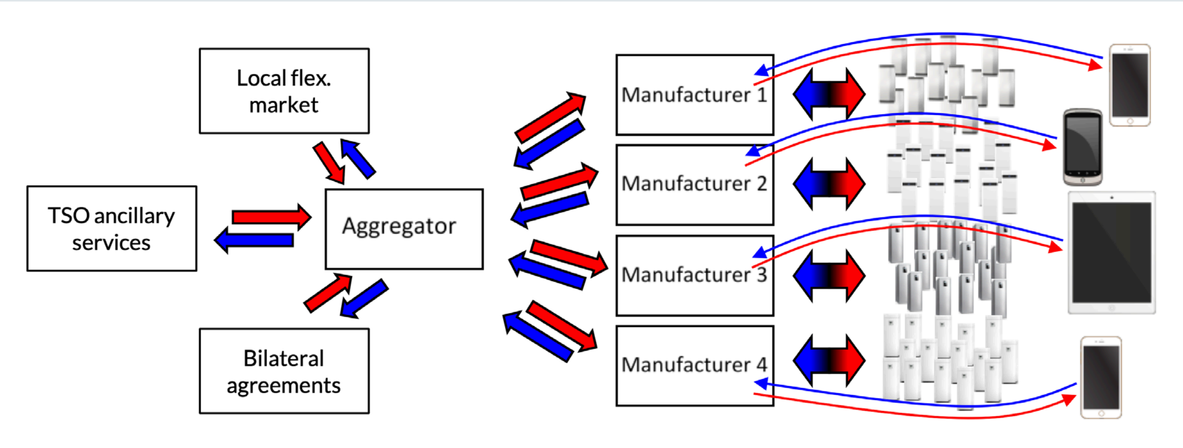

Figure 1. Overview of the communication flow for demand response from heat pumps using the manufacturers' cloud solution.

The manufacturers' cloud and API solutions have been in use for approximately ten years, which means that many installed heat pumps are ready to be used for flexibility purposes once the communication is in place. In Sweden, all the major manufacturers of hydronic heat pumps provide users with functionalities for controlling and monitoring their heat pumps via an app by connecting the heat pump to the manufacturer's cloud infrastructure. From a control point of view, functionality is still lacking to enable demand response to the power system via these cloud services, but as the hardware has been in place for several years, the potential of heat pumps with the hardware already installed is assessed as large. Figure 1 shows a schematic overview of the proposed communication flow to deliver flexibility from heat pumps to the power system.

Communication standards

For the communication between the aggregator, the cloud service, and the individual heat pumps, there are existing communication standards to use. A first, high-level evaluation points out four interesting alternatives. OpenADR and IEEE 2030.5 are two US-based standards that seem to have great potential for enabling demand response from heat pumps. A potential drawback is that they are not that common in Europe today. Interesting European alternatives are EEBus and EFI/S2. All these four standards are free to use or can be bought at limited costs.

Flexibility services

Using heat pumps for demand response is still in the start-up phase, but there are identified potential markets for demand response. Here, we focus on demand response from aggregated heat pumps delivering explicit flexibility to the power grid by having 1) a bilateral agreement with a grid owner, 2) participates at the Swedish Transmission System Operator (TSO, Svenska kraftnät) ancillary services or 3) is active at a local flexibility market. Implicit flexibility, when the heat pump adjusts its heat production based on variations in electricity prices or to lower costs for power tariffs, is not within the scope, neither are conditional agreements included. See Figure 2 for an overview of different flexibility services.

Electricity market barriers in Sweden

Traditionally, aggregated resources, like residential heat pumps, have not been used for the TSOs balancing markets in Sweden, given that the requirements are not always adapted for the new resources. Today, there is even a volume limit of about 10%-15% on the Frequency Containment Reserve (FCR) market for bids from aggregated resources, indicating how cautious the TSO is on these new flexibility resources.

An obstacle for heat pumps to participate in the balancing markets is the lack of standards and definitions of demand response. For example, there is no standard for verifying delivered flexibility today. Each actor must describe this themselves and define their own working methods and how to measure and evaluate their performance. Another barrier is the minimum bid size (100 kW electricity or more) for the balancing markets, which requires the aggregation of many heat pumps. A third barrier is the need to have the same balance responsible party (BRP) for all customers in a bid. The likelihood of customers having the same BRP is very low, as there are several BRPs in Sweden, which is a significant obstacle to scaling up demand response.

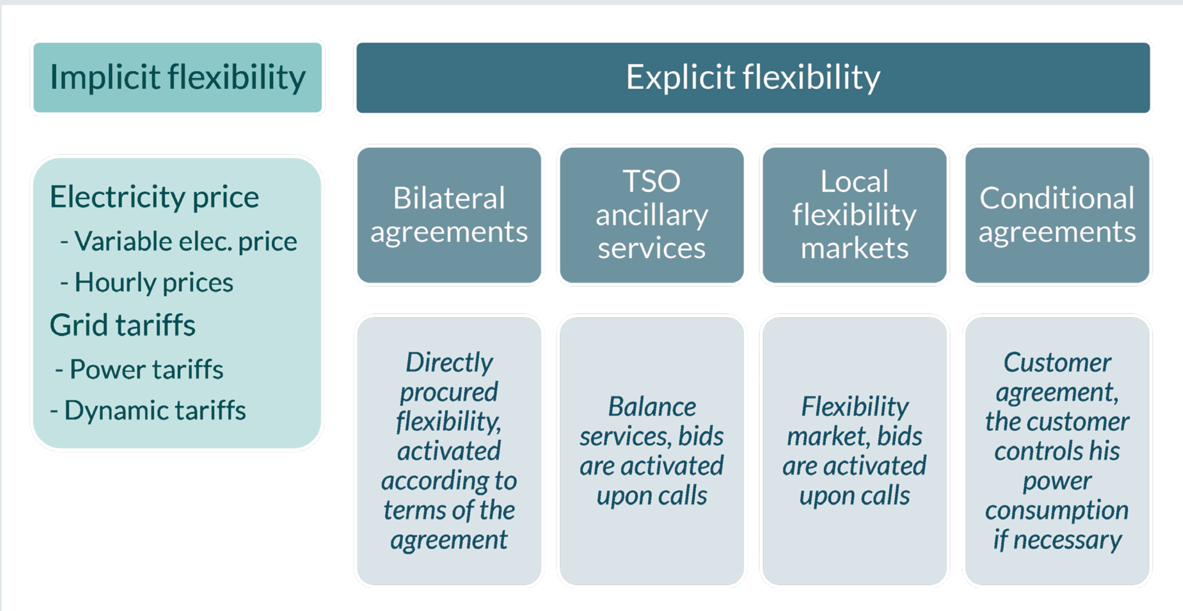

Figure 2. Overview of different flexibility services to the power system [1].

There is also a market requirement for the balancing service provider to measure their flexibility resources in real-time. This can be costly and difficult for an aggregator because heat pumps are usually not measured individually today. This obstacle can be hard to circumvent. Either real-time measurement needs to be added to each participating heat pump, or the aggregator needs to get an exception from the TSO to instead measure or calculate the delivered flexibility in another way.

Technical barriers in the heat pump

Technical experts from the four major heat pump manufacturers in Sweden were interviewed about technical obstacles and possibilities of using their heat pumps for demand response.

As the current heat pumps lack electricity meters, alternative ways to measure or estimate the power consumption were discussed with a focus on measurement uncertainty. Variable speed drive (VSD) heat pumps may have the possibility to measure the power consumption within the inverter, controlling the speed of the compressor. On/off compressors have no technical possibility to measure the power consumption; instead, it needs to be calculated based on the operating temperatures of the compressor and known compressor equations. Based on discussions with the experts, the estimated measurement uncertainty of the power consumption for VSD heat pumps is 2-10%, while on/off heat pumps have an uncertainty of 10-20%. The auxiliary heater has an uncertainty of 0.5-5% if the voltage is known; otherwise, the uncertainty is higher.

For heat pumps, the required activation time for the different flexibility markets is an obstacle. The experts had common ground in how fast their heat pumps could be controlled to decrease or increase power consumption. The auxiliary heater can change its power in a second, but it may need new software to work as a flexible resource. In normal operation, the use of the auxiliary heater in the heat pump is minimized to keep performance up. On/off compressors can also stop in a second, but they need some time to restart. VSD heat pumps are much slower to change their power. It can take minutes to start or stop them or control their speed when they are already running. Control-wise improvements can likely be made to speed up the process of starting and stopping, but some technical aspects will still limit what is possible.

The requirements for the TSO's different ancillary services were discussed, and according to the experts, the heat pumps can technically meet the requirements for FCR-N and FCR-D services, which need 50% activation in 5s. However, they doubt that heat pumps can meet the FFR service, which needs activation in less than 2s. aFRR and mFRR have longer activation times, and it will likely be possible for heat pumps to fulfil the requirements also for these two services. The answers should not be interpreted as an indication that solutions are ready, which might well be the case, but rather that the issues in question are technically feasible to solve by adopting such solutions.

Cybersecurity

Heat pumps need to be controlled over the Internet to effectively contribute to flexibility. This can, as for all Internet-connected devices, make them vulnerable to cyberattacks. On top of ensuring secure interaction with heat pumps, a key cybersecurity challenge stems from the long lifespan of the heat pump systems. Heat pumps are expected to operate for at least 15–20 years, and new cyber threats may demand software and even hardware updates for many years.

The threat from cyber-attacks must be taken seriously as hacked heat pumps could, at least in the future, cause severe problems not only for the heat pump owner but also to the national power system. In the report "Förslag på åtgärder för att möta cyberhot mot elsystemet" [2], RISE has shown that a large-scale cybersecurity attack on heat pumps can already today cause a significant impact on the Swedish power system.

Conclusions

The article investigates a concept where residential heat pumps are aggregated and controlled via the manufacturers' cloud service to support the power system with demand response. Delivering flexibility to the power system is a new area for the heat pump industry, and these new functions are outside their core business today.

There are still several barriers to overcome to make it easier to use residential heat pumps for flexibility. The benefit of using the concept described in the article is that all hardware needed to control the heat pump for demand response is already in place, and many older heat pump models have had the hardware for several years. Thereby, the investment costs to use heat pumps as a flexibility resource will be lower compared to the alternatives. What may be missing is whether electricity meters will be required to measure the delivered demand response from the individual heat pumps.

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