HEAT PUMPS IN MULTI-FAMILY BUILDINGS USED AS A FLEXIBILITY RESOURCE FOR FREQUENCY BALANCING AND CONGESTION MANAGEMENT

Rebecca GRILL	Sabina OEHME	Yvonne RUWAIDA
WSP - Sweden	4C Strategies – Sweden	Vattenfall Eldistribution AB - Sweden
Rebecca.grill@wsp.com	Sabina.oehme@4cstrategies.com	Yvonne.ruwaida@vattenfall.com

ABSTRACT

There is an increased demand for the ability to be flexible in the electricity generation and consumption due to more renewable energy and new consumers with high power demand. Demand response is one of several ancillary and flexibility services that can be used as a flexible resource for electricity consumption to ensure a high electricity quality and security. Heat pumps in multi-family buildings have been recognized as a potential demand response solution. This paper discusses two possible opportunities for using heat pump flexibility as demand response. A balance responsibility party can utilize the flexibility to trade energy or power at different balance markets for frequency balancing and financial purposes, while a distribution system operator can use the flexibility to manage congestion in local grids.

The results show that the benefits of steering flexible loads are dependent on coordination between the actors and access to an advanced predictive steering algorithm. One actor's use of demand response can result in negative effects for the other actor. A holistic approach must therefore be taken when developing a market for demand response solutions to ensure that the solution in itself do not cause larger problems than it is designed to solve.

INTRODUCTION

The share of renewable energy has increased steadily in Sweden, and Europe, and is expected to continue to do so [1]. The increase of intermittent energy sources, such as solar and wind energy, increases the need for the ability to adapt the electricity generation and consumption to maintain the frequency balance and ensure a high electricity quality [2]. At the same time, Distribution System Operators (DSOs) are experiencing new challenges with new consumers, driven by environmental reasons or digitalization, that wants to connect to the power grid. Large new consumers such as data centers and electricity vehicle infrastructure demand a high power capacity, which makes the power load curve hard to predict. The congestion challenge occurs in the local grids, where new consumers want to connect faster than the lead-time for building transmission grid allows [3].

Unpredictable electricity production and larger electricity consumption variations calls for demand flexibility solutions as a frequency balance as well as a congestion management tool. Demand flexibility in a power system refers to the ability to adjust electricity consumption in a system [4]. Demand flexibility can therefore facilitate an increased implementation of renewable energy sources as it can adapt the electricity consumption based on the production from intermittent energy sources. Thus, the electricity quality and security is maintained during the transformation to a more sustainable and digital society. Demand flexibility can be utilized through a demand response solution that enables consumers to shift or reduce their electricity usage during peak periods in response to external signals e.g. electricity price rates.

Heat pumps have potential to serve as a demand response solution in the electricity grid. The thermal inertia of the building envelope can be utilized in a demand response solution together with heat pumps without affecting the indoor temperature as the indoor temperature will decrease slowly after the heat pumps are turned off. Several studies have focused on the heat pump flexibility potential in detached houses whereas this article discusses the potential to utilize larger heat pumps in multi-family residential buildings as demand response [4;5;6].

DSOs can use demand response from heat pumps for local congestion management while a Balance Responsibility Party (BRP) can use it to maintain frequency balance in the Swedish electricity system. The balance market is established and regulated in Sweden, while demand flexibility as a congestion management resource is an emerging market. The balance market is in need for additional flexibility resources and is under development. When evaluating demand flexibility solutions, it is important to include both the BRP's and the DSO's perspectives as the use of flexible loads affects both actors. This article investigates if, and when, the positive and negative effects from using demand response from heat pumps coincide for the BRP and DSO.

HEAT PUMP FLEXIBILITY MODEL

A model for determining heat pump flexibility has been developed in Oehme's thesis [7] for a larger number of multi-family buildings. Oehme's model is based on

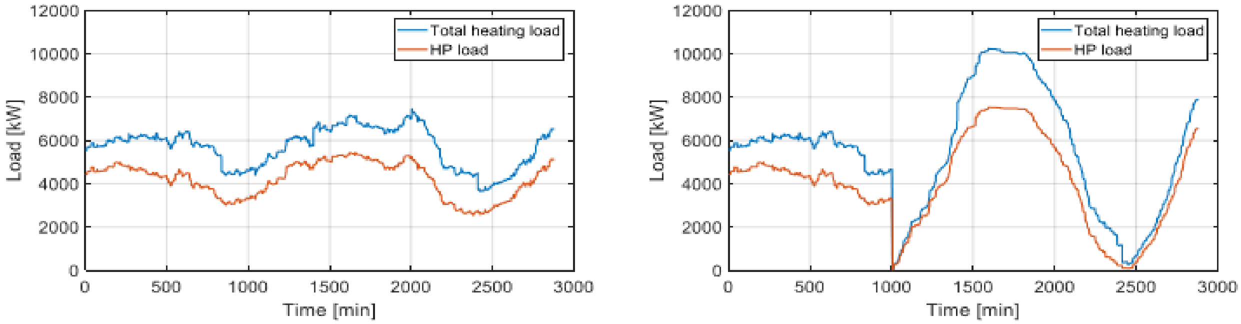

Figure 1. The left figure shows the heat load curve without a steering and the right figure with a steering, turning the heat load off until the indoor temperature reaches a lower limit. The ambient temperature affects the flexibility resource as it determines for how long the pumps can be turned off.

Sandels' single multi-family residential building load model [8] which employs Widén's stochastic non-homogenous Markov chain module [9] to capture and simulate the electricity consumption behavior of the residents. The aggregated heat pump model considers end users' behavior, the heating, ventilation and air conditioning systems, the buildings' thermodynamic properties, the ambient temperature and the space heating system design. The model facilitates an assessment of the flexibility, defined in the seven parameters, that heat pumps provide as demand response [7]. Figure 1 illustrates how the heat load profile changes after a steering where the heat pumps received an off signal that turns them off. A demand response control signal results in a more oscillating load profile due to the synchronization of the heat pumps as they all turned off within a short time interval and then turned on again when the indoor temperature exceeds a lower limit.

An oscillating load profile can generate large problems for a DSO if the peak load coincides with a time of grid congestions. There are often two peak power periods per day in local grids, where using flexibility to minimize the first peak can result in a higher second peak as can be seen in figure 2 due to synchronized heat pumps. A more advanced predictive controller may not experience the same oscillation load profile after a steering but it is important to illuminate the possible complications with demand response solutions that are not managed correctly. With a more advanced prediction, the steering can be optimized to minimize both peaks by steering parts of the load during the first peak and the rest during the second peak as shown in figure 3.

ELECTRICITY TRADE MARKETS

The Swedish electricity market consists of several market places for physical trading of electricity where heat pumps as a demand response solution can participate on the balance markets if it meets the requirements [10]. Nord Pool Spot holds the responsibility for the day-ahead market Elspot and the intra-day market Elbas, whereas Svenska kraftnät is responsible for the Swedish balance markets. Svenska kraftnät maintains the power system balance through financial incentives to BRPs on different balance markets [11]. The electricity supply and demand vary between different regions [12]. The day-ahead and intra-day market are therefore divided into various bidding areas, where Sweden consists of four electricity price regions (SE1, SE2, SE3 and SE4) [11]. If the available transmission capacity is large enough to compensate for the supply and demand differences by transferring capacity, it will result in similar electricity prices in the different electricity price regions [13].

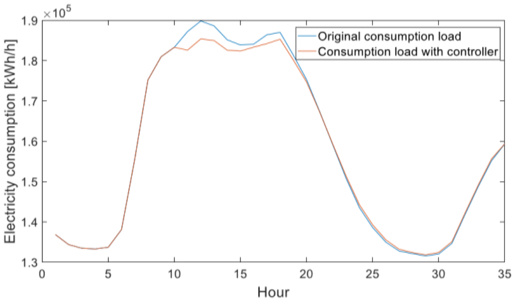

Figure 2. Non-optimized steering where the entire flexible resource is used during the first peak

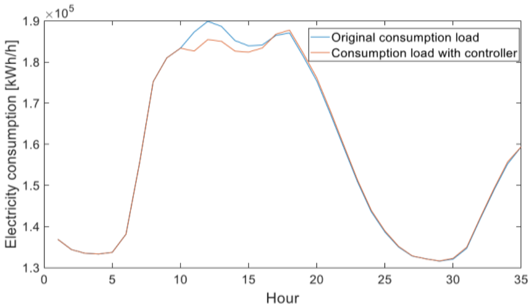

Figure 3. Optimized steering where both peaks are minimized

Table 1. Frequency balance markets in Sweden

	Primary control		Secondary control	Tertiary control	Power reserve
	FCR-N	FCR-D	aFRR	mFRR	Power reserve
Reimbursement	Power and energy	Power	Power and energy	Energy	Power and energy
Min. bidding volume	0,1 MW	0,1 MW	5 MW	10 MW SE4: 5 MW	SE3 and SE4: 5 MW
Required capacity in Sweden	200 MW	400 MW	100 MW	-	187 MW for consumption
Activation time	63% 1 min 100% 3 min	5% 5 sec 100% 30 sec	100% 2 min	100% 15 min	100% 15 min

MARKETS FOR TRANSIMISSION AND DISTRIBUTION GRIDS

The Transmission System Operators (TSOs) control the power system and ensure that the electricity production corresponds to the consumption every instant. The system frequency is 50 Hz when there is an energy balance in the Nordic power system. If the electricity production is larger than the consumption, the frequency increases and needs to be down regulated by a decreased production or an increased consumption. If it is the other way around, the frequency level needs to be up regulated by an increased production or a decreased consumption. Heat pumps are controlled with the purpose of decreasing the electricity consumption during up regulation. Svenska Kraftnät charges the BRP an additional regulation price if the BRP's imbalance volumes contribute to the system's total imbalance, while they pay the BRP the additional regulation price if the BRP is counteracting the system's imbalance by for example using demand flexibility. The frequency balance can be controlled both automatically and manually by primary, secondary or tertiary control shown in table 1 depending on the frequency level deviations [14]. Aggregated number of heat pumps as a flexible load has an activation time of about 6 minutes and can therefore only participate on the mFRR and power reserve market. This study is focused on the mFRR market as Grill concluded in her thesis that it is more financially beneficial to use heat pumps as a flexible load on the mFRR market than on the power reserve market for frequency balancing purposes [15].

There are currently no markets available for DSOs to use flexibility services, but some initiatives have occurred during the last few years. The DSO *Upplands Energi* uses flexibility from heat pumps together with Ngenic in detached houses for better indoor temperature, energy savings and peak shaving [16]. The DSO *Vattenfall Distribution* and *Ellevio* have started working with congestion management by unlocking power flexibility through bilateral treaties. *Svenska Kraftnät, Vattenfall Distribution and E.ON Energy distribution* are working on markets for flexibility where TSOs shall act in a coordinated manner to procure and activate grid services in the most reliable and efficient way through the implementation of TSO-DSO-consumer demonstrations at large-scale within the European Union's Horizon 2020 research and innovation program [17].

European politics encourage DSOs to use flexibility and are working on the implementation of rules and incentives expressed by the proposed article; ”Member States shall provide the necessary regulatory framework to allow and incentivize distribution system operators to procure flexibility services, including congestion management in their service area, in order to improve efficiencies in the operation and development of the distribution system.” It is therefore interesting to investigate how the grid congestion is affected when heat pumps are used as a flexible load for frequency balancing purposes as well as how the BRP is affected when it is used for congestion management.

AGGREGATED NUMBER OF HEAT PUMPS AS A FLEXIBILTY RESOURCE

Load data from a local grid in a larger city region and regulation prices on the mFRR market in the same region have been analyzed in Grill's thesis [15]. The load profile from Oehme's simulations [7] was used to evaluate how the BRP and DSO are affected when steering heat pumps for the two purposes and with different strategies:

1. Frequency balancing on the mFRR market by steering heat pumps when the additional up regulation price exceeds 50 SEK/MWh or 100 SEK/MWh.

2. Congestion management in a local grid and/or optimizing the subscription cost for the local grid towards the regional grid when the cost for exceeding the power subscription level is set to 252 000 SEK/MW/year for the DSO. The analyzed power load level is the average between the two highest power loads during a year. Several steerings are done at different power load levels.

The results from the different steering purposes are compiled in table 2.

Table 2. Compiled results from steering heat pumps for the purposes of frequency balancing and congestion management.

		DSO consequences			BRP consequences	
		Financial		Peak load	Financial	
Balance steering	2016	***Negative impact***	Steering at 100 SEK: −11 519 SEK 50 SEK: −53 855 SEK	***Higher***	***Positive impact***	Steering at 100 SEK: 75 312 SEK 50 SEK: 95 814 SEK
	2017	***Negative impact***	Steering at 100 SEK: −68 250 SEK 50 SEK: −116 123 SEK	***Higher***	***Positive impact***	Steering at 100 SEK: 297 643 SEK 50 SEK: 279 251 SEK
Congestion management steering	2016	***Negative impact***	2 steerings led to lower costs [19 587 SEK, 67 453 SEK] 10 steerings led to higher costs [−11 519 SEK, −430 949 SEK]	***Higher***	***Mixed impact***	8 steerings led to lower costs [6 368 SEK, 145 163 SEK] 4 steerings led to higher costs [−20 241 SEK, −77 893 SEK]
	2017	***Positive impact***	7 steerings led to lower costs [56 461 SEK, 353 883 SEK] 1 steering led to higher costs −626 610 SEK	***Lower in 7, higher in 1***	***Negative impact***	1 steering led to lower costs 8 508 SEK 7 steering led to higher costs [−2 337 SEK, −16 510 SEK]

The results show that when the heat pumps were controlled for balancing purposes, it generated a positive financial impact for the BRP both years when steering at the additional prices 50 and 100 SEK/MWh. However, it resulted in a higher peak power load as well as higher financial costs for the DSO. When steering the heat pumps for congestion management purposes, it resulted in a higher peak power load for the DSO in 2016 and a lower peak load in most cases in 2017. The financial effects for the DSO were mixed, where some cases resulted in a positive impact and some in a negative impact. The higher peak power load as a result from congestion management steering can be explained by the oscillating load curve that occurs after a steering. With a smarter steering, where the flexible resource is divided and used at different times, the peak power could possibly be reduced. Thus, the need for a smart, predictive load profile algorithm is of great importance to determine when the demand response solution should be activated.

CONCLUSION

It is likely that markets for demand response will continue to grow in Sweden as there are benefits for both BRPs and DSOs to be gained. The characteristics of the heat pumps' load profiles mean that a steering of a large number of heat pumps resulted in a more oscillating load profile which might cause problems for DSOs if the top-load of the heat pumps after a steering coincide with a time of grid congestion. It can also affect the BRP in a negative way if a grid operator utilizes the flexibility during high down regulation prices. The characteristics of loads on an aggregated level need to be considered when evaluating market possibilities for demand response management. It is only when heat pumps are considered on an aggregated level the oscillating behavior is detected, the same conclusion cannot be gained from only considering one isolated heat pump.

The results show that the benefits of steering heat pump loads do not always correlate between the BRP and DSO. When a BRP wants to steer heat pumps during up regulation prices to minimize imbalance volumes and costs, it resulted in more congestion in the investigated local grid as well as higher costs. When the DSO steer heat pumps during congestion times, it resulted in larger imbalance costs for the BRP in a majority of the cases as the congestion often occurred during down regulation prices. The interdependency between BRPs and DSOs means that a holistic approach with coordination is needed when developing a new market for demand response solutions activated by grid congestions or high regulations prices. Communication channels and collaboration forums for DSOs and BRPs are necessary to avoid negative consequences for either party when a demand response solution is utilized.

REFERENCES

[1] European Commission, national renewable action plan Sweden, energy, 2018
[2] Energimyndigheten, 2018, “Energy in Sweden, facts and figures 2018”, Eskilstuna, Sweden.
[3] Svenska kraftnät, 2017, “Systemutvecklingsplan 2018-2027”, Sundbyberg
[4] Fischer, D., Madani, H. 2017, “On heat pumps in smart grids: a review”. Renewable and sustainable energy review 70 (2017) 342-357
[5] Baetan, B. Rogiers, F. Helsen, Lieve, 2017, “Reduction of heat pumps induced peak electricity use and required general capacity through thermal energy storage and demand response”. Elsevier. Applied energy 195, 184-195
[6] Hong, J., Johnstone, C., Torroti, J., Leach, M, 2012, “Discrete demand side control performance under dynamic building simulations: a heat pump application”. Renewable energy 39 (2012) 85-95
[7] Oehme, S., 2018, “Demand flexibility potential from heat pumps in multi-family residential buildings”. Uppsala University, Uppsala, Sweden
[8] Sandels, C., 2016, “Modeling and simulation of electricity consumption profiles in th enorthen European building stock” Electric power and energy systems, KTH, Royal institute of Sweden. Stockholm, Sweden
[9] Widén, J,. Wackelgard, A., 2010, “A high reslolution stochastic model of domestic activity patterns and electricity demand”. Applied energy, 87(6) 1880-1892, 2010, ISSN 0306-2619.
[10] Energimarknadsinspektionen, 2017, ”Measures to increase demand side flexibility in the Swedish electricity https://www.energimarknadsinspektionen.se/PageFiles/308320/Ei_R2017_10.pdf accessed 2018-02-05
[11] Nord Pool, 2017, “Bidding areas” http://www.nordpoolgroup.com/the-powermarket/Bidding-areas/ accessed 2018-02-09
[12] Svenska kraftnät, 2017, “Operations and market” https://www.svk.se/en/nationalgrid/operations-and-market/ accessed 2019-01-09
[13] Forsberg, K., Klasman, B., Larsson, E., Leymann, J., Lundgren, J., Östberg, H. 2014, ”Utvärdering av effekterna av elområdesindelningen”, EI R2014:08, Energimarknadsinspektionen: Eskilstuna.
[14] Svenska kraftnät, 2017, ”The control room” https://www.svk.se/en/national-grid/thecontrol-room/ accessed 2019-01-05
[15] Grill, R. 2018. “Market potential for using demand response from heat pumps in multifamily buildings”, Uppsala University, Uppsala, Sweden
[16] Upplandsenergi, Om oss, pressmeddelande, 2018 https://www.upplandsenergi.se/omoss/29354.pressmeddelande-ue_samverkan_med_ngenic.html accessed 2018-10-15
[17] Vattenfall, pressmeddelande, 2018 https://mb.cision.com/Main/865/2621089/911268.pdf accessed 2018-10-15