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TNO report

TNO 2019 R11976 | Final report

Unlocking flexibility of hybrid heat pumps

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Number of pages	32
Customer	Enpuls, GasUnie, GasTerra, Ntra, Cogas, De Consumentenbond and Vereniging Eigen Huis
Project name	Hybride Warmtepompen fase 2 flex
Project number	060.36707/01.03

Contents

1 Management Summary

The hybrid heat pump will play an important role in the energy transition from fossil fuels to renewable energy sources. The electrification of heating with heat pumps will put additional stress on the distribution grid (congestion) and may lead to regular local outages. The hybrid heat pump (HHP) is part of the solution as it has the ability to temporarily switch to gas when the load on the distribution grid becomes too high. The flexibility of the HHP can be used by the DSO to perform congestion management.

In order to make use of the flexibility offered by the HHP a congestion management architecture is needed. This comprises all the ICT components that are needed to go from the detection/prediction of congestion by the DSO to activating a hybrid heat pump to temporarily fall back on gas.

This study presents a high level architecture for the congestion management chain that was also verified in a proof of concept in TNO's Hybrid Energy System Integration (HESI) lab. The test included 3 different hybrid heat pump models that are currently available on the Dutch market. It was shown in the lab that they can be controlled in a rudimentary way to switch from electricity to gas by making use of the Smart Grid Ready (SGR) interface. Although the SGR interface is not ideal as it does not allow for more advanced forms of flexibility, the good news is that it is already supported by most HHPs available on the market today. Therefore the use of the SGR interface is a good step in the right direction for implementing congestion management.

As explained earlier there are also other components required to form a complete congestion management chain. They have been designed to be open and interoperable so that they can be reused for other demand response services that also use the flexibility of a HHP and involve other energy stakeholders such as an aggregator.

In the case of congestion management by the DSO this report shows that the smart meter can be used to convey temporary connection limits to the Home Energy Management System of an end user. This smart meter solution is not restricted to a single device and can work just as well with a HHP as with EV, PV inverters, batteries or a combination of these devices.

Although the results with the congestion management proof of concept in the lab are very promising, a lot of steps still remain to be taken to scale up the lab results to large operational deployments. For this purpose a timeline is presented that describes the most important steps. A first recommendation is to start congestion management pilots that involve larger numbers of HHPs from which practical lessons learned can be derived. Another important step is to put regulation in place that specifies under which conditions congestion management by a DSO can take place and how end users will have to react to connection limits and what the consequences are of failing to do so.

These follow-up steps require urgent action as the number of HHP installations is quickly increasing.

2 Introduction

The current energy system is relying for a large part on fossil fuels. The energy system will need to change drastically to rely on renewable energy sources instead, in order to meet the objectives of the Paris agreement and the Dutch climate agreement. In addition to the climate objectives the Netherlands have chosen to move away from natural gas for domestic heating due to induced earthquakes in Groningen in the north of the Netherlands.

Part of the solution towards a durable energy system is the electrification of the energy consumption that until now relies mostly on fossil fuels. Electrical vehicles are an obvious example; instead of using gasoline or diesel for their power they rely on electrical power that is stored in batteries. Another obvious candidate in the Netherlands is domestic heating, that currently is primarily dependent on gas, but could be electrified by using heat pumps. By electrifying our energy systems important steps can be made, provided that the needed electricity is being produced in a sustainable way.

Focusing on heating, the transition from gas to electricity signifies quite a big challenge. An important technical aspect of that challenge is that the electricity grid originally was not dimensioned to also transport the electricity needed for heating (or charging EVs or the feed in of PV panels). In their report “Flex-potentieel hybride warmtepomp” [1] Berenschot, DNV-GL and BDH explain that (hybrid) heat pumps will put a significant additional load on the electricity grid when rolled out in the large numbers that are anticipated. They expect that the simultaneous peak load of households will be increased by 20% due to (hybrid) heatpumps. This may cause local outages in the electricity grid on a regular basis.

It will take huge investments to increase the capacity of the electricity grid to accommodate such additional loads, especially if this has to be realized in a short amount of time.

Smart solutions are needed to spread the investments in the grid over a longer period of time so that the yearly costs will be significantly lower. The keyword here is flexibility; if devices can be flexible in their production or consumption by lowering or postponing their consumption/production if needed, they can help reduce peak loads.

Hybrid heat pumps (HHPs) are inherently flexible; they can switch to gas to offload the electricity grid in case of congestion. Therefore HHPs are not just part of the problem, but also part of the solution The heat pump will be used for most of the time and the gas boiler only jumps in case of congestion (or peak heat demand).

The “Flex-potentieel hybride warmtepomp” study [1] also quantified the potential flexibility that HPPs have to offer when deployed in large numbers. It was calculated that the ability to switch from electricity to gas in case of anticipated congestion could lead to a reduction of 18% of the simultaneous peak load.

Such a reduction can only be achieved if the HHP is under some form of intelligent external control. However, the design and implementation of intelligent control was not part of the study by Berenschot, DNV-GL and BDH, but it is the subject of this report.

A consortium, consisting of Enpuls, GasUnie, GasTerra, Ntra, Cogas, De Consumentenbond and Vereniging Eigen Huis, is exploring how the inherent flexibility of HHPs can be unlocked in practice for congestion management purposes. The main questions that need to be answered are:

- Which congestion management building blocks do already exist?
- Which congestion management building blocks need to be developed?
- How should these building blocks be integrated into an operational congestion management chain?
- Which steps need to be taken before HHP flex can be used on a large scale?

These questions have been addressed by developing a proof of concept congestion management solution in a lab environment and by providing an outlook towards the necessary steps to deploy this on a large scale. To make sure that such a solution is widely applicable, it will be tested using multiple HHPs from different manufacturers.

This report starts out by describing a high level architecture for congestion management, where the different components are identified and described (see chapter 3). Chapter 4 focuses on the HHP itself and explores the different types of flexibility it has to offer and how this flexibility can be unlocked in practice. The solution that is described in chapter 4 will be tested with different HHPs in a lab situation. The test setup and results are the subject of chapter 5. Chapter 6 elaborates on the steps that need to be taken to scale up the lab results to pilots and roll outs. The reports ends with conclusions and next steps as described in chapter 7.

3 Congestion management chain (with HHPs)

As explained in chapter 2, hybrid heat pumps can be an active asset in managing congestion. However, HHPs cannot be used out of the box by the DSO to perform congestion management. Other (IT) components need to be put in place as well to make sure that the whole pathway from detection of congestion to activating the HHP to temporarily fall back on gas is covered.

The HHP will be one of the first devices that will actively be used for congestion management. Therefore it might be tempting to go for a “quick fix” that is very specific for HHPs and can only be used for congestion management by a DSO. Although the HHP might be one of the first devices, it will certainly not be the last device that can help reduce congestion (think of EV, PV or a battery for instance).

The flexibility of the HHP also does not have to be used exclusively by the DSO. Other stakeholders in the energy market could also be interested in the flexibility that the HHP has to offer. An aggregator, for instance, might want to use the HHP flexibility to help balance responsible parties meet their contractual obligations. To make sure that the same source of flexibility can be used in these different scenarios, flexibility should be unlocked in an open and interoperable way. This way the same basic building blocks can be re-used for congestion management applications by DSOs as well as commercial flexibility propositions by aggregators and other parties.

In addition to openness and interoperability, such a solution also needs to be scalable and reliable. Especially when congestion management is directly performed by the DSO as this is a last attempt to prevent a local grid outage. Therefore it is essential that it can be relied upon and is able to reach a large number of grid connection points in a particular congested area. This can only be achieved by a standardized congestion management solution that is fully supported by all stakeholders and components in the congestion management chain.

Although an early implementation may not yet meet all of the requirements above, it is important to already be aware of these, so that choices made do not become blocking for future developments.

This chapter first explores the wider scope and context of the congestion management chain and then describes its high level architecture.

3.1 Context and scope for congestion management

Congestion management is the responsibility of the DSO, but it can be arranged in different ways and with different stakeholders. To explain the scope of congestion management for this report the operating regimes as defined by USEF [3] are used (see Figure 1). It should be emphasized that USEF is used for illustrative purposes only in this report, it does not imply by any means that USEF is compulsory for the implementation of congestion management chain.

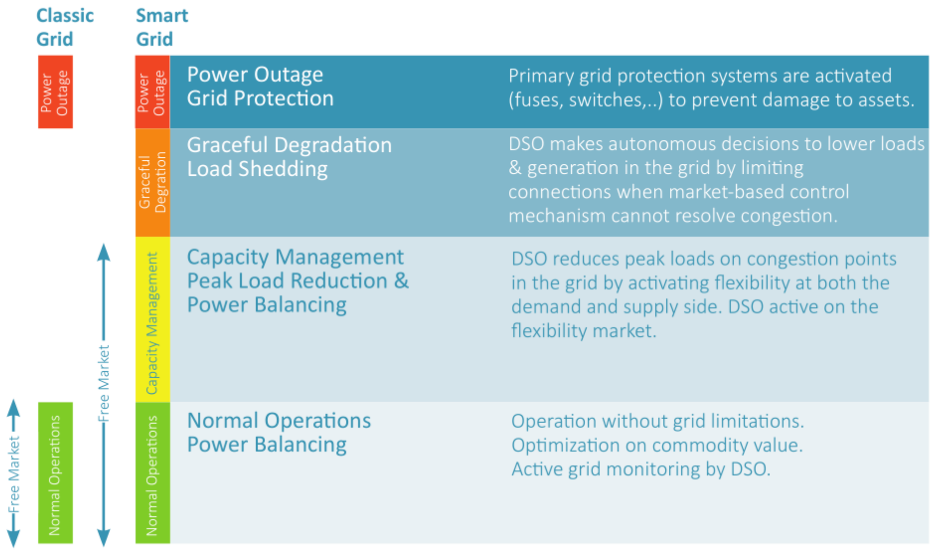

Figure 1: USEF operating regimes

USEF discerns 4 operating regimes; green, yellow, orange and red. It is the orange phase that is the focus of this report. When the market is not capable to deliver the required flexibility to the DSO, the orange regime starts. In this case the DSO sends a congestion signal directly to prosumers without interference by market parties. This regime will only be used as a last resort to prevent moving into the red phase where parts of the grid will be physically switched off. It is essential for the orange phase to work with the large majority of prosumers in a congested area, therefore such a solution should be standardized and reliable.

Where the orange regime should be strictly regulated, the green and yellow regimes are in the commercial domain. The green regime is not relevant for congestion management as this phase has no grid limitations. During the yellow phase there is congestion in the grid and congestion management is being performed. The main characteristic of the yellow phase is that the DSO acquires the necessary flexibility on the market, via aggregators for example. Aggregators focus on their own business models and will therefore use their own incentives/mechanisms to unlock the flexibility at the prosumer's premises. As a result it is not expected that there will be standardized solutions to perform congestion management in this phase.

3.2 Requirements for congestion management in the orange phase

As established the orange phase is about direct congestion management between the DSO and a prosumer. This paragraph focuses on some of the high level requirements that this type of congestion management will have to adhere to.

- **No direct control over devices.** Because a hybrid heat pump represents an important source of flexibility, especially for the Dutch context that moves away from using gas for domestic heating, there may be a tendency to focus on directly controlling the HHP's from the grid[1]. As tempting as this may be, it will make it very difficult to translate HHP bespoke congestion management solutions to other flexible devices in the future, such as EV's, stationary

[1] Much like the German situation with the curtailment of PV inverters.

batteries and PV panels. A very likely but undesirable consequence would be that each flexible device type would get its own congestion management solution. This would make congestion management by the DSO unnecessarily complicated as there are multiple solutions that need to be operated and maintained in parallel. Another disadvantage to directly controlling devices is that it would not be possible to combine flexibility of devices in more advanced ways, e.g. running the HHP using stored energy from the battery[2] (see next point also).

- **Clear separation of concerns between DSO and prosumer.** The DSO and the prosumer have different responsibilities that should be reflected by the interface between them. The DSO should have no control beyond the grid connection point as this is the natural boundary between the DSO and the prosumer's premises. This boundary is marked by the smart meter. The DSO should only be concerned with the total limit that will be imposed on the connection, it is up to the prosumer to stay under this limit. However, the prosumer should be free on how to meet this target. There should also be clear consequences for not meeting the target for example in the form of a fee. Although this is a very important aspect of congestion management, this report focuses on the technical solution only. In Figure 2 this interface can be found between the DSO and the smart meter.

  Prosumer devices should not be managed as grid assets by the DSO. Not only will this lead to a huge number of additional grid assets the DSO will have to manage, but more importantly it introduces conflicts between the DSO and the prosumer as the control of their devices is split between them. Prosumers will likely have issues with the DSO being able to directly control their devices.
- **Re-use of smart device interface.** The interface towards the device should not be limited to congestion management applications only. It should not matter whether the flexibility of the hybrid heat pump (or another device) will be used for congestion management or for balancing the grid. For the interface between the HEMS and the devices the S2 interface will be used. This is a standard that is currently being drafted by CEN/CENELEC TC205/WG18 as prEN50491-12-2. In Figure 2 this interface can be found between the HEMS and the resource manager.

3.3 IT Architecture

The high level IT architecture for congestion management has been developed to meet the requirements that are described above and is depicted in Figure 2.

[2] Please note that staying away from direct control by the DSO may be interpreted as not being in line with the "requirements for generators" network code by ENTSO-e [4].

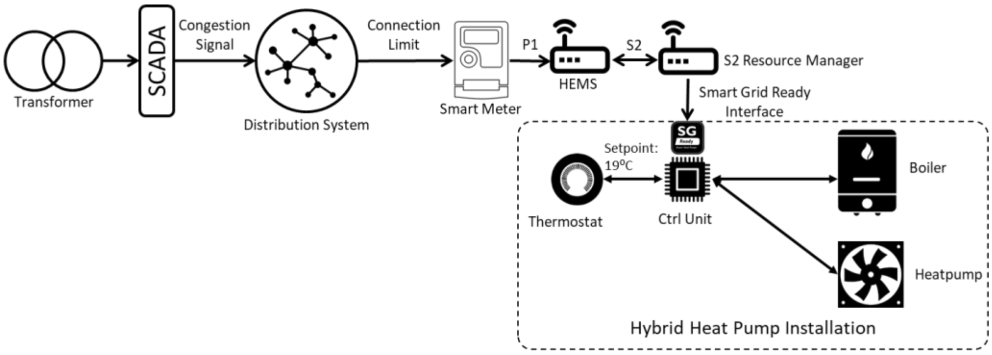

Figure 2: Overview of the congestion management chain

3.3.1 *Components*

The IT architecture of the congestion management chain consists of different components which are described below:

- **Hybrid Heat Pump installation.** The HHP consists of different hardware elements such as the gas boiler, the heat pump, a thermostat and a control unit. The latter contains the logic of this device and ultimately decides how to meet the heat demand that the thermostat is asking for. The control unit determines whether the gas boiler, the heat pump or both need to be engaged and makes sure that this is done within safe operational boundaries. Therefore the control unit is the preferred place to control the flexibility options from.
- **Smart Grid Ready Interface.** It is crucial that hybrid heat pumps offer some form of external control over their flexibility, so that it can be mobilized when needed. Chapter 4 goes into more detail about the types of flexibility that hybrid heat pumps have to offer.

  A lot of heat pumps that are currently on the market support an interface called Smart Grid Ready (SGR). This a relatively simple interface that enables the shutdown of a heat pump’s compressor. When this happens while there is still an active heat demand, the gas boiler will take over. By using the SGR interface the electricity consumption of the heat pump can effectively be curtailed.
- **S2 resource manager/driver.** The SGR interface only consists of two potential free contacts, but an energy management system needs to understand what the energy implications of those actions are. Those energy implications can be described in a generic interface called S2. The S2 resource manager or driver is a software module that translates the SGR actions into generic S2 messages that the energy management system can understand.
- **Customer Energy Manager/Home Energy Management System.** The CEM or HEMS manages the energy flexibility of the whole premises. It will not only look at the flexibility that a HHP has to offer, but it will also take the flexibility of other devices (e.g. PV and EV) into account. When a congestion management signal is received the HEMS decides which device or combination of devices will be used in response to a congestion management signal.

Figure 2 shows to different hardware components for the HEMS and the S2 resource manager. This was the setup that was used in the lab tests. However the HEMS and the resource manager are both logical components that could just as well run on a single hardware platform or even in the cloud. Although that latter option is not possible in combination with the Smart Grid Ready interface as local presence is required to switch the contacts.

- **Smart Meter.** The smart meter represent the boundary between the DSO – and the end-user domain. Using the so called long message mechanism, congestion management signals can be sent to smart meters that find themselves in a congested area. The congestion management message contains an absolute power limit for the connection that has to be adhered to by the end-user. When the message has been received by the smart meter, it will be made available on the P1 port, so that it can be picked up by the CEM/HEMS. The CEM/HEMS will decide how the limit can be met in the best way.

  The smart meter is not used to actively enforce the power limit. In order to verify whether the end-user respected the congestion limits, smart meter measurements will be used after the event.
- **Distribution System.** The DSO detects or forecasts congestion issues in its grid by monitoring transformers through SCADA systems. The DSO will first try to solve these issues on the market, by making use of the services provided by aggregators for example. When it is not possible to solve the congestion problem on the market the orange regime will come into play. The DSO will know which connected parties (e.g. households, offices, etc.) to address in the congested area and will use the long message mechanism to send power limits to their smart meters.

  Smart meters typically rely on mobile communication, which means that it may take minutes before all end-users in a congested area will have received the power limit message. In most cases this time frame will be sufficient for congestion management purposes.

The following chapters will zoom in on two of the components described above. First chapter 4 will look in detail at the different types of flexibility that a HHP installation has to offer and how these can be unlocked. Chapter 5 focuses on the performance of the Smart Grid Ready Protocol in a lab context with actual HHP installations.

4 Types of flexibility offered by HHP

This chapter zooms in on the specific type of flexibility that a hybrid heat pump has to offer. It starts with considering the fundamental flexibility that is inherent to a HHP and then continues with how that flexibility could be unlocked in a practical way. The chapter concludes with explaining a specific protocol that can already be used to manage flexibility in HHP's: the Smart Grid Ready protocol.

4.1 Fundamental forms of flexibility

Hybrid heat pumps can be flexible in multiple ways, three types of flexibility can be discerned:

4.1.1 Buffering of Heat

HHP's have the ability to buffer heat. This is most obvious if there is a hot tap water buffer attached to the HHP, but it can also take the form of exploiting thermal inertia in a building. By buffering heat the HHPs can be engaged earlier (to fill up the buffer) or later (by using the buffered heat first).

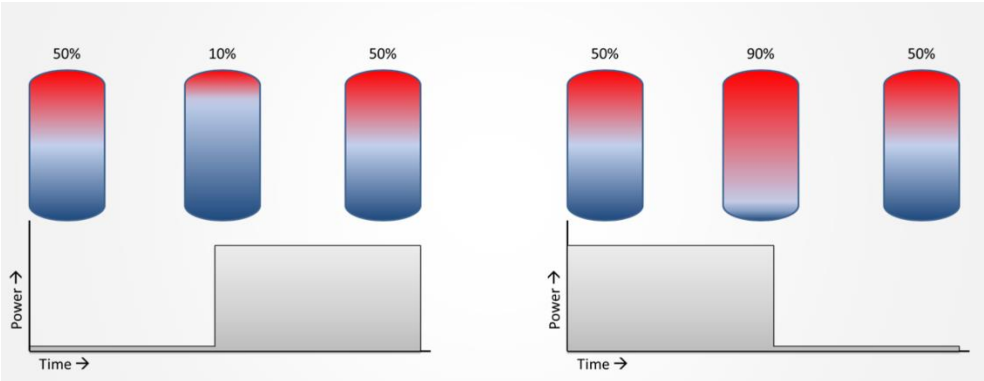

Figure 3: Heat buffering examples

Figure 3 shows two different power profiles that are the result of using the buffers differently. The left example first uses the hot water stored in the buffer until it is almost empty and then turns on the heat pump to restore the buffer to its original level. The right example turns on the heat pump immediately to raise the buffer level to 90%, from that point on the heat from the buffer is used until it is back to 50% again.

4.1.2 Power Modulation

A HHP can also change the amount of heat it produces and therefore its power consumption. This will also have implications on the time it takes to reach a certain setpoint. It could be used to help reduce peak loads, but it can also be used to maximize consumption when there is a lot of production available.

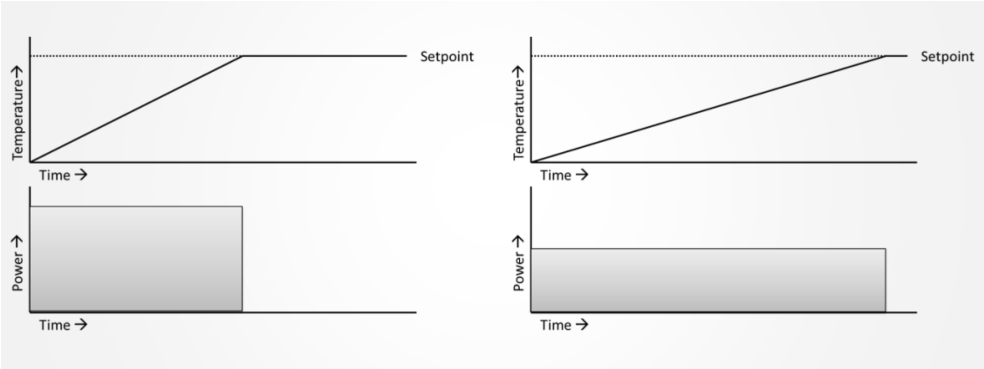

Figure 4: Power modulation examples

Figure 4 shows two different power modulation profiles. The left one has a higher power consumption and therefore reaches its setpoint sooner. The right one consumes less power and as a consequence it takes more time to reach the same setpoint. The surface below the power profiles (energy) will be similar, but they will almost always differ a little bit because of the differences in efficiency of the power modulation levels.

4.1.3 *Change of Fuel*

The first two types of flexibility are also applicable to normal heat pumps, but the ability to change fuel is a characteristic unique to the HHP. The heat demand of a HHP can be met by using the heat pump, the gas boiler or a combination of the two. Normally the HHP will use the heat pump as this is the most efficient way to produce heat. However when it is too cold for the heat pump to operate efficiently the gas boiler[3] will be used. The gas boiler can also assist if the heat demand is too high for the heat pump to deliver by itself. This type of flexibility is also ideal for capacity management in distribution grids, while still maintaining comfort for the end user.

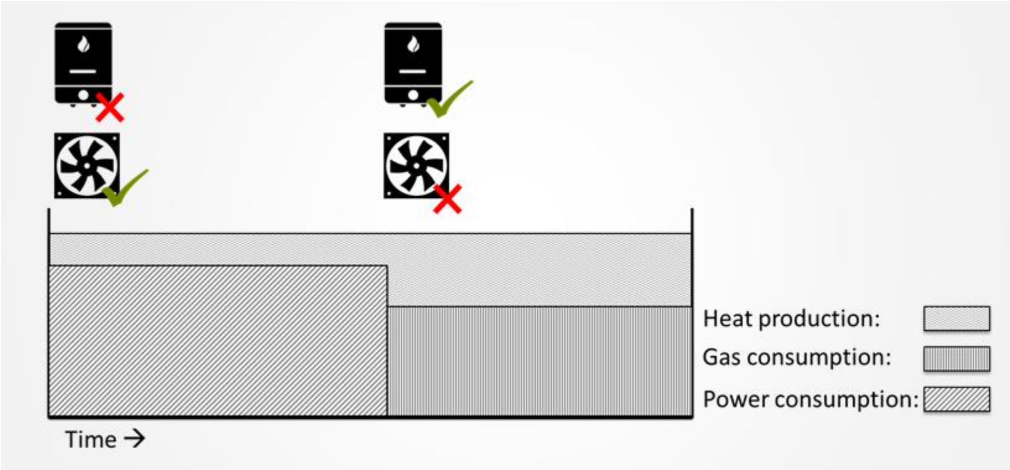

Figure 5: Change of fuel example

Figure 5 shows a “change of fuel” example. The HHP has to produce a given amount of heat. This is first realized by using the heat pump as can be seen by the power consumption. At some point the heat pump is disengaged and the gas boiler takes over. All this time the heat production remains constant.

[3] Other alternative fuels such as oil, pellets or biomass are in principal also possible

The different types of flexibility do not have to occur in isolation, but they are often combined. The power level of a HHP might be modulated when filling the hot water tank for example.

All this flexibility can only be used properly if it can be managed. To make full use of the flexibility that the HHP has, it has to provide insight into its current state and offer an interface to be controlled remotely.

4.2 Unlocking flexibility

As stated above the potential flexibility of the HHP cannot be exploited if it cannot be controlled externally. This section looks into the possibilities to unlock the flexibility so that it can be put to practical use.

4.2.1 Lack of data

In order to know how much flexibility can be used by buffering heat in a hot tap water buffer it is important to know the current fill level. A complicating issue in determining the fill level is the fact that water will stratify into layers with different temperatures. A water tank is often supplied with a single temperature sensor which makes it difficult to know how much hot water is currently stored. This could be solved by using a strip of temperature sensors that are measuring the temperatures at different heights in the buffer. However, adding a multitude of sensors (in combination with more complex control algorithms) increases the total costs of the HHP and is often avoided.

This might change if flexibility becomes more valuable on energy markets and customers will ask for models that can provide more detailed information on the status of their buffers.

4.2.2 Sophisticated models needed

As mentioned above the thermal mass of a building can also be used as a buffer. Of course this is really dependent on the specific characteristics of a building, such as level of insulation, material and thickness of walls, surface area of windows, etc.. Those specific characteristics need to be modelled in order to quantify the amount of flexibility that a HHP has. These models will have to be quite sophisticated to take all of these parameters and their relations into account. Such models will have to be developed to be able to unlock more advanced forms of flexibility. It is likely that they will need to have self-learning capabilities to adapt to a specific building. As AI and machine learning are topics of high interest it is expected that such advanced models will be developed in the near future.

4.2.3 Device protocols

Even when more advanced sensor information or modelling is available, this information still needs to be accessible to an energy management system via an interface or protocol. Many protocols are currently manufacturer specific. Standardization (S2 protocol) is expected to change this.

4.3 Smart Grid Ready protocol

It will take some time before solutions will be available on the market that leverage advanced forms of flexibility in HHP’s, there is, however, a simple protocol that is already supported by a large number of HHPs: the Smart Grid Ready Protocol [2]. The SGR can be used to unlock flexibility that comes from changing fuel (electricity to gas).

The SGR specification prescribes two potential free contacts that can both be switched on or off. This provides four possible SGR operation modes for HHP's. In one of these operation modes the HHP will have to switch of its compressor; effectively shutting down the heat pump. If there is an active heat demand, this will now be provided by the gas boiler. This operation mode will last for a maximum period of two hours. This mode is very usable for congestion management during the orange phase.

Another operation mode refers to the normal operation of the HHP, which can be used to end the shutdown of the HHP so that it will fall back to its standard behaviour.

There are also two operation modes that instruct the heat pump to run on maximum power. This might mean for example that the temperature in a hot water buffer will be raised. Such modes can be very useful when there is too much PV production, as this could be solved locally by activating heat pumps in the same area to consume as much as possible.

The SGR protocol can be used as a building block for a congestion management chain. It is already deployed in a large number of HHPs that are currently on the market. To provide an end to end solution, additional hardware and software is required to switch the SGR contacts.

In order to determine whether the SGR protocol is behaving according to its specs, a number of HHPs have been tested in TNO's HESI lab. The next chapter describes which models were tested, the test setup that was used and the results.

5 Overview of tested HHPs

Part of the integrated congestion management chain was tested in TNO's HESI lab facility. This setup simulates the congestion limit message over the P1 port and further consists of the HEMS, the S2 resource manager and Smart Grid Ready equipped hybrid heat pumps. This chapter focuses on testing the SGR behaviour on various HHPs to verify that they behave according to the SGR specification.

5.1 Selected HHPs for flexibility test

Almost all HHP models on the (Dutch) market support SGR according to their documentation. Due to limited resources it is simply not possible to exhaustively test all HHP models. Therefore three HHPs have been selected that still provide a good indication of the quality of the SGR implementations across different models and manufacturers. This selection consists of the following models:

- Daikin heat pump + Intergas gas boiler
- Elga heat pump + Remeha Tzerra ACE gas boiler
- Vaillant AroTherm Monoblock + Vaillant EcoTEC gas boiler

5.2 Disclaimer

It is important to emphasize that the tests described in this chapter focused solely on verifying the implementation of the SGR specification. No conclusions were/can be drawn on other aspects of the tested hybrid heatpumps. Test conditions that did not influence the SGR behaviour were not controlled. For example the intake temperature of the outdoor units varied across the tests and were not representative for the outdoor temperature range that a heatpump would normally operate in.

5.3 Test Setup

To test the flexibility of the HHPs a testbed has been setup in the lab. A schematic overview of the testbed is shown in Figure 6.

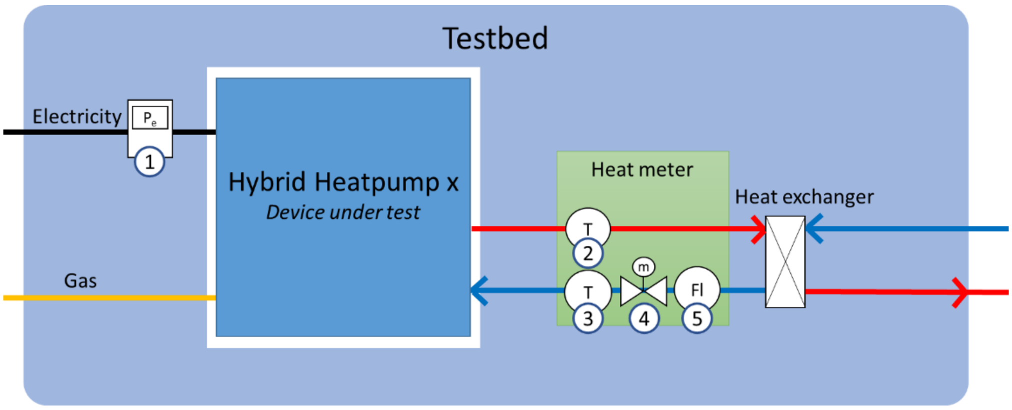

Figure 6: Schematic overview of HHP test setup

The hybrid heat pump block consists of the complete hybrid heat pump configuration which contains the heat pump, the outdoor unit (heat pump and outdoor unit can be combined in a monoblock), the gas boiler and possibly an additional water pump and open exchanger. The HHP has an electricity and gas connection. The heat that the HHP produces is being run through a heat exchanger which mimics the radiators in a household. The hot water cools down and flows back to the HHP to be heated again. The numbered items indicate the measurement points in the testbed:

1. The electricity meter that among other things measures the electrical power consumption of the HHP.
2. The heat meter, it measures the supply temperature of the HHP that is being fed into the heat exchanger.
3. The heat meter, it measures the return temperature after the heat has been exchanged.
4. The heat meter, it is a valve which always stays in the open position during the measurements.
5. The flow meter, it measures the flow rate of the water and is part of the heat meter.

5.4 SGR tests

In order to validate the correctness of the SGR implementation of the selected heat pumps (and thus the ability to provide flexibility), all heatpumps were tested in the same way. The tests are described in this section.

5.4.1 Starting Position

Every time before running the actual test, the following procedure was followed:

1. Request a heat demand to be delivered by the heat pump only (gas boiler inactive).
2. Wait for the heat pump to run at maximum power.

This provided the optimal starting position for the SGR test as switching the heatpump off will have the biggest impact when it is running at full power.

5.4.2 Test Procedures

The following test procedures were used

Test 1:

1. Send SGR signal to the heat pump to reduce the electricity consumption.
2. Measure time until the heat pump is switched off and the gas boiler is switched on (expected < 1 min).
3. Keep heat demand constant until the heat pump switches on (expected as per SGR specification ~2 hour).

Test 2:

1. Send SGR signal to the heat pump to switch off the compressor (and thereby reducing the electricity consumption).
2. Measure time until the heat pump is switched off and the gas boiler is switched on (expected < 1 min).
3. After 30 minutes, stop heat demand.
4. After 30 minutes, request a heat demand again.
5. Wait until the heat pump switches on (expected as per SGR specification ~1 hour).

Test 3:

1. Send SGR signal to the heat pump to reduce the electricity consumption.
2. Measure time until the heat pump is switched off and the gas boiler is switched on (expected < 1 min).
3. After 30 minutes, stop SGR signal.
4. Check the behaviour in response to the SGR signal as the specification is not fully clear about the minimum time that the device should be switched off. It could be that the pump switches on.
5. After 30 minutes, send SGR to reduce the electricity consumption.
6. Measure the time until the heat pump switches on (Expected behaviour: this could either take an hour if the heat pump considers the start of the first interruption or take two hours if the heat pump uses the last send SGR signal).

In addition to the feature of SGR, to reduce the electricity consumption as much as possible, the SGR specification also describes how an ‘Energie Versorgungs Unternehmung’ (EVU) can request to consume as much electricity as possible. This could, for example, be implemented by heat pumps that have the possibility to provide cooling or by heat pumps that are connected to a buffer (the buffer is filled during the request of the EVU to consume as much electricity as possible). Other tests, which are not in scope of this project, should be performed in order to validate the implementation of that SGR functionality.

5.5 Test description

The hybrid heat pump setups were installed and operated as specified in the following subsections.

5.5.1 Daikin heat pump + Intergas gas boiler

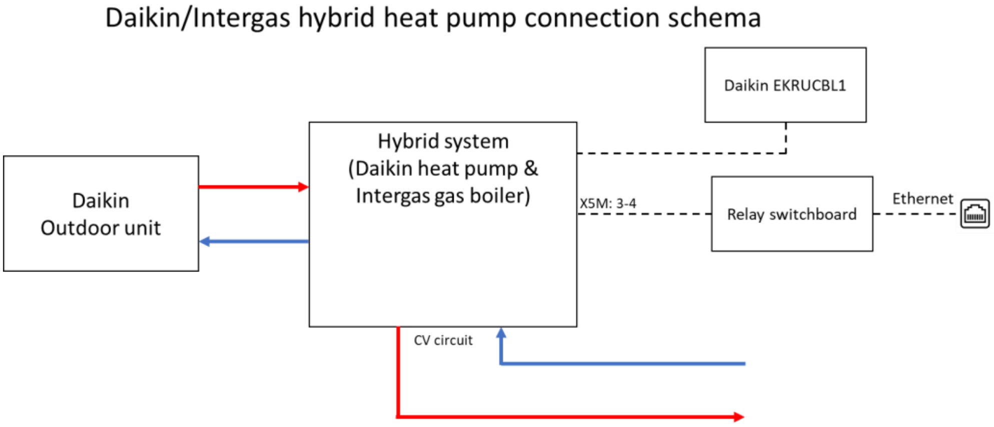

Figure 7: Daikin hybrid heat pump connection schema

To prepare the setup for the SGR tests, a factory reset was performed after which the following settings have been set. First time setup settings:

- Change language: Deutsch → Nederlands

Default price settings:

- Electricity price (high/medium/low): 3 eurocent/kWh
- Energy price: 20 eurocent/kWh

Installer settings:
- A.2.1.6 Geforceerd uit contact: gesloten tarief
- A.3.3.1 OFF-temp heating room: 35 ºC
- A.6.7 Spaarstand: economical

5.5.2 *Elga heat pump + Remeha Tzerra ACE gas boiler*

Figure 8 shows the connection schema for the lab tests with the Elga heat pump.

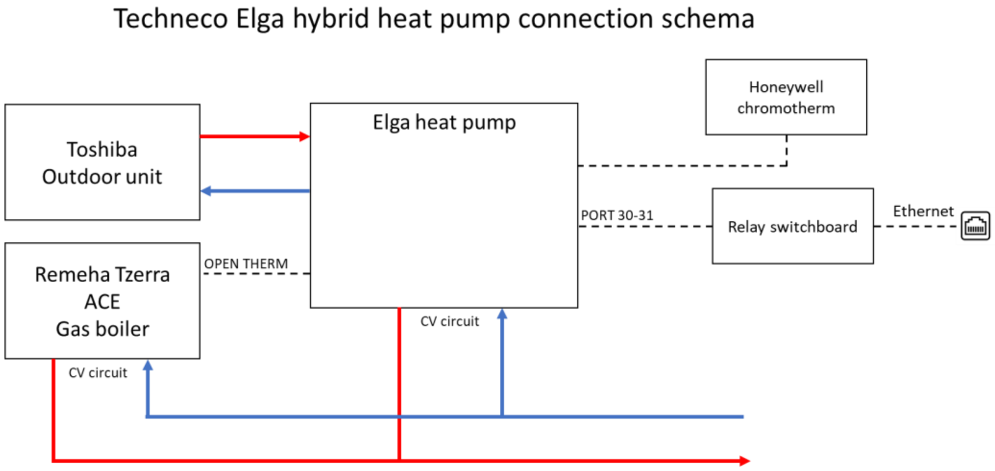

Figure 8: Techneco Elga hybrid heat pump connection schema

Specification of the tested devices:
- Elga heat pump: Techneco Elga 3.0, fabrikagenummer: TELG30304 459818
- Toshiba Outdoor Unit: Toshiba air conditioner RAV-SM304ATP-E
- Remeha Tzerra ACE: Remeha Tzerra M 28c ACE – 1805218211390
- Honeywell thermostat: Chronotherm Touch – TH8210M1003

The connection schema in Figure 8 is based on the schema "K1 OpenThem CV-ketel + Honeywell Touch modulation thermostat" from the installers manual v.16.0. The DIP switches A and B have been set according to the values in *Table 1*.

Table 1: Overview of the Elga DIP switch settings

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A	ON	OFF	OFF	ON	OFF	OFF	OFF	OFF
B	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF

To use the Smart Grids Ready contact, the Elga needs an extra connector (see Figure 9) that is not delivered with the heat pump but should be ordered separately. This cable with connectors allows for using the connections 19, 21, 23-25, and 28-33 (as referred to in the manual).

Figure 9: Cable with extra connectors allowing to use the SGR functionality

To prepare this setup for the SGR tests, the following settings have been set after a factory reset.
In the installers menu the following parameter has been changed:

- P70: 30 ºC

Notes

- The default DIP switch setting allows the Elga and the gas boiler to active simultaneously (DIP.A2 to 'ON'). However, because the hydraulic parallel configuration, the pump settins of the Elga and the pump setting of the gas boiler need to be adjusted very precisely. If the pump pressures differ too much, one of the pumps prevents the other pump form delivering the heated water. Since the pump settings of the Remeha Tzerra ACE could not be altered easily (a dedicated USB cable and Remaha computer software is needed), it was decided to set DIP.A2 to 'OFF'.
- With the default DIP switch settings, the setup tends to prefer to use the gas boiler for heating. For that reason, the tests have been performed with DIP.A4 to 'ON' and P70 set to 30ºC. Under the test conditions (with a relatively high outdoor temperature), this resulted in a low value for the desired supply temperature on the heating curve, leading to the gas boiler being switched off quickly after ignition. For that reason, the high heating curves have been used in the tests (DIP.A1 to 'ON').
- Parameter P88 is about "SmartGrid steering". It can be set to 0=No SmartGrid functions active, 1=Normal use, and 2=Only block Elga for heating/cooling. The lab tests have revealed that the Smart Grid Ready behaviour does *not* depend on the value of this parameter.

5.5.3 *Vaillant AroTherm Monoblock + Vaillant EcoTEC gas boiler*

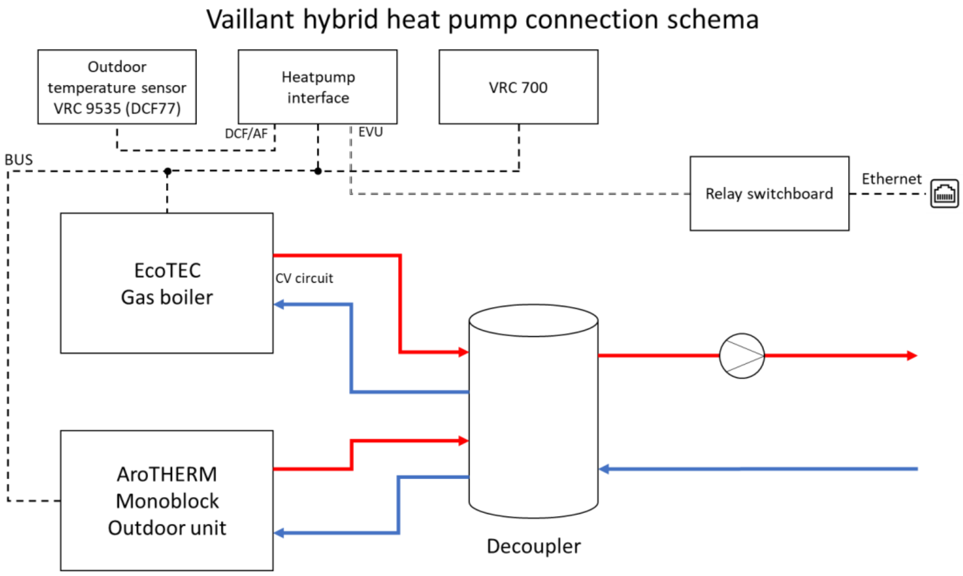

Figure 10: Vaillant hybrid heat pump connection schema

Specification of the devices:

- AroTHERM monoblock outdoor unit: Vaillant AroTHERM VWL 55/3 A. S/N 21180300100197641610005051N5
- EcoTEC gas boiler: Vaillant EcoTEC plus VHR 25-30 CW4, VHR-NL-25-30/5-5L R6, S/N 21181400100219050001006748N2
- VRC 700: Vaillaint MultiMATIC Thermostat, S/N: 21184600201713150082022270N1
- Heat pump interface: Vaillant VWZ AI VWL X/2 A, SMU 2012 2038E S/N: 21174700201170490082008365N9

To prepare the setup for the SGR tests, a factory reset was performed after which the following settings have been set. First time setup settings on the VRC700:

- Language: English
- System diagram: 9
- MA2 addition module function: no function

Then, the following changes were made in the installer menu:

- System configuration → System, Start OT cooling: 30
- System configuration → Heating 1, max limit heating outs temp: 30
- System configuration → Heating 1, room temperature modulation: thermostat
- System configuration → DHW circuit, cylinder: inactive

On the heat pump interface (installer level settings):

- Configuration → Max dur. Pow. cut-off: 2h

Notes:

- The Vaillant setup has a configurable time for which the heat pump is switched off during a SGR signal. For this test, this value has been set to two hours, as per SGR specification. However, if this setting it set to 0h, the behaviour is the same. So it seems that this setting is not used by the Vaillant controller logic.

5.6 Test Results

Table 2 gives an overview of the test results. For each heat pump it is indicated if:

- **Heat pump off after SGR signal**: shows the time it takes before there is a 85% reduction of electrical power consumption compared to Pmax.
- **Heat pump switches on after 2 hours**: indicates if the heat pump switches on after 2 hours of being forced off.
- **Heat pump stays off after heat demand interruption**: indicates if the heat pump is still blocked, given that the SGR signal stays active, if the heat demand is interrupted.
- **Extend SGR session**: shows if a 2-hour SGR session can be extended by deactivating the SGR signal half an hour after it was activated and starting a new 2-hour period 30 minutes later.

Table 2: Test results of the SGR test with the four heat pump setups

	Heat pump off after SGR signal	**Heat pump on after 2 hours**	**Heat pump stays off after heat demand interruption**	**Extend SGR session**
Daikin	< 10s	No	Yes	No
Elga	< 10s	No	Yes	No
Vaillant	< 10s	No	Yes	No

Although the tested heatpumps do not completely adhere to the SGR specification, especially where the maximum switch off time of 2 hours is concerned, they all respond quickly and reliably to the SGR signal. This makes SGR fit to be used for congestion management applications.

The graphs below show more detailed behaviour of the hybrid heat pumps while conducting test 3. The blue lines represent the thermal power, the grey line the electrical power while the orange line indicates if the SGR signal was on (high) or off (low).

5.6.1 Daikin heat pump + Intergas gas boiler

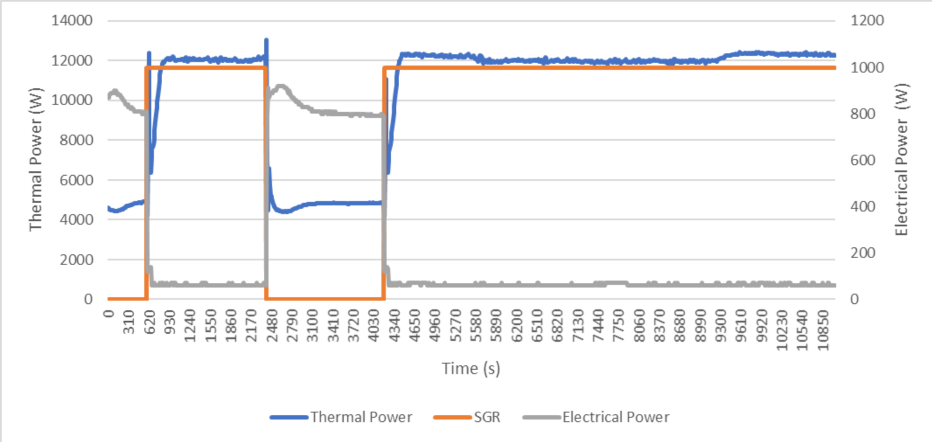

Figure 11: Response to the SGR signal of the Daikin heat pump

5.6.2 Elga heat pump + Remeha Tzerra ACE gas boiler

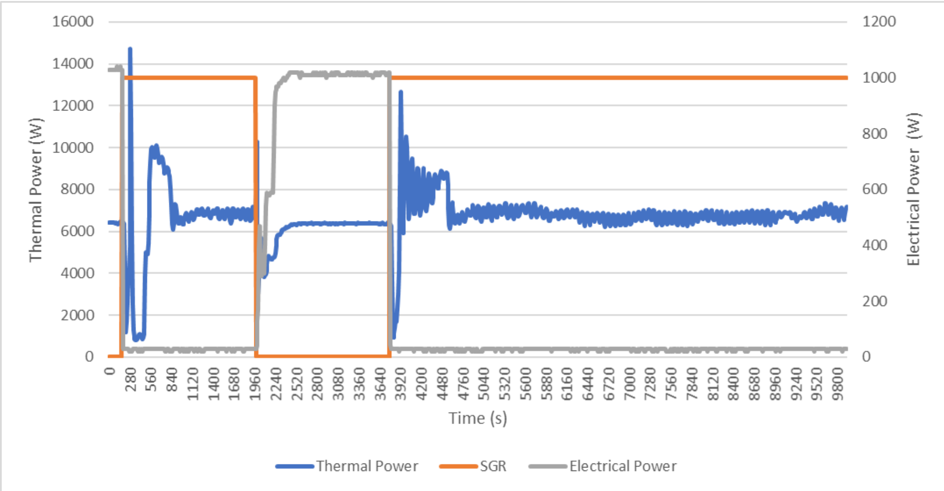

Figure 12: Response to the SGR signal of the Elga heat pump

5.6.3 Vaillant AroTherm Monoblock + Vaillant EcoTEC gas boiler

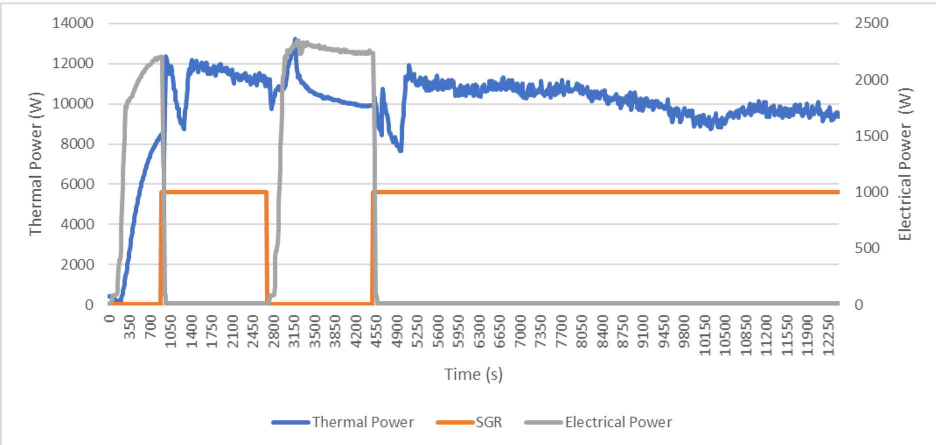

Figure 13: Response to the SGR signal of the Vaillant heat pump

Again it is important to stress that no conclusions can be drawn from the actual numbers in the graphs as the test conditions varied for the hybrid heatpumps. It is the behaviour with respect to the SGR signal that is of interest.

As can be seen in these graphs all hybrid heatpumps respond quickly to the SGR signal by switching off the compressor thereby reducing the electricity consumption to almost zero watt. At the same time the gas boiler steps in to ensure the thermal output of the unit and with it the comfort of the end user. As soon as the SGR signal is off, the heat pump resumes normal operation. This is exactly the behaviour that is required for congestion management.

6 Scaling up from the lab to pilots to roll out

This report proposes a complete congestion management chain from the DSO down to the devices, in particular the hybrid heat pump, that reflects the role and responsibilities of all involved stakeholders. Furthermore, all of the technology that is required is already available today; current HHP's on the market support the Smart Grid Ready technology for example.

To roll out this congestion management chain to a massive number of connections in the field, a lot of work still lies ahead. This chapter considers the steps that need to be taken towards deployment in a pilot and ultimately real life deployment in the field.

6.1 Hybrid Heat Pump Flexibility Roadmap

Figure 14 shows the timeline for HHP flexibility.

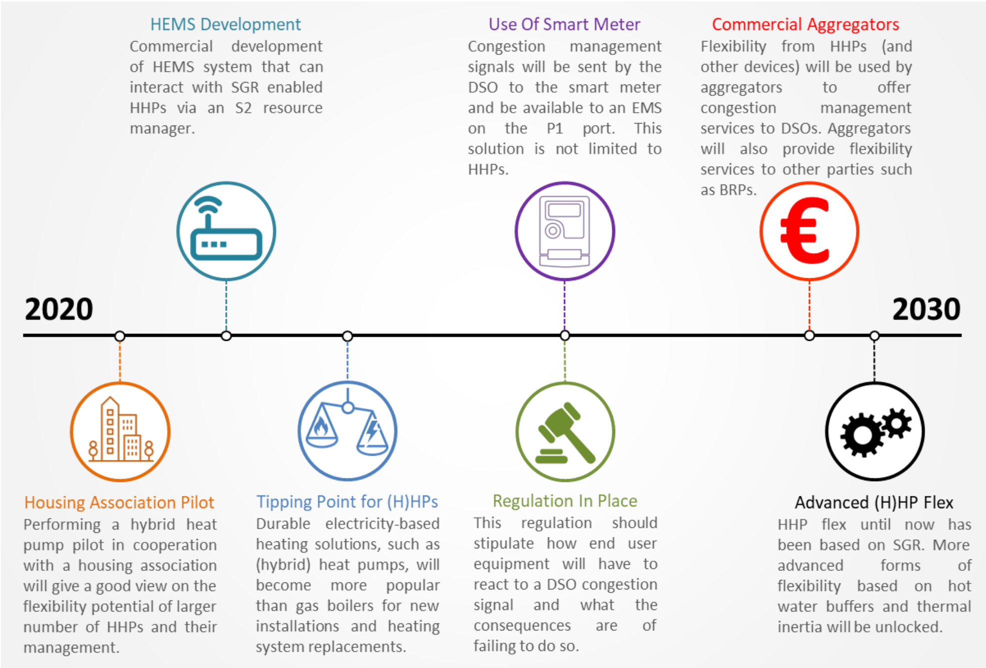

Figure 14: Timeline for hybrid heat pump flexibility

The timeline that is shown runs from 2020 to 2030, but it does not specifically indicate the years for the individual steps, as this is very hard to predict. Instead it focuses on the chronology of the steps that need to be taken. The different steps in the timeline are explained in more detail in the sections below:

6.2 Housing Association Pilot

This section focuses on the steps that need to be taken to scale the current lab proof of concept to an implementation that can be used in pilots with up to hundreds of hybrid heat pumps. It is important that pilot projects are started as soon as possible so that practical lessons learned for future steps can be derived.

The following points should be taken into account when developing a pilot:

- In a pilot it is preferable to concentrate as many hybrid heat pumps in a confined grid section as possible as this would allow for a good assessment of the volume of their flexibility in practice. This will be hard to achieve with individual house owners in a neighbourhood. An already high penetration of hybrid heat pumps would be required and the individual owners would also need to be involved in a pilot. A pilot with a housing association would be a very good option. The housing association could choose to invest in replacing a large number of traditional gas boilers with HHP's at the same time.
- If possible a pilot should consist of a mix of different hybrid heat pumps. This way the lab findings that the congestion management will work with a variety of HHP's can be validated again in practice.
- Ideally the smart meter would be used for sending congestion management messages. However this will take time as this functionality is not supported by default in currently rolled out smart meters. It would at least require firmware rollouts and changes in the backoffice. The best alternative for using the smart meter is to send congestion messages directly to the HEMS. Since it is not possible to take advantage of the already secured communication path of the smart meter, an encrypted connection between DSO and HEMS will have to be put in place.
- The software that has been developed for this project (the resource manager/driver and the HEMS implementation) can be reused for a pilot project. This software is available as open source and may be altered if desired. The HEMS implementation will have to be adapted in order to receive congestion messages directly from the DSO instead of the route via the P1 port of the smart meter.
- Consider including aggregators in a pilot. This report has been focusing on the orange phase, but it could be very beneficial to integrate the yellow phase as well. This way the interaction with the aggregators can be tested and it will push the development of directives that specify the exact conditions that have to be met to justify transferring from the yellow to the orange regime.
- Setup monitoring and reporting tools. Some of the infrastructure in the pilot will have to be actively managed. Think of the HEMS systems that will be deployed at the prosumer premises. It is very practical to have remote access to the HEMS to ensure its proper functioning and to deploy software updates during the pilot. Another aspect is to collect measurement data to be able to validate the effect of congestion management.

6.3 HEMS Development

After the lessons learned from one or more pilots, several steps need to be taken to ensure that such a solution can be rolled out in real life. One important step is the commercial development of Home Energy Management Systems that are able to receive congestion management signals and a S2 Resource Manager/driver that can interact with the Smart Grid

Ready interface on the HHPs. The S2 interface is used to communicate the flexibility of the HHP in a generic way towards the HEMS.

The open source implementations of the HEMS and the S2 resource manager for SGR enabled HHPs that have been developed in this project may serve as the basis. However, it can also be a completely new development as long as both the HEMS and the resource manager implement the S2 interface.

It is worth noting that the resource manager can be re-used for different manufactures and types of HHPs as long as it uses the Smart Grid Ready interface to interact with the heat pump. This will cut down the required development effort.

The commercial availability of HEMS (related) products is a prerequisite for larger operational deployments as end-users will require support for these products.

Of course there needs to be a viable business case for congestion management by DSO's before commercial parties are willing to invest in the development of such hard- and software. Therefore the DSO's will have to clarify in an early stage under which conditions congestion management solutions will work and what they will look like.

Another important aspect that has to be solved is the management of a HEMS. The HEMS is a crucial element in the congestion management chain, but also in other demand response services. It is should be clear who will be managing a HEMS; this be could the DSO, the aggregator, the end user or a specialized third party. This aspect will also need to be worked out.

6.4 Tipping Point for (H)HPs

In their "efficiency requirement" manifest [1] a broad consortium of organizations propose stricter requirements for heating systems that can only be met by (hybrid) heat pumps or a heat grid. Also, newly built houses will no longer have a gas connection.

These developments will lead to a tipping point after which the number of (hybrid) heat pumps will increase rapidly. This will sooner or later lead to congestion problems in the distribution grid. Although the (hybrid) heat pump will not be the only cause of congestion, as EV and PV also play an important role, it will have a very significant impact on the distribution grid.

6.5 Use Of Smart Meter

In order to efficiently deal with congestion problems a standard and reliable solution should be in place. For this purpose the existing smart meter infrastructure is a serious option. The smart meter can be used to provide a congestion management signal to an end user. The DSO can use the so called long message mechanism to send a congestion management signal to the smart meter. This long message will be visible over the P1 port where it can be picked up by a HEMS.

The advantage of such a solution is that there is a clear separation between the domain of the DSO and that of the end user. The HEMS will decide on behalf of the end user how to react to the congestion management signal. This solution is not specific for HHPs and can also be used for EV or PV.

One aspect that needs to be investigated further is performance. The long message mechanism that is proposed in this report will take some time to reach all end users in a congested area. Performance tests should be conducted to make sure that this can take place in acceptable time windows

As stakeholders such as the DSOs and Netbeheer Nederland all need to agree on this solution, it is important that the discussions on the use of the smart meter for congestion management start as soon as possible. The specifications on smart meter usage should be clear in order for commercial parties to bring the necessary (HEMS) products on the market.

6.6 Regulation In Place

The technical solution should be accompanied by rules that specify under which conditions congestion management by a DSO is allowed.

Regulation should also specify how to react to a congestion management signal. End users will have to be motivated to respond to a congestion management signal. If too many ignore this signal it will not be effective. End users might be rewarded for responding or penalized for failing to do so. This aspect will have to be worked out.

Another aspect is the settlement; how will the 15 minute energy readings from the smart meter be related to the power limit. Peak power is not part of the smart meter data at the moment. Should this be added to the smart meter functionality or are the current 15 minute energy readings sufficient to verify that end users responded to a congestion management signal?

Regulation should not focus on specific devices, as is the case in Germany where specific rules have been setup for PV inverters. Rather it should focus on setting absolute limits on the connection to the grid as a whole. This way congestion management can work with a (H)HP, but also with EV, PV and other devices or a combination of devices.

As regulation typically takes quite some time to be in place, discussions on regulation should also start as soon as possible.

6.7 Commercial Aggregators

In the beginning congestion management will mostly be performed by the DSO. As congestion will become a more widespread problem over the years, it also becomes an interesting commercial proposition. There will also be more end-user devices that can offer flexibility; in addition to the (H)HP one could also think of electrical vehicles, batteries and PV panels. Commercial aggregators can deal with the end users and offer aggregated flexibility services to the DSO for a particular congested area.

Aggregators will use their own incentives and settlement schemes to motivate end users to offer flexibility. These mechanisms may completely differ from the regulated congestion management as performed by the DSO. This flexibility will not be used exclusively for congestion management purposes as the aggregator may also sell this to other energy stakeholders such as balance responsible parties (BRPs)

The smart meter route will not be used by aggregators, that is a strictly regulated route that is reserved for the DSO. Instead the aggregators will connect directly to the HEMS of the end user over their internet connections. It is important to note that the HEMS and the S2 resource manager will be used for both the aggregator and the DSO.

As is apparent, the HEMS is a crucial element in the congestion management chain, but also in other demand response services. It is yet unclear who should be managing the HEMS; should this be the DSO, the aggregator, the end user, a specialized third party? This aspect will need to be worked out further.

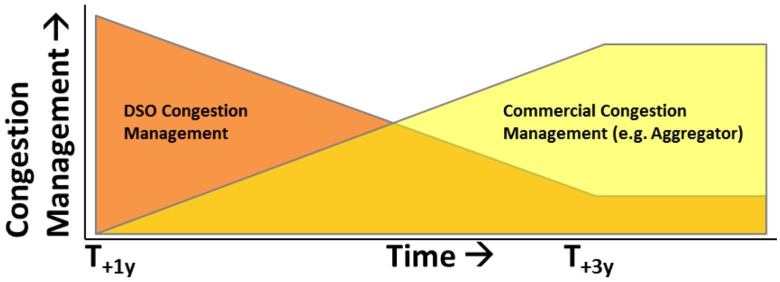

Figure 15: Introduction of commercial congestion management by aggregators

Figure 15 shows how most congestion management tasks will be taken over by aggregators over time. However, aggregators will not be able to take over all congestion management responsibilities as can be seen in the figure above. There will be times when there is simply not enough flexibility in the market, aggregators may also be unavailable because of technical problems or prices for flexibility may be unacceptably high. In such cases the DSO will step in, the exact conditions under which this may take place are subject of regulation.

6.8 Advanced (H)HP Flex

As described in chapter 4 there are also more advanced forms of flexibility that can be realized with a HHP. They do require investments in additional sensors and sophisticated models that describe the relation between HHP installations and specific building characteristics. Such additional investments will likely only happen if the value of flexibility increases and customers will start to see flexibility as an important feature of (H)HPs.

7 Conclusions and recommendations

This chapter presents the main conclusions that can be drawn from this practical study on congestion management with hybrid heat pumps and also makes recommendations for next steps.

7.1 Conclusions

- All of the technology needed for congestion management is already available and (most importantly) rolled out in current hybrid heat pump products. This flexibility can be unlocked using the Smart Grid Ready interface and has been successfully tested with 3 test configurations featuring relevant hybrid heat pumps for the Dutch market from different manufacturers.

- Although all of the technology is already available, it still needs to be integrated to form a fully functional congestion management chain. Also, additional components that communicate locally with the HHP have to be rolled out on the end user's premises. This report presents a high level IT architecture for the complete congestion management chain that also has been successfully implemented as a proof of concept in a lab environment.

- The smart meter can be used to communicate connection limits in case of congestion. This can be achieved within the current smart meter specifications. The smart meter forms the gateway between the DSO and the end user domain. It is not desirable that the DSO crosses this domain boundary by communicating directly with devices such as the HHP, as it is up to the end user to decide how to meet the connection limit requirements and which devices will be used to achieve this. Further studies with respect to the performance of the smart meter in this respect are needed.

- More advanced forms of flexibility are currently difficult to implement. The solution that has been successfully proven in the lab relies on switching from electricity to gas (using the SGR interface). This type of flexibility is not applicable to full electric heat pumps. More advance forms of flexibility (based on buffers and modulation) need to be supported to be able to also extract flexibility from full electric heat pumps. This is currently blocked by a lack of sensor information and advanced heating models. It is expected that manufacturers will only start working on this when flexibility becomes more valuable and such features will be requested by customers.

- Regulation will have to be put into place that stipulates the conditions under which congestion management by the DSO can take place. It should also clarify what the consequences are of exceeding a connection limit. Discussions on regulation will need to start soon.

7.2 Recommendations

This lab study has been a first step in implementing a fully operational congestion management chain, however further steps are required to take this solution out of the lab and scale it up to large numbers that are required. Below the most important recommendations have been described.

- The local components on the end user premises should be open and interoperable so that they can be reused to exploit (HHP) flexibility for other stakeholders (e.g. aggregators) and services as well.

- Pilots should be started that focus on the steps that need to be taken to scale the current lab proof of concept to an implementation that can be used in pilots with up to hundreds of hybrid heat pumps. It is important that pilot projects are started as soon as possible so that practical lessons learned for future steps can be derived.

- Start discussions on regulation. A sound regulatory framework is a prerequisite for further developing congestion management solutions. It is very important that all stakeholders know what their responsibilities and obligations are. Since regulation takes a long time to materialize it is important that these discussions will start as soon as possible.

- Further study on the use of smart meters for communicating connection limits is needed. This should be specifically focused on performance as hundreds of end users will need to be reached in a relatively short amount of time in case of congestion.

- Start discussions on the management of HEMS. The HEMS plays a crucial role in smart grids, but is not clear who should be managing the HEMS. This needs to be worked out further.

8 References

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