Lessons Learned from Use Case DE#3
Version 1.0

Deliverable D5.9

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EXECUTIVE SUMMARY

Deliverable 5.9 describes the results and lessons learned from the German Demo of InterFlex in Use Case 2. UC3 dealt with the activation of flexible loads on low voltage networks by the DSO. The line of communication for meter readings and control signals is the national smart meter framework. Control signals originated in the DSO grid control room and were handled by the DSO flexibility platform Smart Grid Hub.

Among the flexible devices activated were storage heaters and heatpumps owned by private customers who participated in the InterFlex field trial in the area near Lüneburg, Germany. During use case testing Avacon could successfully demonstrate the ability to control small scale flexibility directly and individually directly from its grid operation centre in Salzgitter.

While the general feasibility of the concept could be proven, it also showed room for improvement. In all testing scenarios only a share of control signals could be communicated to customers and not all customers responded to control requests as expected. The success rate of measurement- and control requests overall was 50% for storage heaters and 61% for heat pumps. In the case of a successful request the data showed a surprising diversity of behaviour of devices and sometimes inconsistent responses.

Use case demonstration have confirmed the feasibility of replacing old broadcasting signal technology with a digital smart-meter-based infrastructure and with that also confirmed that the expected benefits of such a change can be captured. To which degree depends on how quickly the system will mature. As of today the limitation to LTE mobile data places a burden on the use case, as the signal coverage in rural Germany is poor. Also, the smart meter framework as a whole is rather cumbersome and inflexible and in its current iteration not suited to support the use cases required in a rapidly changing environment.

It is recommended that regulators encourage DSO to further explore the possibilities of flex activation via smart meter framework. One roadblock for the wider application of these use cases in Germany is the unclear situation of the control box. While the control box plays a crucial role in enabling the demonstrated use cases, it is as of today not strictly considered a part of the smart meter and hence its financing not clear.

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1. INTRODUCTION

1.1. Scope of the document

1.2. Notations, abbreviations and acronyms

The table below provides an overview of the notations, abbreviations and acronyms used in the document.

Table 1 - List of Acronyms

ADMS	Advanced Distribution Management System
CLS	Controllable Load System
DER	Distributed Energy Resources
DSO	Distribution System Operator
EC	European Commission
HV	High Voltage
KPI	Key Performance Indicator
LV	Low Voltage
MV	Medium Voltage
OT	Operational Technology
PLC	Powerline Communication
SCADA	System Control and Data Acquisition
SGH	Smart Grid Hub
SMFW	Smart Meter Framework
SMGW	Smart Meter Gateway
UC	Use Case
UI	User Interface
UTC	Coordinated Universal Time
VHV	Very High Voltage
WPL	Work Package Leader

2. DESCRIPTION OF USE CASE

Use Case DE3 evaluates the new technology that has been developed as part of the InterFlex field trial in Germany and to validate new applications and control strategies that become possible with this new technology. The focus of use case 3 is the control of flexible loads in the residential segment with the goal of improving DSO operations, increased hosting capacity for DER and higher quality of supply in low and medium voltage networks.

The target segment consists of residential customers that are participating in existing flexibility schemes with a controllable or interruptible heating device, e.g. a heatpump or storage heater. Many of these customers are part of decades old flexibility mechanisms that go back to pre-liberalization times. These mechanisms are not designed for the challenges of the contemporary energy transition and were never meant to be. They do however present an immediate opportunity to leverage dormant flexibility in low voltage networks without the need for an updated regulatory framework or new activation and remuneration mechanisms.

InterFlex has already demonstrated the feasibility of an integrated IT-architecture that includes DSO systems (SCADA, ADNM), a public smart meter framework (“BSI-framework”) and an additional control platform for flexible elements (Smart Grid Hub - SGH). With these systems in place InterFlex and Avacon aim to validate the new solution under 3 key considerations:

- Can we replace old control technologies with our new development and carry out existing use cases on a digital infrastructure?
- Can we leverage these recently developed systems to increase the impact of new technologies and better utilize flexibility?
- Can we leverage the new technology to create new use cases that improve DSO-operations and economics?

To address these concerns, InterFlex has carefully designed use case demonstrations of increasing complexity. The following report describes design and execution of use case testing, highlights key learnings and notes some recommendations for the future development of DSO-owned flexibility platforms.

2.1. State of the art load control in Germany

Use case DE3 targets the segment of residential customers in Germany with flexible loads. For the purpose of the field test demonstration in Germany we define flexibility as:

“The ability of a device to modify its interaction with the network in response to an external signal.”

In previous tests and deliverables InterFlex has already proven the general capability to control privately owned devices through the public smart meter and hence classify them as flexibilities in the sense of the above. With this in mind, customers in Germany could theoretically offer large amounts of flexibility to the grid, and in fact they do already albeit not in the most practical manner.

2.1.1. Legal and regulatory context

The directive 2012/27/EU art 15 (4) states that « Member States shall ensure the removal of those incentives (…) that might hamper participation of demand response, (…) » as well as improving customer participation in demand response. In Germany we find these aspects reflected in §14a Energy Industry Act (EnWG), which states that « Network operators are obliged to offer a discount on grid charges for those customers who offer controllability and flexibility to the system operator ». It further states that the details of this controllability and flexibility scheme remain to be defined in a statutory law which is yet to be finalized. Until then however, a number of historic flexibility- and control-mechanisms have been grandfathered in under EnWG §14a.

The most common among these historic control mechanisms is a DSO-controlled switching of storage heaters that once applied to double-tariff customers. This kind of customer would receive a discounted energy tariff during off-peak hours. These tools were conceived in an era before the German energy system underwent unbundling, so back then the discount would apply on a combined retail- and grid charge price. The distribution company would determine the discount and retain control over the definition and switching of peak and off-peak windows. Today retail and grid are unbundled so that the retail share of a customer's energy does not necessarily reflect the old double tariff model. However, under §14a EnWG the grid operator is still granting a grid charge discount in exchange for controllability and is still using the same systems to carry out the tariff switching, even though it might not have any effect on the retail side. The contractual agreement states that the DSO defines preferred charging times, guaranteeing a sufficient number of hours to cover customers energy demand. In practice, DSO usually have fixed charging windows during the night that amount to 8 hours of charging time. During these hours the customers heating device would charge up with thermal energy and release the heat throughout the following day. On particular cold days and in some regions, DSOs might also activate heaters for additional heating periods during the day to cover high demand.

Heatpumps on the other hand have not been around when the first installation of the double-tariff scheme took place in the 60s and 70s, so they are less burdened with historic flexibility mechanisms. Taking into account customer's expectation for comfort and the capabilities of the devices, today's agreement between DSO and customer under §14a EnWG states that Avacon has the right to interrupt the heatpumps operation for up to 2 hours, up to 3 times per day.

2.1.2. Technological aspects and controllable devices

There are three commonly used technologies to carry out the control actions described above.

First there are clock timers installed locally on the customer's installation. These simple devices open and close the charging windows for storage heaters at fixed and predefined times each day, independent of temperature, load or other grid considerations. This simplest of all technologies has no communication, no online data and cannot be accessed or modified from the outside. Customers equipped with clock timers do not offer flexibility.

Secondly, we find load control via long wave radio signals. Here customers are equipped with a long wave radio receiver that switches devices on or off according to the current status of the signal. The sender is owned and operated by a third party and not part of the DSO infrastructure. This system does not provide any live data or signal confirmation.

And lastly some grid operators employ acoustic ripple control to carry out load control. The senders are owned and operated by the DSO and often fully integrated with the grid OT. However the system does not have any advanced data processing capabilities and offers very limited options for dynamic load control. In practice the system is used to broadcast the same signals day in day out. Signals are only modified by manual intervention when a fault occurs.

What all three systems have in common is a lack of data processing capabilities and that none fits into the smart meter framework. This circumstance makes it impossible to carry out complex use case algorithms and in turn renders the existing flexibility in households useless for the DSO.

2.1.3. Shortcomings of present approach and potential for improvements

Even though both regulatory mechanisms could theoretically offer a fair amount of flexibility to the DSO the technological limitations prevent DSOs from making use of it. For once, the existing technology employed to control these flexibilities is not suited to enable a dynamic and integrated approach to the control of small scale flexibilities. On the other hand, the uncertainty about future developments of the regulatory framework, particularly the final content of the statutory law concerning §14a EnWG, leaves DSO hesitant to commit resources to design a decision- and control framework that can take full advantage of the target segment. Before InterFlex there was also a lack of suitable technologies that enable precise, dynamic and transparent control of small scale flexibilities.

To sum up the shortcomings of the existing approach:

- No or limited possibility to discriminate for location
- No possibility to control individual devices
- Outdated analogue systems
- Limited integration with peripheral IT/OT-systems
- Limited potential to increase degree of integration with peripheral IT/OT-systems
- No potential to integrate with future smart meter systems

This list of shortcomings presents a number of possibilities for InterFlex to improve on the status quo. For example, InterFlex and the Smart Grid Hub

- Are fully integrated with peripheral IT/OT-systems (Smart meter administration, SCADA / ADMS)
- Are digital systems that enable complex use case algorithms
- Leverage the smart meter framework to enable individual and dynamic control of flexible elements.

The use case demonstrations that follow are designed to investigate the transition between new and old technology. It shall also shed light on open issues and ways to further improve the system design for future deployment.

3. FIELD TEST DESIGN

The field test use case demonstration of WP5 are carefully designed to investigate how well the current DSO-systems can be transitioned to a new digital infrastructure. Furthermore, it shall shed light on the practical performance of the newly developed technology and show how well the system performs the tasks of grid operation. Finally, it shall provide insight on the potential for improvement in DSO operations.

The field tests have been carried out with increasing complexity.

3.1. Results of field testing

3.1.1. Test 1 – General Switching Capabilities for Storage Heaters

Test 3 demonstrates how the SGH in combination with a Smart Meter and control box on the customers premise can replace the broadcast or ripple control technology to manage the consumption of double-tariff devices in private households. Today only a single charging slot is defined across the entire service area of a DSO. These charging windows can neither be modified easily nor can they be adjusted for location. As a result, the charging signal at Avacon is set at 10 pm day in, day out.

Within InterFlex Avacon set out to demonstrate how the SGH can enable dynamic control for this customer segment. The SGH shall enable a switching regime that can be adjusted from day to day and behave differently for different customers. Having these capabilities would enable the DSO to take advantage of the flexibility in this customer segment. Potential upsides include:

- Staggered switching of sub-groups to reduce peak load
- Preventive reduction of remedial actions in high-feed-in scenarios
- Optimized load dispatch to improve DSO economics

To capture these upsides however, the general switching and control capabilities have to be demonstrated first.

Table 2 - Overview of Storage Heater Activations

Test Run #	Date	Action Performed	No. of customers activated	Success Rate
1	14.04.2019	Modification of Charging Slot (Delay Start 2hr)	3	2/3
2	15.04.2019	Modification of Charging Slot Delay End 2hr)	3	2/3
3	15.04.2019	Modification of Charging Slot (Delay 1hrs)	3	2/3
4	22.04.2019	Modification of Charging Slot (Delay 0.5 hrs)	4	2/4
5	24.04.2019	Load Reduction	4	2/4
6	26.04.2019	Live Data Streaming	4	0/4
7	29.04.2019	Load Reduction	4	2/4
8	29.04.2019	Load Reduction	4	2/4
9	29.04.2019	Load Reduction	4	2/4
Total				**16/33**

During the demonstration period a number of test runs have been executed. For the purpose of evaluating the function of the storage heater link, a total of 9 demonstrations has been run with groups of storage heating devices.

The rate of success of switching and metering requests never exceeded 67% and was as low as 50% most of the time. While the cause for this disappointing rate remains to be researched, one reason is likely the LTE-connection between the gateway administration service and the smart meter gateway.

Figure 1 shows the data of a storage heater customer with successful modification of the customers charging slot. On 14.04.2019 the charging slot was delayed by two hours from 10pm to 12am, on 15.04.2019 it was delayed by one hour from 10pm to 11pm. Both days demonstrate the typical behaviour of a storage heater: a sharp rise of power demand once activated, followed by a reduction in demand in steps when one individual device after another shuts down once it has charged enough. The only difference, as intended, is the time of the start of the charge.

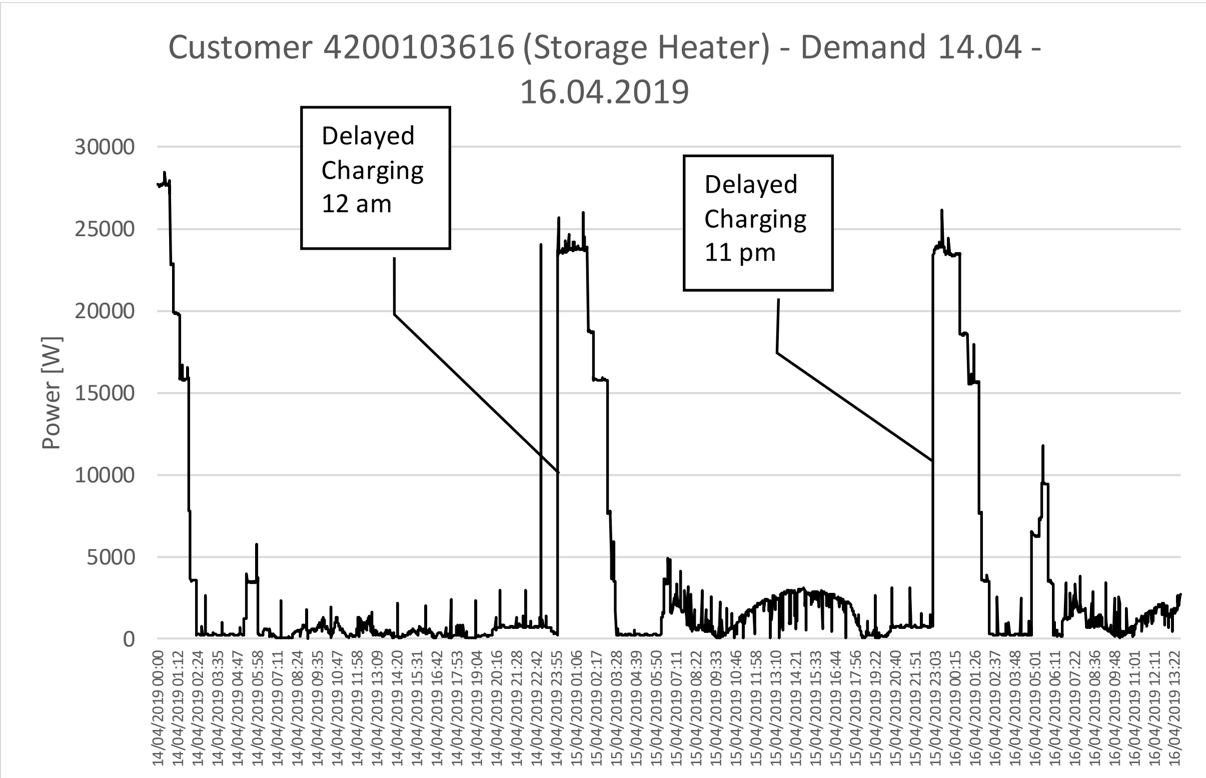

Figure 1 - Charging Slot Modification of Storage Heater via SGH

3.1.2. Test 2 – General Switching Capabilities for Heatpumps

When it comes to adding more flexibility to the power grid, leveraging thermal inertia of buildings is a good place to start looking. As we saw in 3.1.1, storage heating devices can introduce an additional element of controllability and flexibility in the otherwise uncontrollable and inflexible segment of residential customers. Storage heating devices however are oftentimes outdated and based on 70's and 80's technology. They also leave many customers wanting for more comfort, easier usage and better transparency. New storage heating devices are rarely installed in Germany anymore and the existing pool of devices shrinks per year at rate of roughly 4%. So, while storage heaters can play a vital role during a transitional phase towards a flexible cross-carrier energy system, they are not the last word in sector-coupling in the residential segment. Another technology that is already widely deployed and could potentially offer flexibility are heatpumps. These device work by extracting heat from the surrounding air or ground by pumping a heat-carrying fluid between two heat-exchanger. The pumps are driven electrically and represent the only energy consumption of the device to provide heat for the building.

In Germany, heatpumps can qualify for a reduced grid charge if they offer some level of controllability or interruptibility to the DSO. In the case of Avacon, it is contractually agreed that in exchange for a reduced grid charge, Avacon can interrupt a heatpump's operation for a period of up to 2 hours, a maximum of 3 times per day, with a minimum of 1 hour of operation between two interruptions. With this, heatpumps enable a type of flexibility that can be classified as interruptible load. During a period of interruption, the building draws upon thermal energy stored in the building envelope and recovers the "missing" energy once operation is resumed. This rebounding can be detrimental to the goal of the flex-activation if the device causes an ill-timed spike in consumption when operation is resumed.

InterFlex enables for the first time in Germany to control individual heatpumps directly from the grid control room by using the Smart Meter Framework. The focus of use case testing lay primarily on demonstrating the general capability to measure and switch heatpumps via the newly developed technology and investigate the potential pitfalls and teething troubles of new technology. Since for the first time the DSO has direct access to metering data on the household level, this also presented an opportunity to better understand customer's behaviour and refine concepts for load control.

Figure 2 and Figure 3 display the measured data from two customers between April 16th and 18th 2019. These two serve as an example of how differently heatpumps behave towards the grid. Both customers exhibit a pulsing profile (with implications for the available flexibility to be discussed later), but the pulsing patterns vary widely. The device of Customer #4201491105 in Figure 2 charges for about 1 hour at a time and displays an ability to modulate how much power it is drawing, with the load increasing as the night gets colder. On the contrary, the device of Customer #4205311511 in Figure 3 is charging for about 10 minutes at a time and barely modulates its power demand while charging.

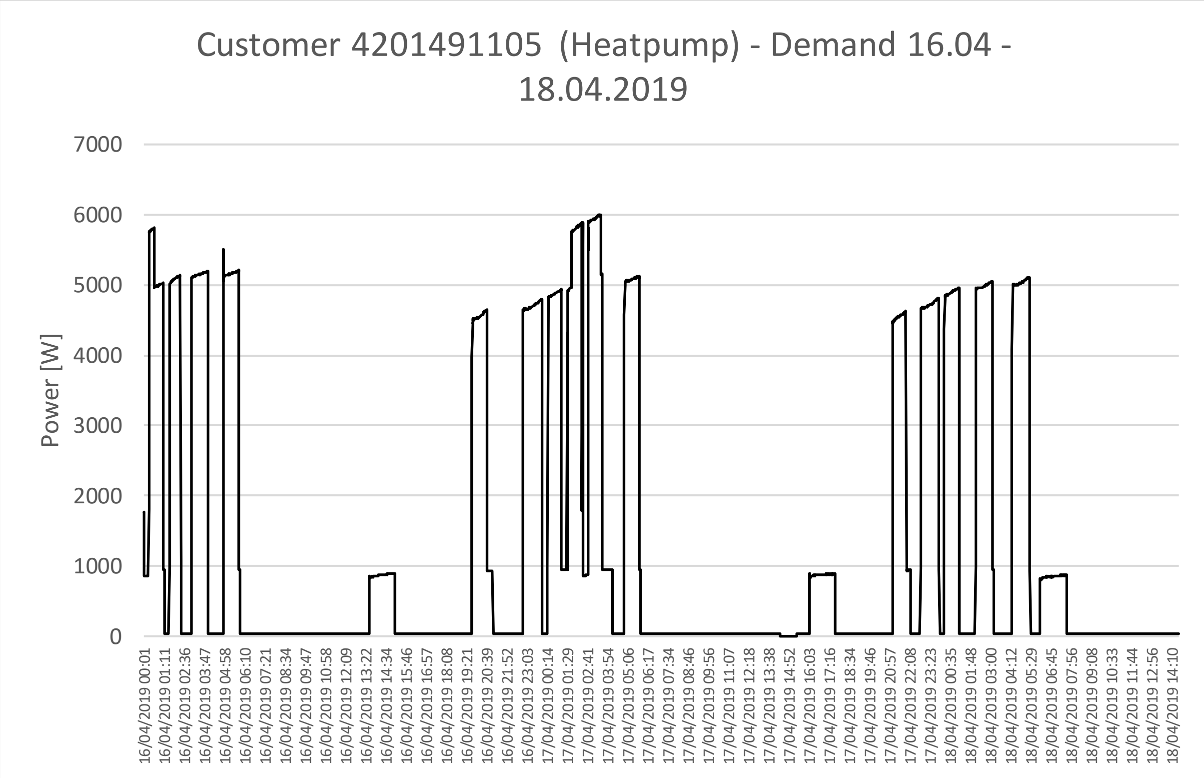

Figure 2 - Power Demand of Heatpump #4201491105 16.04. - 18.04.2019

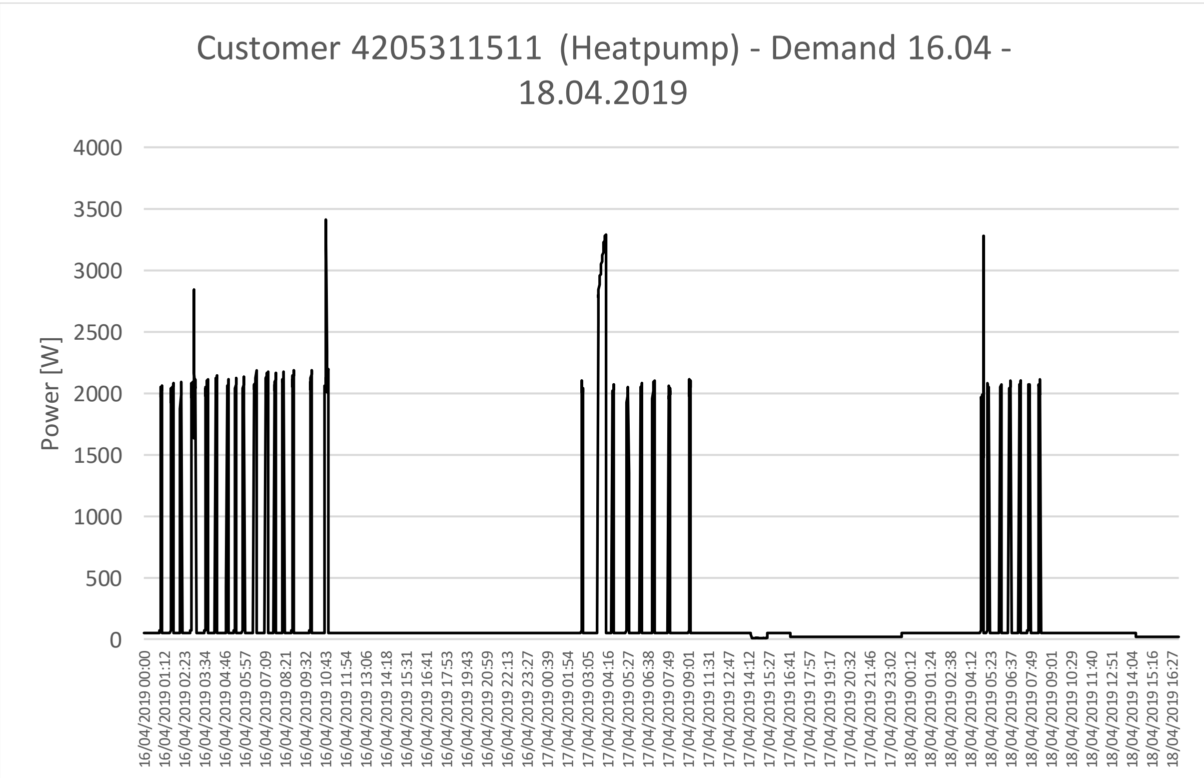

Figure 3 - Power Demand of Heatpump #4205311511 16.04. - 18.04.2019

Both devices however responded to a test switch signal on April 17th at 2:20pm, when the Smart Grid hub requested the heater to interrupt operation for 60 minutes. Figure 4 and Figure 5 display the data of the heatpumps for the test switch window between 2:20pm and 3.20pm. While both devices did respond to the shut-off signal, there were notable differences in the behaviour of the two. We can see one device reducing power consumption to exactly zero while the second device maintained a base loading of about 11 Watts during shut-down. Further we see a delay in response in both. The load interruption request was timed for exactly 2:20pm, #4205311511 reached the floor of reduction of 11 Watts at 2:25pm with a delay of 5 minutes. #4201491105 reached the target within two minutes at 2:22pm. The ramp up once the shut-down signal expired exhibits almost the same delays, two and four minutes respectively.

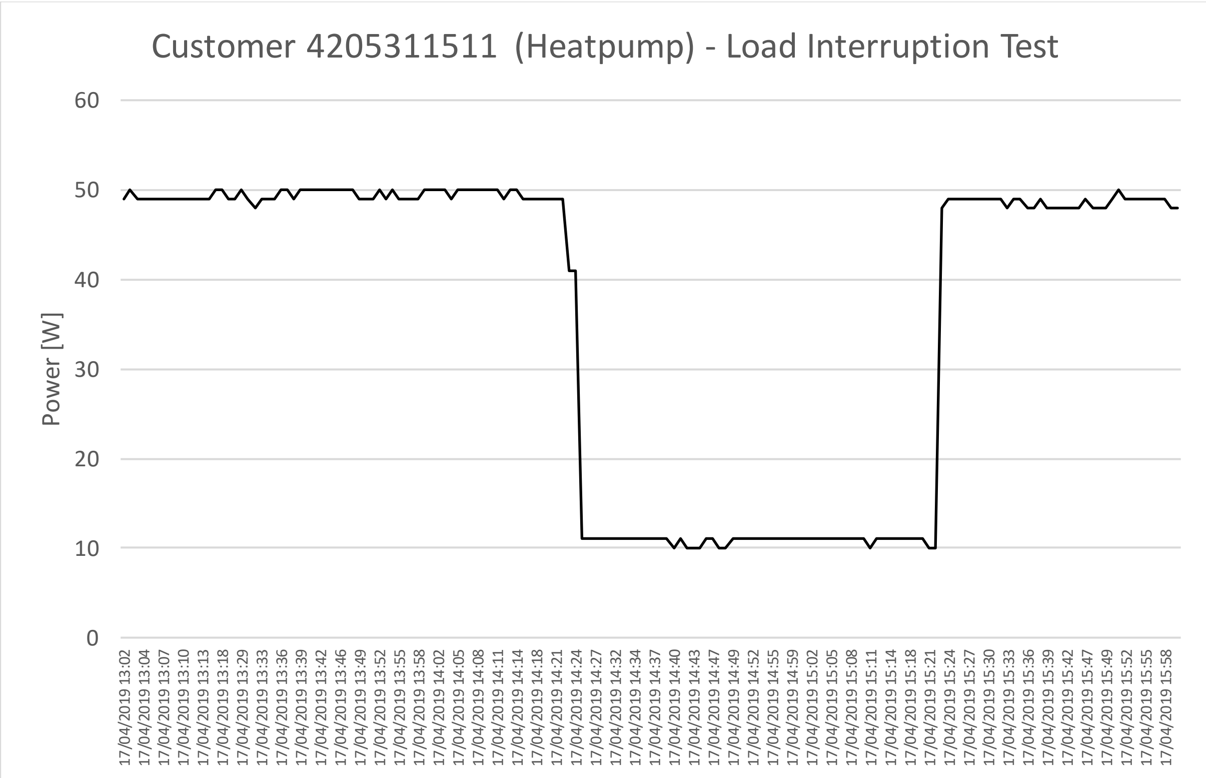

Figure 4 - Load Interruption Test 17.04.2019 at Customer 4205311511

Both switching tests were scheduled for low load scenarios with an expectation of higher ambient temperature on purpose. During the preparation of field-testing customers expressed concerns about their heater being controlled by a third party. Residential heating is of the utmost importance for the comfort and wellbeing of customers and handing of even a share of control to the DSO made some customers feel uneasy. For the very first field tests with real-life customers InterFlex therefore scheduled trial switching for hours when an error would not result in immediate loss of noticeable heating power but rather for warm hours that would leave room for fault response

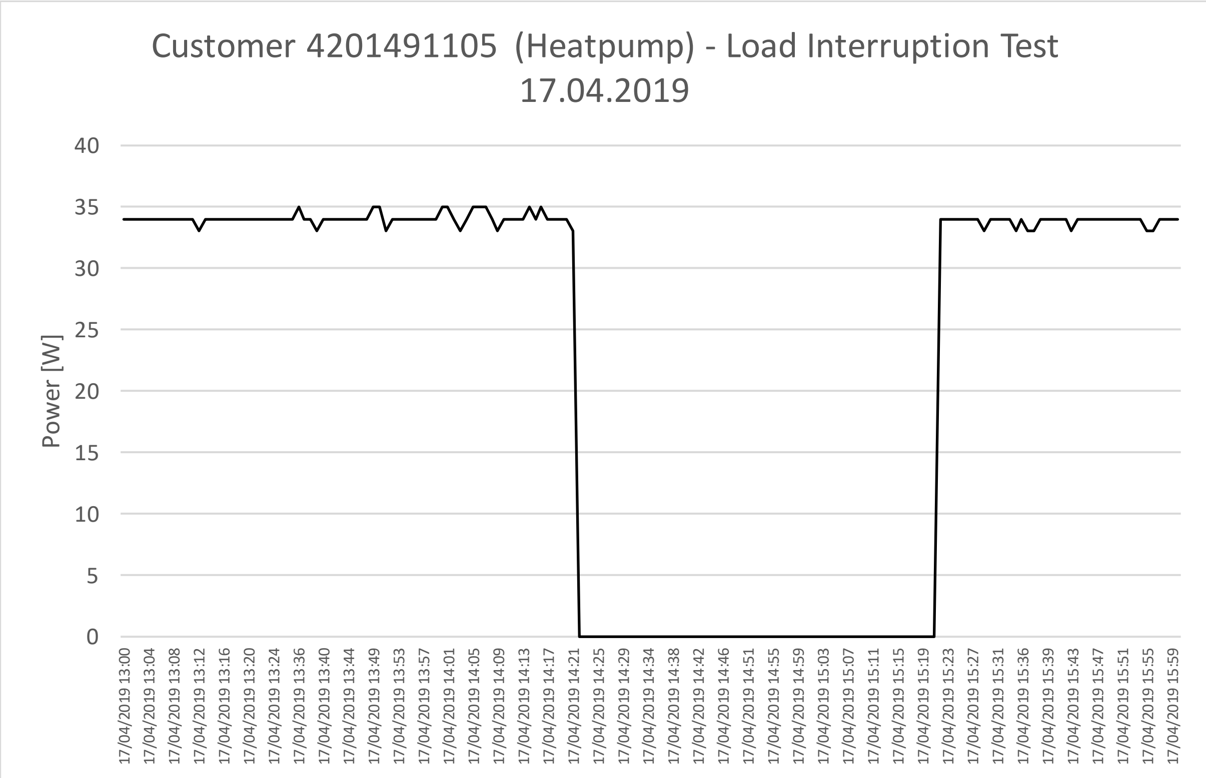

Figure 5 - Load Interruption Test 17.04.2019 at Customer #4201491105

Following up on successful first trials, the next test run was scheduled for times with higher heater load to investigate how devices under load would respond. Figure 6 displays the results for customer #4205321708 during the tests of April 23rd. Load interruption requests were scheduled for 7:00am and 8:30am for 60 minutes at a time. The data shows the heatpump reacting precisely as requested, reducing load almost immediately and ramping back up after an hour had passed. Load was reduced to zero Watts, with a delay of 2 minutes (7am shut off and 8am ramp up) and <1 minute (8.30am shut off and 9.30 ramp up). The data also shows that the rebound effect of the heatpump catching up on lost consumption did not happen immediately. Instead the device first went into base load at about 150 Watts before increasing demand to close to peak power at roughly 1200 Watts about 10 minutes later.

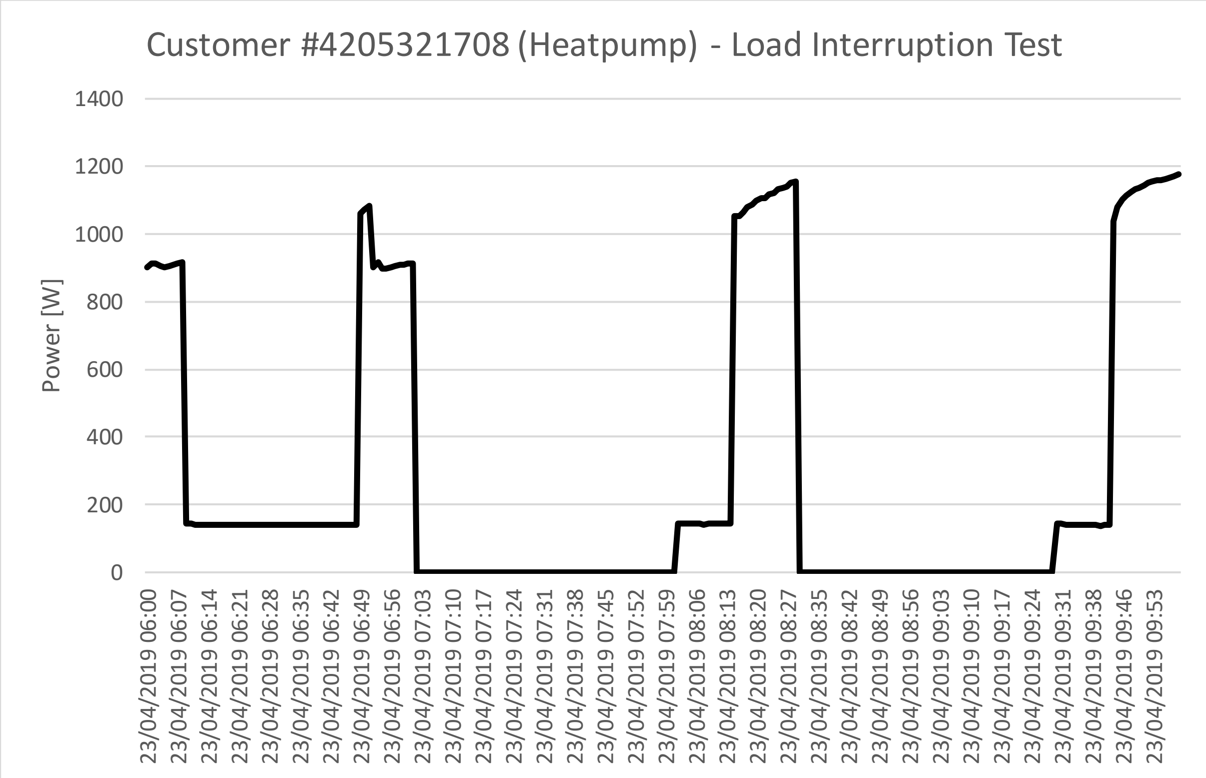

Figure 6 - Load Interruption Test 23.04.2019 of Customer #4205321708

Beside these very successful trials InterFlex also encountered a fair share of unsuccessful test switching. On 06.05.2019 load interruptions were scheduled for 14 heatpumps at 10am and 2pm for 60 minutes at a time. The first test the SGH noted an error in 4 of 14 heatpumps, the second reported errors for 5 of 14. Further, a large number of customers operates a heatpump in combination with a rooftop PV generator, both sharing the same point of connection. In these cases, the data was too messy to draw clear conclusions on the success of the switching action.

Figure 7 exhibits the data from customers #4201320273 and #4201488794, both of which were supposed to interrupt their load at 10am and 2pm for 60 minutes at a time. Both failed to respond to the signal. Both can be seen operating during the first shut-down window and neither displays a discernible rebound at the end of the shut-down period. For the second switching window we see #4201488794 ramping down consumption near 2pm. At closer inspection the reduction already starts at 1:52pm, does settle into a base load of 175 Watts and fails to produce a noticeable ramp up once the control ends. While the data does in fact not show significant load during the switching window it lacks a change of behaviour in any way at or near 2pm and 3 pm. This suggests that no control signal was received or computed. The maintained standby load of 175 Watts furthers this even more, to the point where the switching at this customer must be considered a failure.

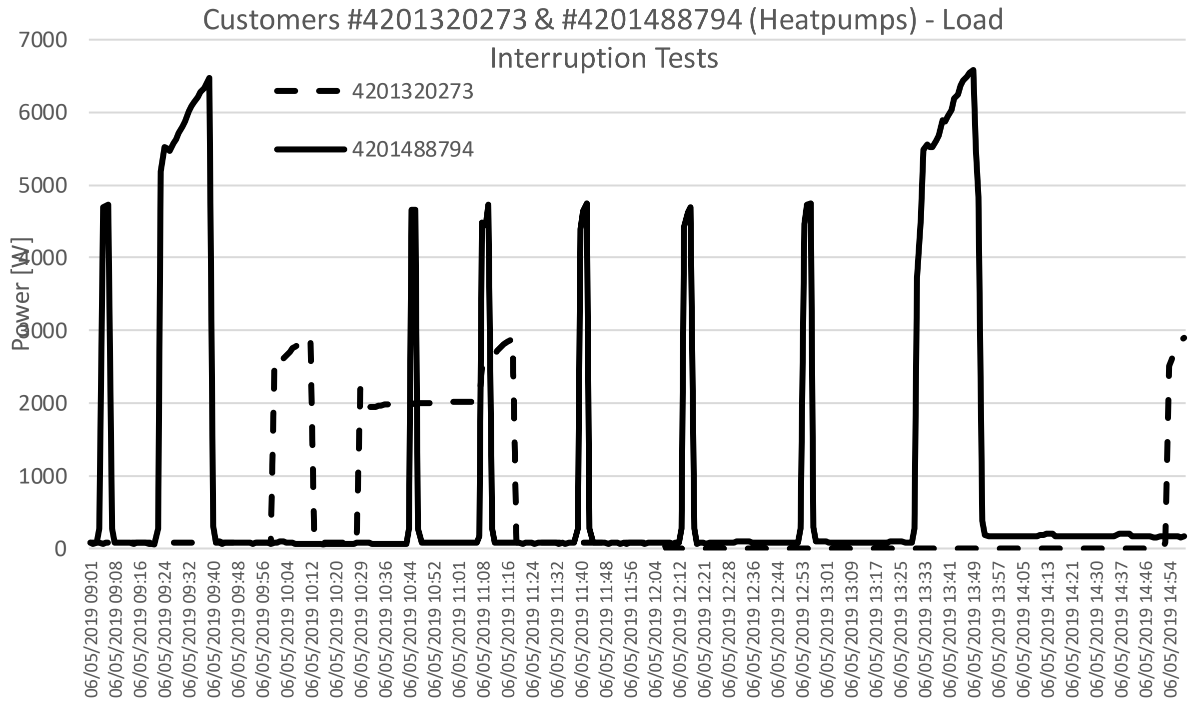

Figure 7 - Load Interruption Test 06.05.2019 of Customer #4201320273 & #4201488794

Figure 8 shows the data at customer #4205321708, a customer who had demonstrated a working connection in previous tests. In this instance however, the customer displays rather odd behaviour. We see a complete shut-down at 11am and ramp up at 3pm. Lacking a reliable control confirmation from the customers device we can only guess what exactly caused this behaviour. There are several ways to interpret the data:

1. The customer did not receive any signal and behaved the way he did independently of SGH interaction.
2. The control box failed to sync its internal clock properly the first time around and shut-down was delayed by one hour. Ramp up was not received or ignored the first time around, but then at the second instance at 3pm.
3. Control signals were sent for shut-down at 11am and ramp up at3pm, but not reported in the SGH's switching protocol.

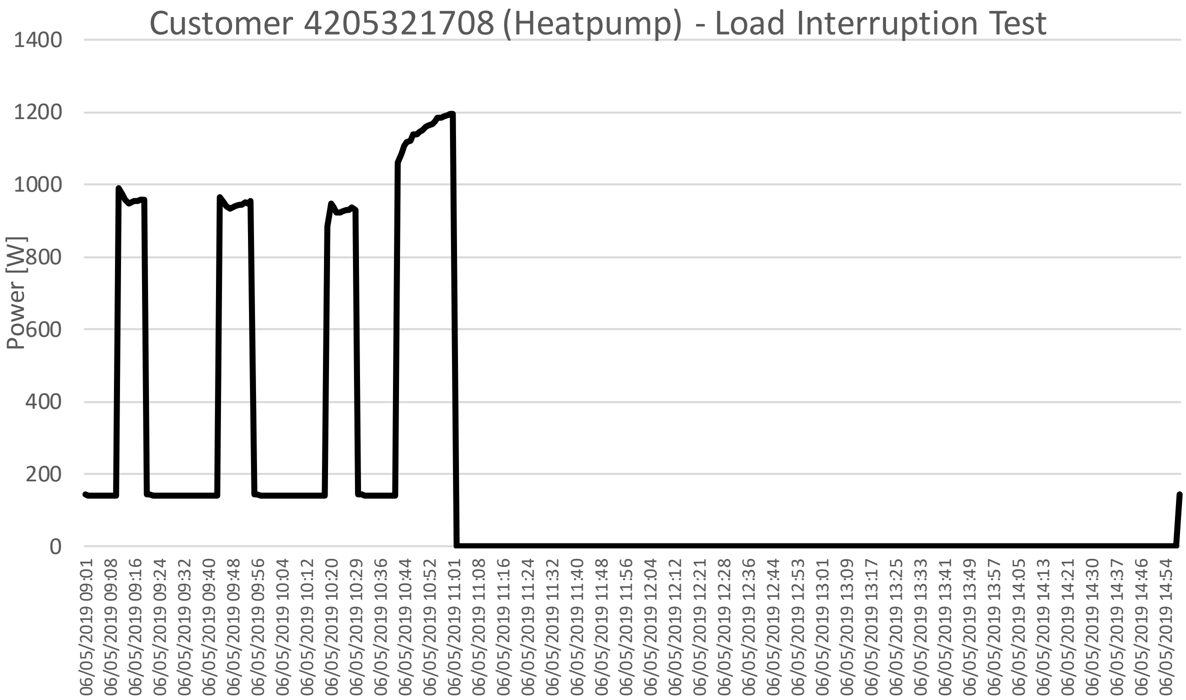

Figure 8 - Load Interruption Test 06.05.2019 of Customer #4205321708

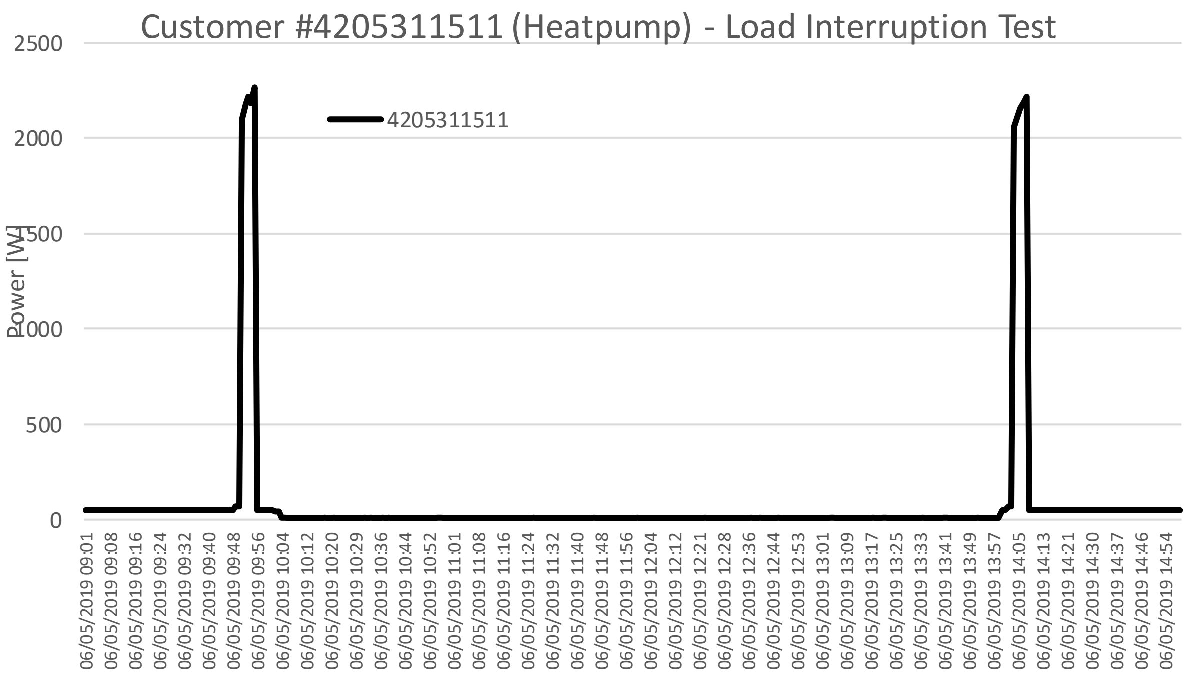

Figure 9 - Load Interruption Test 06.05.2019 of Customer #4205311511

Finally, Figure 9 which shows the data of customer #4205311511 the same day. In this case, the heatpump responds to the first shut-down at 10am but fails to activate again at 11am. Instead it remains off until the second ramp up signal at 3pm arrives.

Overall the rate of success for switching and measuring heatpumps turned out slightly higher than for storage heaters. Not counting individual activation trials and only those fed through the "group-function" of the SGH a total of 131 attempts have been made to switch or measure a heatpump. Of those, 80 activations were reported technically successful, meaning the signal was properly routed through the entire smart meter framework, CLS-channels have been established successfully and data has been transmitted. At a rate of 61% success, heatpumps can be considered to be slightly better available than storage heaters and this part of the field trial a success overall.

Table 3 - Overview of Heatpump Activations

Test Run #	Date	Action Performed	No. of customers activated	Success Rate
1	26.03.2019	Live Data Streaming	1	0/1
2	27.03.2019	Live Data Streaming	1	0/1
3	12.04.2019	Live Data Streaming	17	10/17
4	17.04.2019	Load Interruption	14	10/14
5	23.04.2019	Load Interruption	14	10/14
6	23.04.2019	Load Interruption	14	10/14
7	29.04.2019	Load Interruption	14	10/14
8	06.05.2019	Load Interruption	14	10/14
9	06.05.2019	Load Interruption	14	10/14
10	10.05.2019	Live Data Streaming	14	1/14
11	10.05.2019	Load Interruption	14	9/14
Total				80/131

3.1.3. Data acquisition via the smart meter framework

Another benefit of the integrated approach is that the SGH enables grid operators to collect and monitor data directly acquired by the smart meter installed on the customers premise. The key metric used at the moment is the real-time power demand or feed in of the individual customer at the point of connection.

The InterFlex use cases rely on a stable connection and reliable supply of real-time data to enable efficient and precise control of flexibilities. For this, InterFlex is using what the German Smart Meter Framework defines as common smart meter use case 9 (TAF9 in German). TAF9 can be triggered momentarily with a single activation, for example to confirm successful switching or determine the currently available flexibility. InterFlex has also explored the streaming of TAF9 values in 60 to 90 second intervals, which is a significant improvement on the basic smart meter framework design.

For UC3 InterFlex had a total of 21 customers available for switching and testing. Figure 10 shows the distribution connected to the SGH for field testing of use case 3.

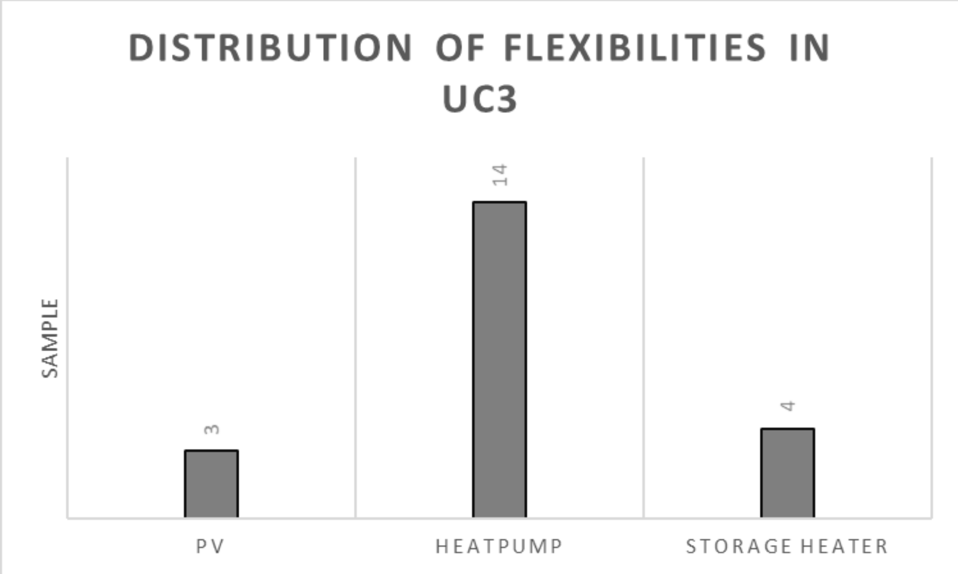

Figure 10 - Distribution of Flexibilities in UC3

The first step towards proving a successful use case would be the successful acquisition of momentary power exchange. By triggering TAF9 the grid operation engineer operating the smart grid hub can trigger a measurement and acquire individual power data from each customer that is connected to the SGH. Since UC3 is focusing on demand side management and flexible loads the available PV generators were included in the data acquisition tests but excluded from the switching tests in these scenarios.

In the first measurement iteration all 21 available devices were requested to transmit the available grid relevant data. Of these, 14 transmitted data successfully, 7 failed to communicate data.

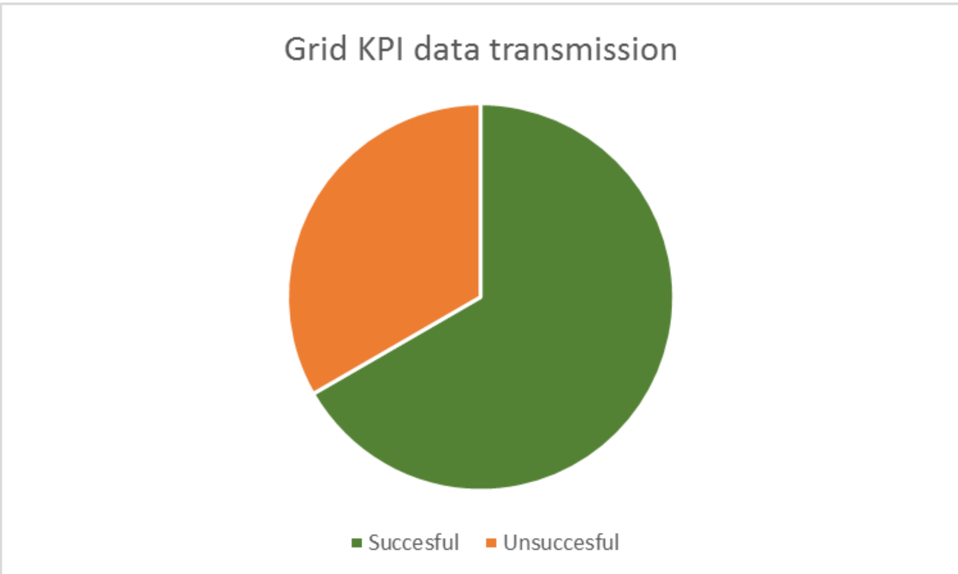

Figure 11 - Share of Successful Data Transmissions

When tested for the continuous streaming of grid KPI data, the same devices remained successful, while the same 33% as before did not deliver complete data.

The way the SMFW is designed in Germany, data collected by the smart meter is first stored in the SMGW and can be transmitted to an outside agent, e.g. the DSO, at request. Taking into account that InterFlex has demonstrated customer data collection by the DSO operator for the first time, a successful export of previously locally stored data can be considered a success. To enable even more advanced use cases, more precision and higher degree of improvement over the status quo, InterFlex has also developed the data collection capabilities of the SMFW beyond the minimum requirement set out by the BSI. While the BSI requires the SMGW to provide locally stored data at request, it currently does not foresee the streaming of live data to the DSO. Notwithstanding the BSI minimum requirements, a case can be made in favour of live data streaming to allow the DSO to have clearer view of the situation in the network and more importantly, to track a device response to a control signal in near real-time. To achieve a satisfying level of transparency and near real-time data streaming, InterFlex developed the capabilities in the SMFW to allow for higher frequency data transmission. Once triggered by the DSO, the SMGW would send data periodically in 1-2 minute intervals, until the DSO requests a discontinuation of data streaming.

In practice the streaming of near real-time data could be demonstrated successfully only in 15 of 114 attempts. The cause remains unclear and is being investigated over the remainder of the project.

4. LESSONS LEARNED OF USE CASE 3 DEMONSTRATIONS

4.1. Customer behaviour and available flexibility

For the purpose of analysing InterFlex field trials, we'd like to recollect our definition of flexibility as "The ability of a device to modify its interaction with the network in response to an external signal.". With this in mind, we can classify the flexibility in WP5 according to the following structure:

Table 4 - InterFlex WP5 Flexibility Classification

	Generation	Load
Activate		
Shift		Storage Heaters
Interrupt	PV	Heatpumps

The use case demonstrations of UC3 have shown more clearly, what flexibility is available under which circumstances and demonstrated ways to tap into this flexibility.

4.1.1. Storage Heaters

One key learning of InterFlex is that storage heaters come in a much wider variety than expected. Depending on manufacturer, time of installation and policy of the distribution company at the time of installation, storage heater can range in thermal capacity and charging strategy. The most common types are start-loading devices, which simply begin to charge until full once the DSO signal reaches the customer. The second most are reverse charging devices, which follow a complex logic to delay charging so as to finish charging at the time of anticipated end of the charging slot. Practical experience of InterFlex has shown very clearly, that reverse charging storage heaters require a much more complex control algorithm at best. At worst the way these devices operate could make it impossible to include these in larger flexibility schemes at all. For all intends and purposes of InterFlex, these subset of storage heaters must be excluded from the immediate application of UC3 in practice.

Front-loading devices on the other hand behave exactly as expected and show potential to bring useful flexibility to the DSO. Avacon has a total of 37,000 storage heaters connected to its service area. If we discount half of it as reverse-charging devices, we are left with 18,500 storage heaters, with an average charging power of 5 – 10 kW. If we capture this flexibility using the SGH and SMFW in Germany, this amounts to between 92 - 184 Megawatts of constricted flexibility. Constricted, because the load can only be shifted within a few hours and cannot be activated randomly.

Further applications of this constricted flexibility in DSO operations will be discussed and demonstrated in later Deliverables. What remains clear is that for the first time, flexibility in storage heaters is now available for productive use by the DSO.

4.1.2. Heatpumps

Just like storage heaters, heatpumps have displayed a much wider range of behaviour than initially expected. The load profile of a heatpump appears to be made up of a relatively low base load and spikes or pulses in load when heating is required. Heatpumps differ in their base/peak-ration, the length and frequency of heating pulses and the range of pulse power. Some run for 60 minutes at a time while others only peak for 10 minutes.

This erratic behaviour makes it difficult to include heatpumps in control strategies that go beyond emergency response actions. If at any given moment a heatpump is off, it might ramp up the next minute and vice versa. And while it seems likely possible to predict the daily consumption of heatpumps, the 1-minute profile appears to be near unpredictable.

All this puts heatpumps firmly in the class of “interruptible load” with little to no potential for a more active use of their flexibility. This can be useful to reduce peak loads in parts of the networks or influence the power exchange with the TSO, it does not offer much hope to support the effort to integrate DER into the network.

Crucially, the heatpump can only be blocked for a certain amount of time, but not be influence once the blocking period is ending. This means that any rebounding effect happening after a shut-down could potentially undo the intended lowering of global peak consumption in the DSO’s network.

4.2. Implications for future operation

The field trials revolving around UC3 in WP5 have clearly shown the potential and feasibility to replace existing analog technology with a digital solution that leverages a public smart meter framework. In doing so, new use cases and application become possible and can help to improve DSO operations and support the integration of DER. This is particularly interesting because replacing and upgrading existing technology allows DSO to apply the new technology right away. There is no need for new flexibility mechanisms, only for a new interpretation of existing mechanisms.

The field trials have successfully demonstrated how the SGH makes dormant flexibility available and have shown that direct control of individual heatpumps and storage heaters by DSO grid operation can become a reality.

Figure 12 shows a potential path how use case 3 could be developed into day-to-day operations. Starting with the confirmed but delayed rollout of smart meters in Germany, DSO could begin replacing the legacy technologies mentioned in 2.1.2 with a SGH + control box infrastructure. Once a sufficient number of elements has been connected nothing stands in the way of migrating the double-tariff mechanism for storage heaters onto the new technology. The next step would be to make active use of the interruption actions for heatpumps. Reducing peak load might not be of the highest concerns for DSO in Germany today, but it will likely rise in importance in coming years.

The next step, to be demonstrated as part of use case 2, would be to include the flexibility offered by heatpumps and storage heaters in the remedial and curtailment action portfolio. The change towards a more comprehensive approach is imminent and these flexibilities could contribute to more efficient congestion management strategies. Finally, depending on the final version of the statutory law governing the application of §14a EnWG, more technologies could be added, such as EV chargers and batteries. Today these devices are just out of reach for regulatory and technical reasons to be covered in use case 2 reports.

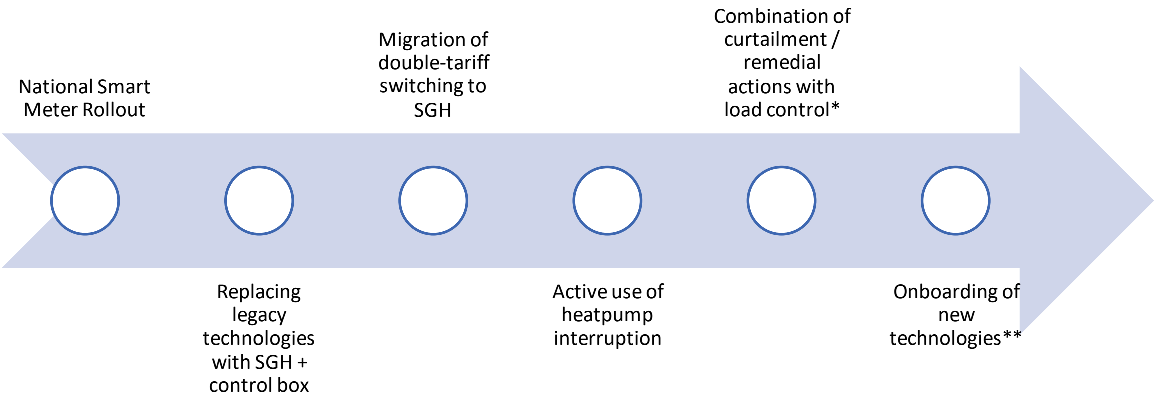

Figure 12 - Potential Path of Development for Use Case 3

The level of technological maturity today is not yet sufficient to put the system into production. Among the shortcoming with the biggest impact are:

1. The lack of LTE coverage in rural areas. Large numbers of customer can not be onboarded in the first place because of a lack of data communication.
2. Reliability of data transmission. As shown in 3.1.1 and 3.1.2, the success rate of switching and measuring remains well below 75%, in the case of real-time data streaming even worse.
3. The SMFW is cumbersome. InterFlex had to put much more effort into bringing the system to live than initially planned for. The reason was a level of complexity and security guidelines beyond anything encountered before.
4. Customer acceptance for the SMFW is low.

Even though this list shows only a part of the remaining shortcomings, the potential upsides described earlier far outweigh these required efforts to bring the system closer to production.

4.3. Recommendations for the evolution of the regulatory framework

Since the potential upsides outweigh the teething troubles of our demonstrated technology, it seems apparent that DSO should be incentivized to invest into technologies that allow them to use residential flexibility in general and improve existing processes with it. Incentives might come in the form of political encouragement and acceptance of this new technology as part of a DSO's regulated asset base. Crucial in Germany in this context is the financing of the control box. While the smart meter and SMGW are covered by separately regulated metering fees, the control box is currently not being included. Starting the smart meter rollout without a clear solution for the control box would be an enormous mistake because it would waste the synergies in installation costs. One possibility to solve this issue could be to accept the control box as part of the DSO operational infrastructure and its regulated asset base, and subsequently finance the control box via grid charges.

Regarding the application of flexibility mechanism it seems surprising at first how much might be possible even under today's regulatory framework. A new interpretation of the existing rules for tariff-switching and interruptible load already enable DSO to capture some of the value flexibility can bring to the system. Clearly policy makers should aim at encouraging this new interpretation and make sure that new regulation improves on what is being demonstrated today. At all costs it should be avoided to discontinue the existing mechanisms without a clear path on how to continue the use of flexibility.