Lessons Learned from Use Case 1
Version 1

Deliverable D5.7

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Short Description
Deliverable 5.7 presents the first results and lessons learned from use case DE_UC1 – Feed In Management. Focus of this use case are novel curtailment strategies for small scale DER which are enabled by the Smart Grid Hub. Of importance is the evaluation of the Smart Grid Hub's performance and reliability of connections for metering and control signal transmission.

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EXECUTIVE SUMMARY

This report documents the first field testing phase of Use Case 1 – Feed In Management in the German Demonstrator. Here the newly developed technology of the Smart Grid Hub in combination with smart metering and communication devices was used to control generators owned and operated by residential real-life customers in the field test area of Lüneburg, Germany.

This test campaign was the first time an IT-system of this kind was demonstrated in a real-life environment. The focus of early tests was to validate the fundamental functionalities and determine the availability of flexibility, the reliability of control and data transmission and the speed of command execution and data transmission.

Operating on the national smart meter framework with a security assurance level of 4+ the Smart Grid Hub offers unbeatable security. If this security comes at the price of cumbersome and slow processes was one of the objectives of this field trial.

Starting with 28 generators several tests were carried out. The tests started with simple off-line switching action on individual elements and then progressing to more complex on-line tests with groups of elements.

Key learnings were that the IT-architecture including the Smart Grid Hub central engine as well as all peripheral systems and interfaces generally performed as planned. The Smart Grid Hub as a tool to integrate DSO operation with a public smart meter framework and which makes privately owned flexibility of small scale devices accessible via a high degree of automation has been proven a viable concept.

Switching actions can be carried out in less than 60 seconds including command confirmation and post-switching measurement. This is a significant improvement on today's DSO operation in terms of speed and efficiency. For a full measurement – switching – measurement cycle the system required on average less than two minutes, which is also a notable improvement in many aspects.

Among the shortcomings are the poor communication and availability of flexibilities. Caused in part by yet to be defined installation errors and a volatile mobile communication network, about 1/3 of measurement and switching requests could not be carried out as specified.

The report concludes with recommendations on further testing and how to improve the IT-system in order to increase system performance even further.

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1. INTRODUCTION

1.1. Scope of the document

Following the successful design and development of the Smart Grid Hub (SGH) and the completion of lab and site acceptance testing WP5 has begun its field trial phase at the end of August 2018. The first use case (UC) to be evaluated is Use Case DE1 – Feed In Management in which the newly developed SGH-technology is employed to control small scale DER in low voltage networks. This use case is motivated by the current situation in Germany, where the feed in by renewable DER leads to critical loads of distribution lines and transformers.

DSO in Germany have a curtailment mechanism to deal with grid congestion, but oftentimes these concepts do not reflect the current state of the art. The upcoming nation-wide rollout of smart meters enables grid operators to take advantage of new technologies which in turn allows for more advanced curtailment mechanisms.

The goal of UC DE1 is to demonstrate the feasibility of an automated curtailment mechanism operating on a public smart meter framework. InterFlex further hopes to show how these newly developed curtailment strategies help to reduce the total volume of curtailed energy and therefore reduce the economic costs caused by temporal bottleneck in distribution grid hosting capacity.

The first phase of field trials seeks to evaluate the basic performance and reliability of the SGH-system. For this several pre-defined tests have been carried out. The results presented in this report shall give a better understanding of the SGH’s strengths and weaknesses and guide the ongoing refinement. It shall also provide input towards designing the second phase of field testing in 2019.

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

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
PLC	Powerline Communication
SGH	Smart Grid Hub
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 1 – Feed In Management is primarily driven by the challenge presented to DSO's in Germany by the renewable energy law. Particularly grid operators in more rural regions are facing difficulties to accommodate all the energy that is produced locally and renewably. This energy has a right of way into the grid, but at times the total feed in from distributed and non-dispatchable generators exceeds the local consumption and power export capacity. In critical situations when reverse power flows cause the critical overloading of equipment or violations of local voltage bands, a grid operator can, as a last resort, opt to temporarily curtail the local feed in. The national regulatory agency Bundesnetzagentur reports total costs of 373 Mio. € for DER curtailments across Germany in 2016.

Contrary to a conventional power system with relatively few easily dispatchable power stations, DSO of today has to deal with a much higher level of complexity. For example, Avacon connects in total roughly 10 GW of renewable energy generators to its network, which is the equivalent of about 8 conventional power stations. The equivalent of 10 GW in the form of renewable decentralised units however goes into the thousands, 40,000 in the case of Avacon. To control these very large numbers of individual generators requires a new set of control strategies that accounts for complexity and unpredictability. Use case DE-1 demonstrates a new approach to the curtailment of distributed generation with a high degree of automation, using state of the art technologies and a future-proof IT-architecture that integrates seamlessly with the national smart meter framework in Germany. The goal is to automate the decision-making process to free up the operator capacity for more critical situations and to enable more complex solutions to the curtailment problems. In turn, more complex and more powerful curtailment algorithms should reduce the total amount of curtailments and reduce the economic costs inflicted by temporal grid congestion, effectively raising the hosting capacity of the distribution network.

2.1. State of the art strategies for congestion management and DG curtailments

2.1.1. Legal and regulatory framework for DG curtailments

The legal basis for Use Case DE-1 lies in the renewable energy law ("Erneuerbare Energien Gesetz" or "EEG"). §12 EEG states that grid operators are obliged to connect all sources of renewable energy to their network at request and ensure that their network offers sufficient hosting capacity to accommodate all energy that is produced under the EEG. This includes the obligation to optimize, expand and reinforce the network whenever necessary. If the grid capacity is temporarily insufficient, §14 EEG enables a curtailment mechanism which allows grid operators to temporarily reduce the feed in by DER to maintain safe and stable operation. When curtailments are carried out, owners of DER qualify for financial reimbursements which are recovered via the grid operator's grid charges. The obligation to increase grid capacity remains nonetheless.

2.1.2. Common Scenarios to Trigger Curtailments

In practice this curtailment mechanism is triggered when a grid operator identifies a critical situation and has exhausted all other options to bring the network back to normal. TSO and DSO can trigger the mechanism alike, if the TSO owns the congestion it usually requests underlying DSO to reduce feed in on relevant lines and substations accordingly. Common scenarios to trigger a curtailment are for example:

- Overloading of powerlines in the VHV system
- Overloading of transformers connecting HV and VHV networks
- Overloading of powerlines in the HV system
- Overloading of transformers connecting HV and MV networks

The curtailment mechanism is rarely triggered by events below the HV/MV substation because of a lack of monitoring and control capabilities. In the future technologies like the Smart Grid Hub in combination with a Smart Meter + Control Box infrastructure can enable curtailment mechanisms on the MV and LV level, which may even react to a violation of voltage bands.

2.1.3. Shortcomings of present approach and room for improvement

The present approach is based on legacy technologies which were available and operational when the curtailment of decentralised units became an issue for DSO in Germany. 10 to 15 years ago when it became apparent that in some areas the reinforcement of the network could not keep up with how quickly new generating capacity was being installed, grid operators stuck to technology that was ready at hand. The system we find today at many grid operators is based on long-wave radio signals. The control command from a DSO is handed over to a communication service provider who broadcasts the signal via a radio signal across the entire service area. With this, the signal can be communicated over long distances without the need to install additional communication infrastructure apart from a signal receiver on the customer's premise. There are however a few drawbacks. For example, the radio receiver is limited to four discrete setpoints, it can only limit the generator to 0%, 30%, 60% or 100% of its nominal power output. It is also limited to transmitting signals from the DSO to the customer's device, there is no backchannel over which the DSO could acquire additional data. This means that DSOs have no backchannel to confirm whether their signal has been acted upon and can neither identify faulty or malfunctioning receivers. The technology also requires setting the address parameters offline at the customer's device and does not allow for dynamic addressing or remote updating. This leads to the practical limitation that large numbers of DER must be grouped together. All in all, this creates a situation where the downstream signal is imprecise and not perfectly reliable and the backchannel does not exist.

With the development of the SGH InterFlex aims at providing the technological basis to improve on these shortcomings. Use case DE1 demonstrates a curtailment management that enables individual addressing, the building of dynamic groups of DER and a backchannel which allows for command confirmation and the acquisition of additional data points to better estimate the state of the grid.

3. FIELD TEST DESIGN

Laboratory and site acceptance tests have already demonstrated that the fundamental functionalities of SGH and the vital communication links have been established to allow for field testing. Within the field test phase the performance of the Smart Grid Hub architecture, all interfaces and communication links will be tested and evaluated according to the KPI defined in the project proposal. Once this first stage of field tests has been carried out the demonstrator will be used to evaluate the performance of use case algorithms under real life conditions.

The set of KPI as laid out in the project proposal Part B is shown in

Table 2.

Table 2 - List of KPI

KPI #	Key Performance Indicator	Description	Covered in Use Case	Unit
1	Speed of data transmission	- No. of established connection per time unit - Transmitted data volume per time unit	DE1-2-3	1/s
2	Security of data transmission	- Number of connection losses	DE1-2-3	1
3	Reliability of data transmission	- Number of connection losses	DE1-2-3	1
4	Observance of grid restrictions	- Relevant grid parameters kept within limits	DE1-2-3	1
5	Anticipation of violations of grid constraints and good choice of measures to avoid these	- Correct forecast* - Avoidance with least number of interventions	DE1-2-3	1
6	Amount of curtailed energy	- Amount of curtailed energy compared to 7theoretical optimum (least intervention)	DE1-2-3	kWh
7	Speed of command execution	- Number of executed commands per time unit	DE1-2-3	1/s
8	Overall costs	- Comparisons of conventional grid expansion measures with flex activation	DE1-2-3	€
9	Active participation of all kinds of flexibility	- Each type of technology should be represented in the test system and have the possibility to act as flexibility	DE1-2-3	1
10	Precision obtained by SGH for execution of control center commands	- Deviations of resulting figures obtained by SGH from the original high level target figures	DE1-2-3	kWh

11	Number of interventions	-	Number of interventions at optimal level	DE1-2-3	1, kWh

To generate data to evaluate the system performance based on the KPI, a succession of structured tests has been carried out. The tests have been designed to put emphasis on different aspects of system performance.

Table 3 gives an overview over individual test cases which are then detailed in the following chapters. During this first testing stage the demonstrator is used to determine the KPI to evaluate system performance, while use case performance testing will be carried out at a later stage and be described in the final report.

Table 3 - Overview Test Cases

Test #	Description	KPI	Result
1	Switching of single generators & groups of generators off-load	1,2,3	×
2	Availability of flexible elements	2,3	×
3	Switching performance	7	✓
4	Device schedule override	-[1]	×
5	Switching of single generators on-load	1,2,3	✓
6	Switching of groups of generators on-load	1,2,3	✓
7	Switching of generators w/ detailed performance break down	1,2,3,7	✓
8	Switching of generators on-load while firmware update is active	-[2]	✓

3.1. Results of field testing

3.1.1. Test 1 - Switching of single generators & groups of generators off-load

Test Overview	
Title	Off-load switching, single & multi
Type of elements activated	PV
Number of elements activated	3

[1] To account for potential future developments the SGH already offers a scheduling function. This way a flexible device could be controlled and dispatched in advance by the DSO or market players. To ensure a secure grid operation the DSO has to retain the right to override third party schedules. This was not part of the initial workplan but proved to be of importance for use case evaluation.

[2] The SGH has to perform reliably even in times of firmware updates on control box devices. This was not part of the initial workplan but proved to be of importance for use case evaluation.

The goal of test 1 was to carry out fundamental switching actions on individual devices and groups of devices. For this, 3 generators were chosen to be switched individually and as a group of 3. To minimize the risk by a malfunctioning SGH or loss of connection the curtailment action was scheduled to 9pm when PV production was minimal. This way the switching procedure itself could be validated without curtailing any meaningful DER production. Once the first tests were deemed successful, later tests would also carry out switching actions while the PV was producing power.

The first round of individual curtailment signals ("0%") was sent at 9pm and cancelled ("100%") at 9.15pm, the group signal was sent at 9.30 and cancelled at 9.45pm. In both tests 2 of 3 devices did not communicate any data and the command queue showed no active use cases.

The test was repeated a day later with similar results.

It was repeated a third time but this time with devices that were known to be sending data. Still the scheduled switching action were not carried out, not cleared from the command queue and not documented. Still the switching schedule marked all use cases as "executed".

After fixing potential sources of errors the test was carried out a 4th time with positive results. Once again, with elements that have been confirmed earlier as being online. The curtailment signal ("0%") was scheduled for 9pm and reset at 9.30pm. All devices except one carried out the switching command and the results were displayed correctly in SGH GUI.

Table 4 - Evaluation of Test 1

	Attempted Connections	Succesful activation	Number of Connection Losses (KPI2)
Trial 1 (Off-load, single)	3	1	2/3
Trial 2 (Off-load, multi)	3	1	2/3
Trial 3 (Off-load, multi)	3	0	3/3
Trial 4 (Off-load, multi)	3	2	1/3
Total	12	4	8/12

The extent of connection losses per trial is of concern for a reliable control scheme and further investigations appear to be necessary. A detailed follow up analysis and a second field trial as part of Interflex is planned to further investigate the cause and potential solutions to this issue.

3.1.2. Test 2 – Reliability of communication

Test Overview	
Title	Reliability of communication
Type of elements activated	PV
Number of elements activated	19

The aim of Test 2 was to quantify the reliability of the communication link between SGH and flexible devices. The basic test set up was to combine all elements which were available at the time of testing into one group and then request an ad-hoc measurement for this group. The test was initiated ad-hoc at 12.37pm and carried out immediately. Shortly after the test was interrupted with errors. Results showed that of 19 elements that should have been online only 11 provided data.

The reliability of the communication link between flexibility and SGH remains a concern for a reliable live operation and should be investigated further. As part of Interflex the communication will be subject to further anlysis along with the testing of alternative ways of data transmission via powerline communication.

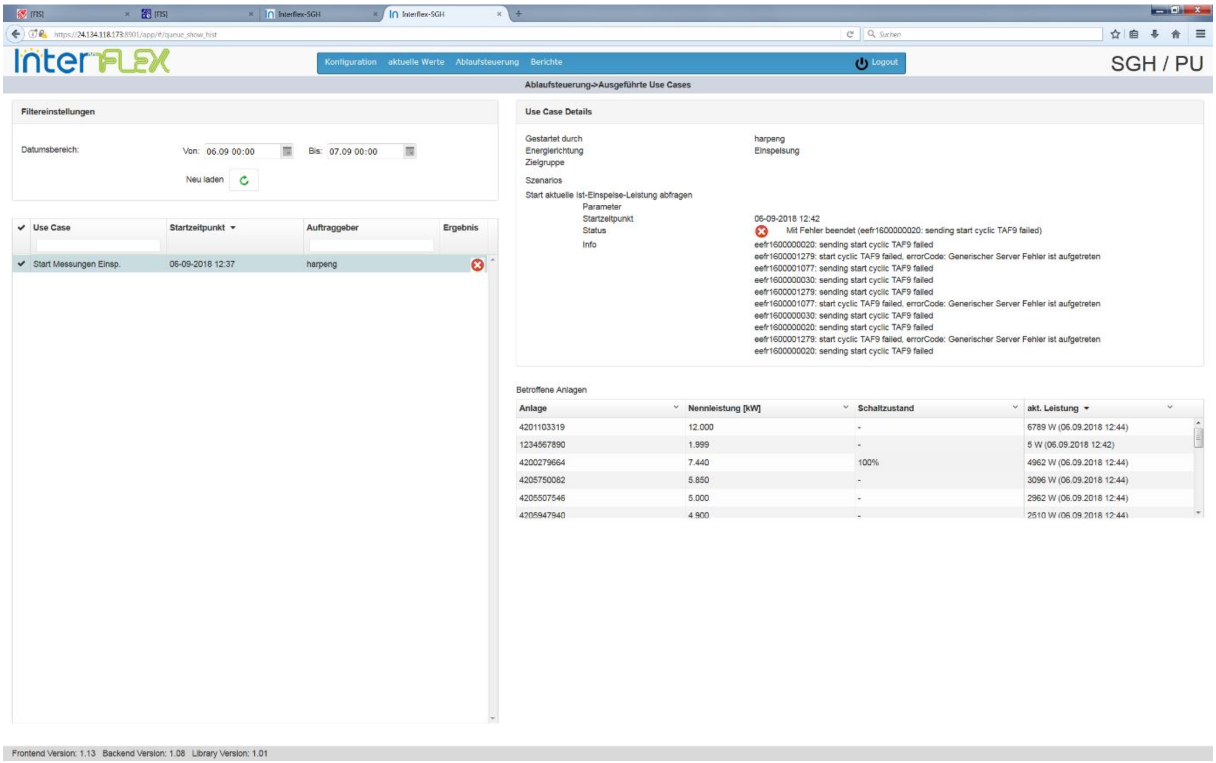

Figure 1 - Screenshot of SGH GUI after termination of Test 2

Table 5 - Evaluation of Test 2

	Attempted Connections	Succesful activation	Number of Connection Losses (KPI2)
Trial 1 (Measurement, single)	19	11	8/19

3.1.3. Test 3 – Multi-Switching Requests

Test Overview	
Title	Multiple Switching Requests
Type of elements activated	PV
Number of elements activated	19

The objective of Test 3 was to quantify the performance of the SGH architecture under higher workloads. In its first iteration Test 3 would request different switching commands from a group of generators at intervals of 10 minutes. The requested flex activation would be to cap power production at 60%, 30% or 0% of nameplate rating. The tests were carried out between 6 pm and 6.30 pm. The second iteration would reduce the time between commands to 1 minute. The second iteration was scheduled between 9pm and 9.20 pm.

The results were mixed, all tests were completed but with errors.

1. In both iterations one generator was not responding, neither transmitting meter data, nor carrying out flex requests.
2. Despite all requests being carried out eventually the SGH did not stick to the initial sequence of the scheduled commands.
3. There was a noticeable gap between the time a command was scheduled and when it was carried out.
4. Commands were not carried out in parallel, but strictly in sequence.

In the light of these results, these issues have to be investigated further as part of a second field trial on feed in management scheduled for 2019

The second run of Test 3 aimed at probing the ability of the SGH to control several groups of flexible elements in parallel. The test set up required the SGH to switch off the generators in different substations at roughly the same time and to reset to 100% power output 1 minute later. To minimize the risk of unnecessary curtailments these early tests were scheduled for non-production time of day at 9pm. The results were positive, the switch-off command was transmitted at 9.01pm and confirmed by 14 of 16 elements. Subsequently the switch-on command was transmitted between 9.30pm and 9.44pm and received by 12 of 16 elements. It is noted that the control of different groups even in short sequence does not pose a problem. As the first run of tests showed the SGH struggles to perform the switching of individual elements with high frequency. This does not have a direct impact on the use cases within InterFlex, as here the origin of commands will be the SCADA system which communicates flex requests every 10 minutes. Moving forward however this issue can be a limitation to the implementation of more advanced use cases with a higher switching frequency.

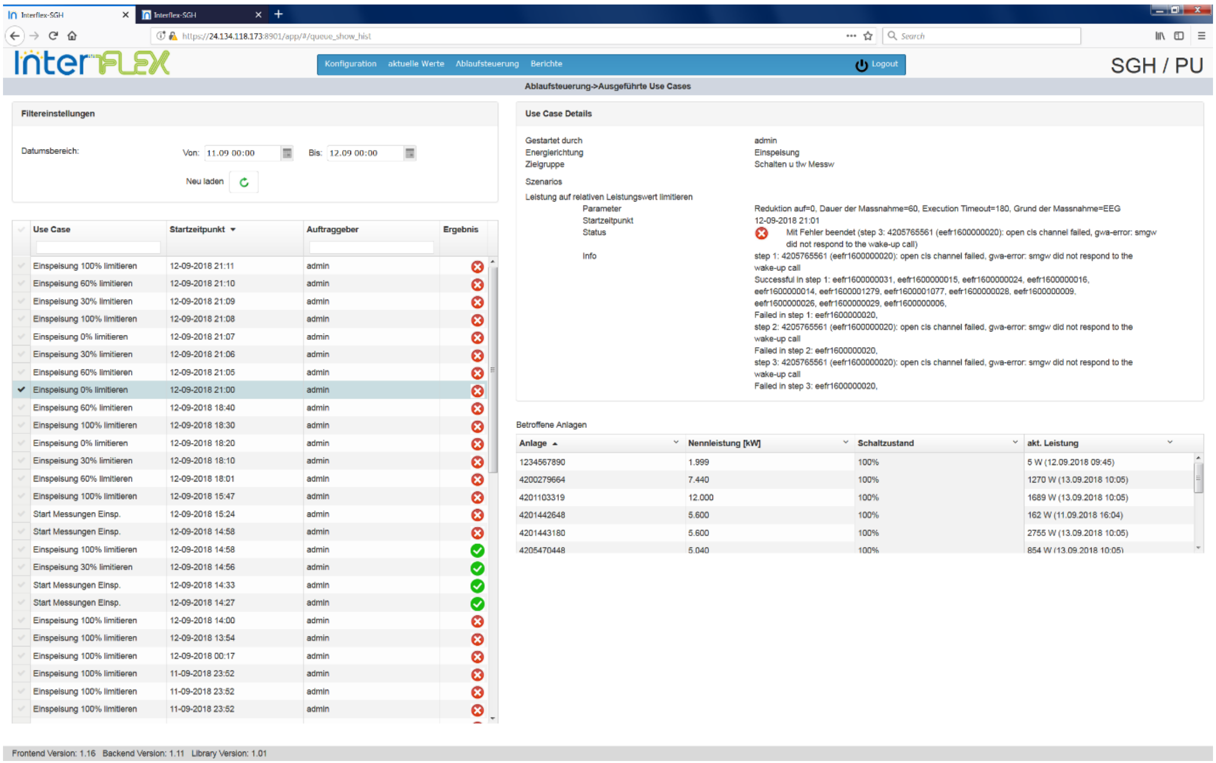

Figure 2 - Screenshot of SGH UI for Run 2 of Test 3

Test 3 highlighted several weak spots in the current architecture to be investigated further in later field trials within Interflex. In part these issues can be traced back to the communicatin uplink via the mobile network. Other parts appear to relate to the performance of adjacent IT-systems (e.g. the gateway administration service) and the internal workings of the Smart Grid Hub itself (e.g. command being carried out strictly in sequence).

Table 6 - Evaluation of Test 3

	Attempted Connections	Succesful activation	Number of Connection Losses (KPI2)	Speed of data transmission (KPI1)	Speed of command execution (KPI7)
Trial 1 (On-load, multi)	16	15	1/16	< 60 sec	1/min
Trial 2 (Off-load, multi)	16	15	1/16	< 60 sec	1/min
Trial 3 (Off-load, multi)	16	14	2/16	< 60 sec	1/min
Trial 4 (Off-load, multi)	16	12	4/16	< 60 sec	1/min
Total	64	56	8/64	< 60 sec	1/min

3.1.4. Test 4 – Local Schedule Override

The control box solution is capable of receiving, storing and following schedules. Moving forward more advanced use cases will go beyond ad-hoc commands and deploy schedules for flexible elements hours, days or a week ahead. Given the nature of the German feed in regulation for DER this scheduling function does not yet have an immediate relevance for generators, but with increasing numbers of DER dropping out of the feed in tariff and migrating into the competitive market, day- and week ahead scheduling will soon become highly relevant.

The aim of test 4 was to set a predefined schedule for a single device and then override the schedule with a SGH command. The schedule for a full week was set to full feed in from 4pm to 2pm and "off" from 2pm to 4pm every day for a week. To test the override the operator would then set the generator to full feed in after 2pm and check whether the device fed in or stayed off. In the first trial the schedule was transmitted successfully, but the control failed to carry out the planned schedule. Figure 3 shows a screenshot of the SGH UI in scheduler mode.

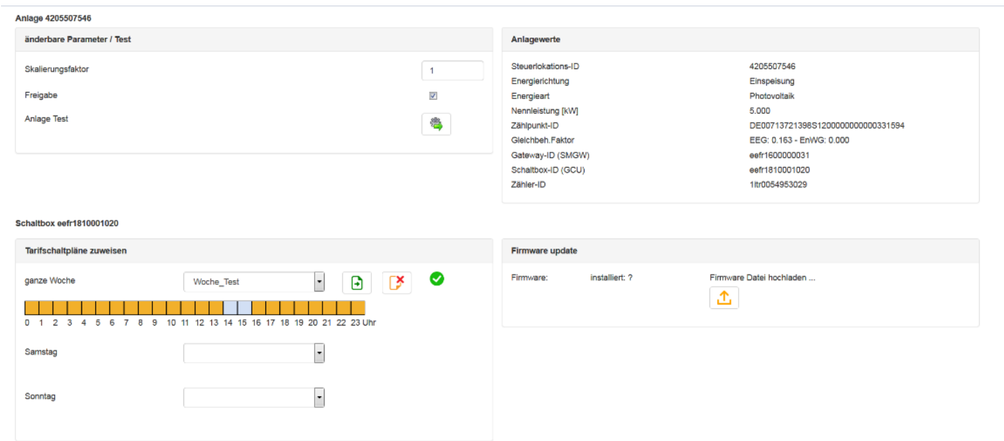

Figure 3 - SGH UI Scheduler

Analysis of trial 1 revealed that the control box schedules are interpreted as UTC (Coordinated Universal Time), so the alleged failure to follow the schedule in trial 1 might have been caused by this confusion. Trial 2 accounted for this and planned all schedules accordingly for UTC-2. The planned schedule, which set the generator output to 100% from 5pm to 3pm and to 0% from 3pm to 5pm, was transmitted successfully. The operator then scheduled a request for full production starting at 4pm, to override the 0% schedule starting at 3pm, and added another request for 1 hour 0% starting at 4.30 pm, overriding the scheduled switch from 0% to 100% at 5pm. Figure 4 shows the planned schedule and override commands for trial 2.

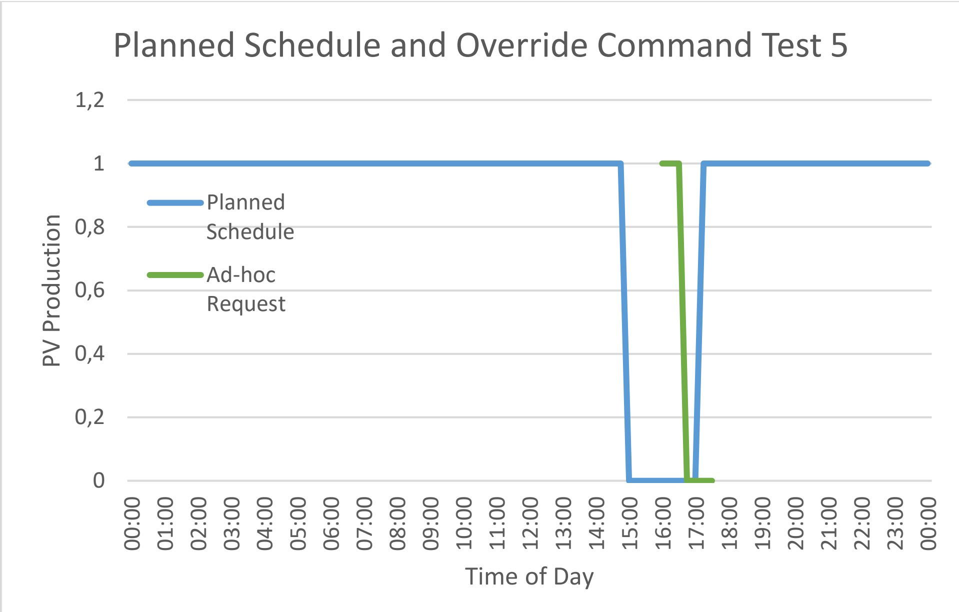

Figure 4 - Planned Schedule and Override Command Test 5

This time the schedule was carried out as planned, reducing the power output to 0% at 3pm. The following attempt to override the scheduled 0%-limitation with a request for full power was not successful. Further the schedule would have been followed to de-limit production at 5pm, however the override command to extend the limitation to 5.30pm was successful. Figure 5 shows the resulting data from trial 2. The diagram clearly shows the sudden limitation of power output to 0% beginning at 3pm / 15h. The production does not ramp up when the 100% command is supposed to override the schedule. Later production does not ramp up at 5pm / 17h as per schedule, but waits until 5.30 / 17.30h as per ad-hoc command.

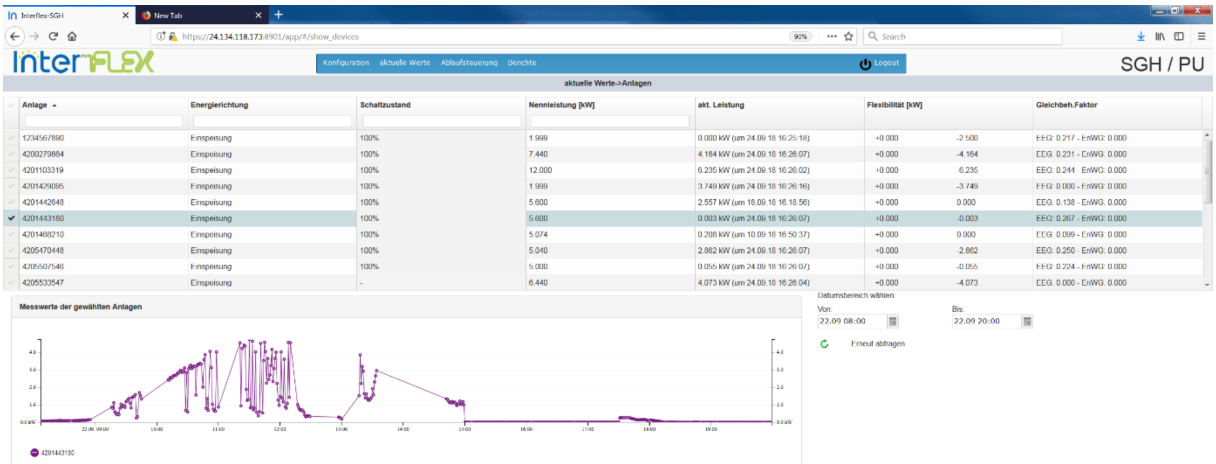

Figure 5 - Results of Test 4 Trial 2

At the time of write-up of the present deliverable it remains to be investigated, why a 100%-override was not successful, while a 0% override was. This issue requires deeper evaluation in several aspects but mostly because the override function will be most likely applied when DSO and external market players request switching access on a single element.

3.1.5. Test 5 – On Load Switching of Single Elements

Test Overview	
Title	On-load switching, singles
Type of elements activated	PV
Number of elements activated	19

. The first set of tests was designed as an off-load trial to avoid unnecessary hardships for customers in the case of unexpected malfunctioning. Once these tests numbered 1 through 4 were completed successfully the system was deemed ready for testing in on-load conditions with generators producing during daytime.For this test a single generator was to be switched off and switched on again during daytime with good power production conditions. Establishing the Controllable Load System (CLS) channel over which the control and metering data is transmitted was not part of the drill, the CLS channel itself was established beforehand.

Generator 4201443180 was switched off at 1.27pm, the command was confirmed almost immediately. Less than 60 seconds later the next set of measurements confirmed the successful switching. The command to de-limit the generator was communicated at 1.31pm and confirmed almost immediately. The next set of measurement confirmed this less than 60 seconds later. Test 5can be considered a success.

Table 7 - Evaluation of Test 5

	Attempted Connections	Succesful activation	Number of Connection Losses (KPI2)	Speed of data transmission (KPI1)	Speed of command execution (KPI7)
Trial 1 (On-load, single)	1	1	0	< 60 sec	1/min

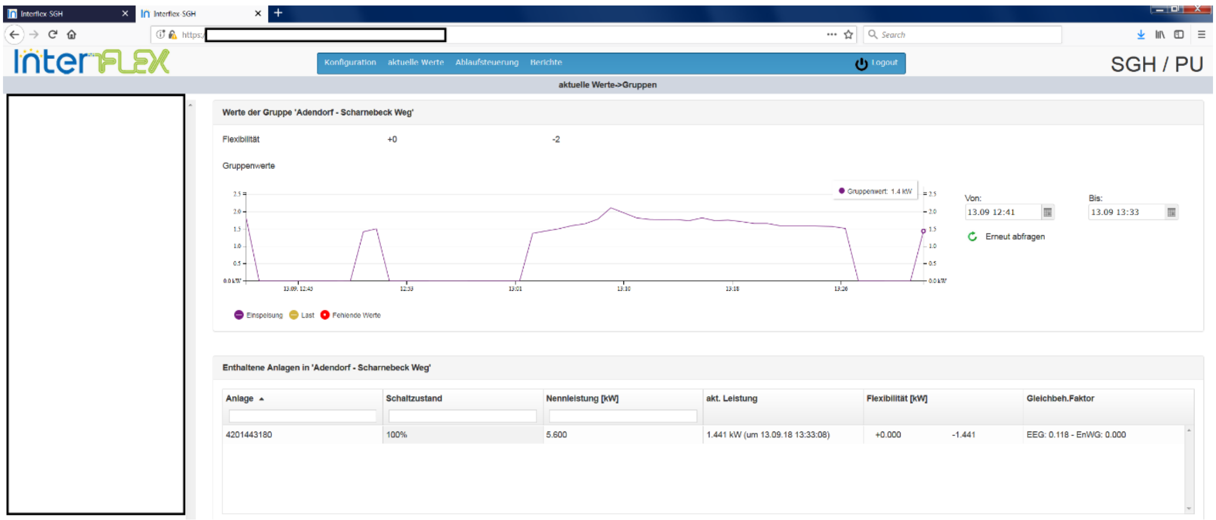

Figure 6 - Screenshot of SGH UI in Test 5

3.1.6. Test 6 – On-Load Switching of Multiple Elements

Test Overview	
Title	On-load switching, multiple
Type of elements activated	PV
Number of elements activated	13

Test 6 replicates the prior test 5 but instead of a single element the aim was to control a group of flexible elements. For this test a group of generators was defined which contained 12 customer-owned generators and a test installation co-located with the q-system in Munich. To ensure that the command showed a measurable effect the tests were scheduled to a time of the day when power production was high. During the test window between 1pm and 2pm all 13 elements were online and power-producing. The CLS channel via which the control commands and measurement data would be communicated has been established beforehand.

At the beginning of the test the command “Limit to 0% power output” had been assigned to the group of elements. The command signal was confirmed almost immediately at 1.41pm, evidently so by the next set of measurements less than 60 seconds later. At 1.45 pm the command to de-limit power production was transmitted and confirmed almost immediately.

It must be noted that while almost all control signals have been transmitted and carried out successfully, some generators still struggle to reliably transmit meter data. Of 13 elements in this group 1 could not be reached at all and 5 more transmit data only infrequently. This poor reliability will be the subject of further investigation.

Figure 7 shows a screenshot of the Smart Grid Hub User Interface after successful operation of Test 6. The red square highlights the switch-off/on commands.

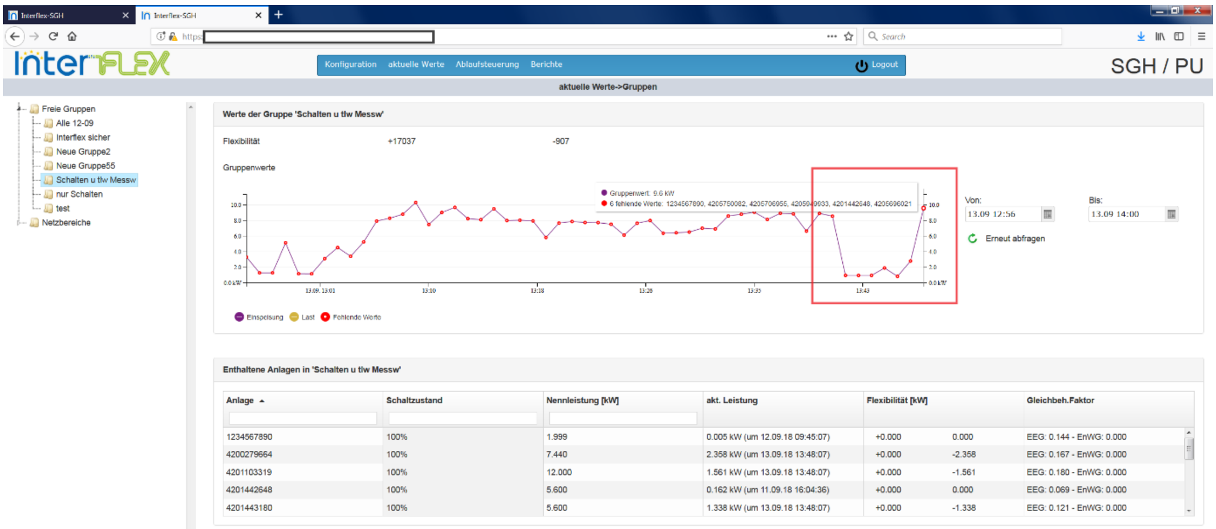

Figure 7 - Screenshot of SGH UI of Test 6

Table 8 - Evaluation of Test 6

	Attempted Connections	Succesful activation	Number of Connection Losses (KPI2)	Speed of data transmission (KPI1)	Speed of command execution (KPI7)
Trial 1 (On-load, multi)	13	12	6/13	< 60 sec	1/min

3.1.7. Test 7 – Detailed Breakdown of Time Steps

The switching and metering of flexible assets via the Smart Grid Hub is a sequence of several discrete actions. The exact timing and duration of these steps are not visible to the SGH operator. To have full visibility on these details however a test application has been developed which enables testers to determine these values for a set of actions. The SGH test app allows operators to determine the exact value for the time it takes to

1. Retrieve most recent meter data from data base (METER1)
2. Establish CLS channel (CLS CONN)
3. Switch Generator (SWITCH EEG)
4. Close CLS channel CLS DISCONN)
5. Retrieve the next meter data point after switching (METER2)
6. Time used to access external data base (EXTERN)

The time step breakdown protocol has been executed with 8 flexible elements using the test application. Table 9 shows the results for each time step for each individual tested element,

Table 10 shows the overall maximum, minimum and mean value for each step of the process.

Table 9 - Detailed Time Step Breakdown per Unit

#	Meter 1 [ms]	CLS Conn [ms]	Switch EEG [ms]	CLS Disconn [ms]	Meter 2 [ms]	Extern [ms]	Total Duration [ms]
1	300	92537	928	17076	5452	486	116779
2	317	82501	311	18801	14314	138	116382
3	309	84912	887	18415	10529	1135	116187
4	297	91714	419	17508	5706	821	116465
5	303	90259	207	18052	6495	1486	116802
6	317	94607	170	18709	2902	170	116875
7	315	97977	157	32908	45466	1802	178625
8	317	82197	525	19508	12748	211	115506

Table 10 - Overview Detailed Process Step Duration

	Min	Mean	Max
Meter1	297	309	317
CLS CONN	82197	85588	97977
SWITCH EEG	157	450	928
CLS DISCONN	17076	20122	32908
METER 2	2902	12951	45466
EXTERN	138	781	1802
TOTAL	115506	124202	178625

Overall the meter-switch-meter use case took between 115.506 and 178.625 milliseconds (1,92 to 2,98 minutes). In each case the most time-consuming step was to establish and close the CLS channel, a process that requires several checks of access rights and certificates and which involves the gateway administration service. Without the necessity to establish the CLS channel first and then close it once the action has been carried out the performance of a use case can be shortened by 100 to 130 seconds, an improvement on overall time of 73% to 97%.

One technical solution which deserves further investigation later in the project would be to establish the CLS channel ex-ante and maintain an open CLS channel the entire time a unit is online in the SGH.

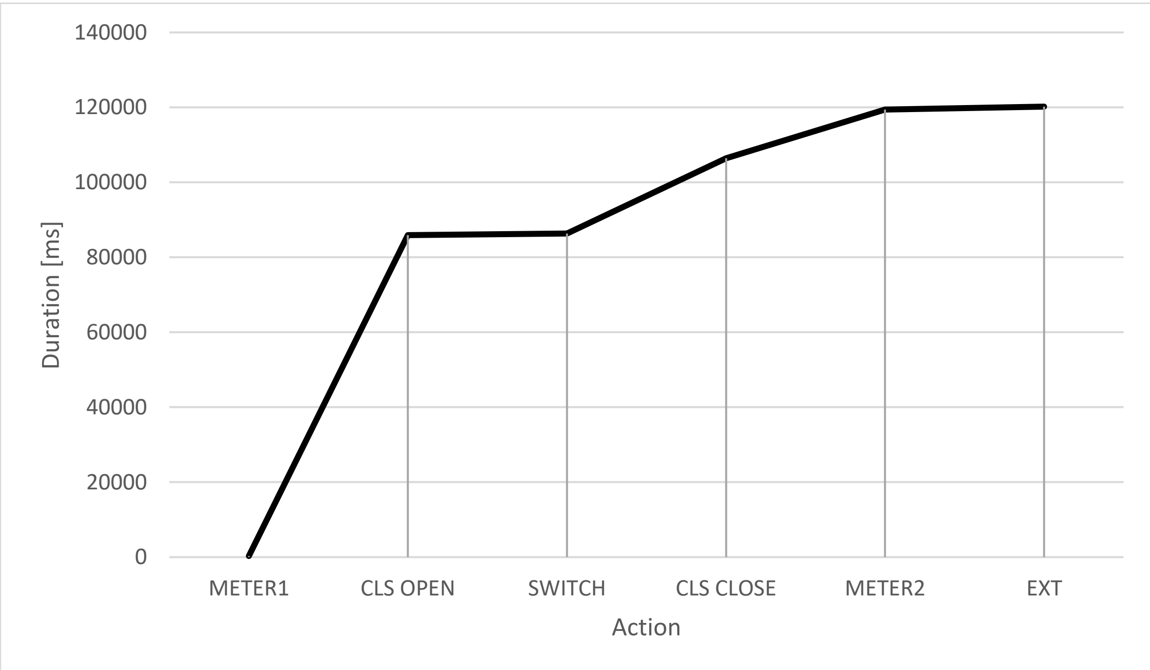

Figure 8 - Duration for Individual Steps in a Switching Action

4. IMPLICATIONS FOR FUTURE OPERATION AND LESSONS LEARNED

The first field demonstration can be deemed a success with respect to demonstrating a general functionality of the Smart Grid Hub architecture developed in InterFlex. Devices owned and operated by private customers and connected only via a public smart meter infrastructure have been switched and metered successfully, data has been transmitted and documented in the SGH data base, operation engineers have tested the user interface and use case algorithms have generated practical switching schedules. Integrating two highly secured IT-systems, both of which considered critical infrastructure by federal agencies, is a technical feat. However, the tests have also shed light on shortcomings in performance and reliability that are not satisfying for day-to-day operation. For example, the time spent to open and close the CLS channel via which controllable devices can be switched and metered directly by the DSO consumed much more time that what would be practical in a real life setting with a realistic number of connected elements. Also, the comparably low level availability and high error rate of communication channels proved to be a risk for a reliable day-to-day operation that would be crucial for network stability. Apart from minor incidents and performance that can be improved upon the system performed as planned and enables further testing of use case algorithm performance in later stages of the project.

The evaluation of system performance and functionality has shown that a high degree of automation for the control of small scale DER can be achieved, even on the highly secured smart meter framework in Germany. This enables more effective, more precise and more reliable use case algorithms in the future, some of which will be tested over the remaining course of the InterFlex field trial. The fact that the system has already performed in full compliance with the Smart Meter Framework security requirements offers superior scaling opportunities across Germany.

The experiments have also shed light on some areas and elements that require refinement and opened a few questions which require further investigation. The most important lessons learned are described below.

In accordance with the general design of the smart meter framework the SGH communicates with flexible devices via the mobile communication network using the LTE standard. Coverage with LTE signal in the field test area is well below 100%. To account for this, customers have been pre-validated for sufficient LTE-signal at the smart meters location inside the customer’s house based on data provided by mobile network operators. Following these signal checks it was expected that all devices equipped with the InterFlex metering and control devices would be unlikely to experience any communication issues. It turned out that connectivity and reliability of communication was significantly lower than expected.

The combination of Smart Meter, Smart Meter Gateway (SMGW) and Control Box was pre-assembled at the supplier’s premises by technicians. SIM cards were installed and the required parameters set and certificates installed as well. This way the risk for errors during the installation process was reduced to a minimum allowing for a focused testing of SGH system performance, not evaluating the efficiency of the installation process itself. Once the testing had begun, a device could fall into one of four categories:

1. Devices that switched and communicated faultlessly.
2. Devices that switched faultlessly but failed to transmit data.
3. Devices that failed to switch but transmitted data faultlessly.

4. Devices that behaved erratically, switching and transmitting data only occasionally.

The quest for the cause of a device falling into category 2, 3 or 4 is ongoing, so far, a few theories are competing for the explanation.

Category 1 is the normal condition for every device and clearly the minimum requirement for a faultless operation of the Smart Grid Hub.

Devices in category 2 and 3 appear to have a faulty connection between the SMGW and either the smart meter or the control box. In category 2 the control command could be carried out via SMGW and control box, but the meter data would not reach the SMGW and subsequently neither the SGH. In category 3 the meter data can be transmitted via the SMGW and LTE uplink, but the control command would not find its way to the control box. The cause for this could be a missing or faulty connection cable, a false connection, a faulty SMGW or smart meter. The actual cause can only be determined with certainty during a visit of a technician. To restore proper function the root of the problem must be identified on-site and then mitigated by either ensuring a functioning connection or replacing the faulty equipment. Since a second visit by a technician is time- and cost-consuming and puts another burden on the customer to provide access to his or her building and device, it is imperative to minimize the number of devices falling into any category other than category 1 from the start. To mitigate this risk the workflow of SGH-customer installation should include a quality control element to confirm adequate functionality right after installation. This test would require running a few basic test scenarios to assure proper functioning before the technician leaves the customer.

Devices in category 4 appear to be suffering from volatile or unstable mobile data signal. Even though customers had been accepted based on preliminary analysis of LTE coverage data provided by communication network operators and individual measurement of signal strength at the exact location of the smart meter, the signal strength can be lacking at times. There seems to be little room to improve on the ex-ante evaluation. Once a system is installed and shows erratic behaviour that indicates LTE-signal issues, fixing this issue can be very time consuming and costly, especially once a roll out is underway and larger number fall into this category. To monitor the state of the system it is recommended to include an alarm function in the SMGW which notifies the operator about a lack of communication channel. This way a poor connection can be addressed outside of activation windows and be excluded from the pool of available flexibility until the situation is fixed. Otherwise the operator would only realize that an element is not responding when a data or control request gets turned down, which would introduce an unnecessary element of uncertainty into the monitoring of available flexibility.

Apart from improved or added communication links, e.g. a second SIM card to switch to alternative mobile networks, there would be the option to use powerline communication technology (PLC). Powerline communication offers an alternative way to transmit data independent of mobile network coverage, but it comes with downsides. For once, powerline communication requires a high degree of penetration to work properly. The PLC signal is damped severly over the transmitting conductor and requires regular repetition and amplification. Depending on the geographical extend and type of conductor the penetration of InterFlex field trial networks might not meet the minimum requirements for a successful implementation of PLC. Also in this context PLC would only be available as “last-mile” technology, offering communication from the household to a data concentrator in the next substation, where the signal would again be handed over to a mobile network based uplink.

That connection quality and reliability can generally be improved upon is also reflected in KPI 2 – Number of Connection Losses shown in Table 11 for these tests. Across all tests carried out during this period, 28% of all connections were either interrupted or could not be initiated due to faulty equipment or poor connection. To address this issue InterFlex will further investigate improved quality management during the installation process and explore the potential use of alternative technologies such as PLC.

Table 11 - Evaluation of KPI 2 "Number of Connection Losses"

Test #	Trial #	No. of connection losses	Failure rate
1	1	2	66%
	2	2	66%
	3	3	100%
	4	1	33%
2	1	8	42%
3	1	1	6%
	2	1	6%
	3	2	12%
	4	4	25%
5	1	0	0%
6	1	6	46%
Total		30	28%

4.1.1. Duration of Open / Close CLS Channel Action

The speed of command execution and data retrieval, compared to state of the DSO processes, can be considered sufficient. In all tests the transmission and confirmation of a successful control signal took less than 60 seconds, which is plenty fast in the DSO realm where often the 15-minute interval is the relevant metric. A complete iteration of measurement, switching and post-switch measurement took between 1 min 55 sec and 2 min 58 sec, which again is sufficient for day-to-day DSO operation. It must be noted that establishing the CLS channel requires the longest duration and should be the first step in the process to be investigated further for efficiency gains.

4.1.2. Schedule override

Overriding a decentralised stored schedule was successful when overriding with a lower setpoint but failed when trying to override a low setpoint with a higher value. This can prove tricky because when unexpected grid capacity opens up but distributed generation remins limited. It might cause even more issues down the road with flexible loads, when heating appliances remain limited beyond strictly critical situations in the network. In the end a schedule override function must be answered in the context of an overarching framework for flexibility activation. It is most likely that in the future different market players will have control over the same flexible devices in different scenarios. Retailers, aggregators, TSO's and DSO's alike might have a stake in anybody's flexibility. In all these scenarios the SGH can offer the technological basis to handle the practical switching and metering of privately owned flexibility in the residential segment. The question of how to prioritize requests however must be evaluated together with all stakeholders and with respect of the evolution of the regulatory framework in Germany, e.g. the amendment of §14a Energy Industry Act on flexible loads and industry led discussions on a control box framework. Critical for the success of the SGH and something that could be addressed in InterFlex is the implementation of a sophisticated access rights mechanism for different market players that reflects the current situation at any point in time.