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Energy Demand Aware Open Services for Smart Grid Intelligent Automation

SmartHG

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Contents

Executive Summary **1**

1 Retrospect **2**
1.1 Svebølle (Denmark) test-bed . . . 2
1.2 Minsk (Belarus) test-bed . . . 2
1.3 Central District (Israel) test-bed . . . 2
1.4 IMDEA Smart Energy Integration Lab (SEIL) . . . 3

2 Introduction **4**
2.1 Motivation and Objectives . . . 4
2.2 Achievements . . . 4
2.2.1 Svebølle (Denmark) test-bed . . . 4
2.2.2 Minsk (Belarus) test-bed . . . 4
2.2.3 Central District (Israel) test-bed . . . 4
2.2.4 IMDEA SEIL . . . 5
2.3 Outline . . . 5

3 Test-beds Data Analytics **6**
3.1 Tables . . . 6
3.2 Charts . . . 9

4 Hardware Devices **11**
4.1 Develco Products Smart Meters . . . 11
4.2 Panoramic Power Sensors . . . 12
4.3 Home Energy Controlling Hub (HECH) kit . . . 12

5 Sensor Interfaces **14**
5.1 Develco Products Smart Meters Interface . . . 14
5.2 Panoramic Power Sensors Interface . . . 15
5.3 Home Energy Controlling Hub (HECH) Interface . . . 15

6 Svebølle (Denmark) Test-Bed **16**
6.1 Deployment and Maintenance Status . . . 16
6.2 Distribution System Operator Interface . . . 18
6.2.1 SmartHG generic interface towards Distribution System Operators (DSOs) . . . 18
6.2.2 Exploiting Common Information Model (CIM) interface towards DSOs . . . 18

7 Minsk (Belarus) Test-Bed **23**
7.1 Deployment and Maintenance Status 24
7.2 Distribution System Operator Interface 24

8 Central District (Israel) Test-Bed **25**
8.1 Deployment and Maintenance Status 25
8.2 Distribution System Operator Interface 26

9 IMDEA Smart Energy Integration Lab **27**
9.1 Introduction 27
9.2 SEIL Architecture 28
9.3 Energy Bill Reduction Test Architecture and Methodology 30

10 Data Showcase **33**

11 Conclusions **34**

12 List of Acronyms **35**

Bibliography **37**

Executive Summary

Objectives The purpose of this document is to describe third year achievements of SmartHG WP6. This WP started on M12 and its role within SmartHG is that of building test-beds to gather field data in order to enable evaluation of the services developed inside SmartHG.

Retrospect At the end of the second year, hardware deployment was complete in 20 houses out of 25 at Svebølle (Denmark) test-bed. Minsk test-bed was not deployed due to problems with Belarusian customs. As a recovery plan we deployed an unplanned test-bed in Central District (Israel) where, at the end of the second year, deployment was complete in 9 houses out of 13. We have also deployed one more test-bed at IMDEA SEIL where we have also experimented with actuation of energy storage devices (modelling Plug-in Electric Vehicle (PEV) or home batteries).

Present Achievements We completed deployment of sensing devices for appliances and main in 25 homes in Svebølle test-bed out of the 25 planned in the project. Communication devices have also been installed so that measurements are visible in real time on the Web. Four HECH kit have successfully been deployed.

We had problems with Belarusian customs in shipping hardware devices in Minsk. Accordingly, we just used historical data from Minsk test-bed and increased recruiting in Central District test-bed.

In Central District test-bed, we completed deployment of sensing devices for appliances and mains in 19 homes out of the 13 foreseen in our recovery plan.

We kept experimenting with actuation of energy storage devices (modelling PEV or home batteries) at IMDEA SEIL.

Chapter 1

Retrospect

In this chapter we briefly recall the main achievements obtained (and the main shortcomings identified) in the second year SmartHG demonstration activities, which were described in Deliverable D6.2.1.

1.1 Svebølle (Denmark) test-bed

We completed deployment of sensing devices for appliances and main in 20 homes in Svebølle (Kalundborg, Denmark) out of the 25 planned in the project. Communication devices have also been installed so that measurements are visible in real time on the Web.

We planned to deploy five Home Energy Controlling Hub (HECH) kits in the Svebølle test-bed to further assess the effectiveness of SmartHG Energy Bill Reduction (EBR) service on the user premises.

1.2 Minsk (Belarus) test-bed

Minsk test-bed has not been deployed due to problems with Belarusian customs. We were only able to plan sensor deployment in Minsk and send there smart meters and gateways (but not sensors and bridges). We planned to install sensors in 25 flats in Minsk monitoring only main consumption since electrical energy consumption is quite low in each flat. In case problems with Belarusian customs cannot be solved, we planned to just use historical data from Minsk test-bed and increase recruiting in Svebølle and Central District test-beds.

1.3 Central District (Israel) test-bed

In order to meet our goal of having two different test-beds ready by the end of second year as a recovery plan we deployed a test-bed in Central District (Israel). We completed deployment of sensing devices for appliances and mains in 9 homes out of the 13 foreseen in our present recovery plan. In Israel we were monitoring appliances and mains whereas in Minsk we were (planning) only for main monitoring.

1.4 IMDEA Smart Energy Integration Lab (SEIL)

We have also experimented with actuation of energy storage devices (modelling Plug-in Electric Vehicle (PEV) or home batteries). This cannot be done at the home premises. Accordingly we have also deployed one more test-bed at IMDEA SEIL where we drove Micro grid loads using data from SmartHG home test-beds and we drove Micro grid batteries using data from PEV usage (recorded from the Danish project *Test-an-EV*) and SmartHG services. This allowed us to carry out experiments with actuation much as if we were in one of the homes in our test-bed equipped with a PEV and a battery.

Chapter 2

Introduction

This deliverable reports about the work carried out in tasks T6.1, T6.2, T6.3 and T6.4 of WP6 of the SmartHG project.

2.1 Motivation and Objectives

SmartHG has the goal of devising economically viable open services for Intelligent Home Automation. WP6 role within SmartHG is that of building test-beds to gather field data in order to enable evaluation of the services developed inside SmartHG. Accordingly, WP6 main objective is to plan and carry out deployment of the hardware devices in SmartHG test-beds.

2.2 Achievements

We outline SmartHG WP6 third period achievements for each SmartHG test-beds.

2.2.1 Svebølle (Denmark) test-bed

We completed deployment of sensing devices for appliances and main in 25 homes in Svebølle (Kalundborg, Denmark) out of the 25 planned in the project. Communication devices have also been installed so that measurements are visible in real time on the Web. Four Home Energy Controlling Hub (HECH) kit have successfully been deployed.

2.2.2 Minsk (Belarus) test-bed

We had problems with Belarusian customs in shipping hardware devices there. Accordingly, we just used historical data from Minsk test-bed and increased recruiting in Central District test-bed.

2.2.3 Central District (Israel) test-bed

In Central District (Israel) test-bed, we completed deployment of sensing devices for appliances and mains in 19 homes out of the 13 foreseen in our recovery plan. In Israel we are monitoring appliances and mains whereas in Minsk we were (planning) only for main monitoring.

2.2.4 IMDEA Smart Energy Integration Lab (SEIL)

We keeped experimenting with actuation of energy storage devices (modelling Plug-in Electric Vehicle (PEV) or home batteries) at IMDEA SEIL where we drove Micro grid loads using data from SmartHG home test-beds and we drove Micro grid batteries using data from PEV usage (recorded from the Danish project *Test-an-EV*) and SmartHG services. This allows us to carry out experiments with actuation much as if we were in one of the homes in our test-bed equipped with a PEV and a battery.

2.3 Outline

The rest of this document is organised as follows:

- Chapter 3 describes the SmartHG Test-Bed Data Analytics;
- Chapter 4 describes the Hardware Devices deployed in SmartHG test-beds;
- Chapter 5 describes SmartHG Sensor Interface;
- Chapter 6 describes the Svebølle (Denmark) test-bed;
- Chapter 7 describes the Minsk (Belarus) test-bed;
- Chapter 8 describes the Central District (Israel) test-bed;
- Chapter 9 describes the Smart Energy Integration Lab at IMDEA;
- Chapter 10 describes the Data Showcase.

Table 2.1 maps tasks of WP6 to chapters of this document.

Task id	Task Name	Chapters
T6.1	Hardware Deployment in Kalundborg Test-Bed	3, 4, 5, 6, 9, 10
T6.2	Interfacing Kalundborg DSO with the project services	4, 5, 6
T6.3	Hardware Deployment in Minsk Test-Bed	3, 4, 5, 7, 8, 9, 10
T6.4	Interfacing Minsk DSO with the project services	4, 5, 7, 8

Table 2.1: Mapping between tasks of WP6 and chapters of this deliverable.

Chapter 3

Test-beds Data Analytics

After SmartHG hardware deployment, we collected directly data from test-beds sensors (for Svebølle and Central District). We included also other historical data, which are supplied by SmartHG partner SEAS-NVE for Svebølle and by SmartHG partner MinskEnergo for Minsk. Data are secured and analytics on single householders have been anonymised, for security and privacy issues.

This chapter describes some statistics and analytics on such data in terms of:

- Tables (Section3.1): showing the number of measurements stored in our services (taken both from deployed sensors and from historical data), the number of sensors deployed in all houses, and for each house in each test-bed the number of sensors deployed, divided by producer.
- Charts (Section3.2): showing significant aggregations at substation level (aggregations and averages on users demand).

Further charts showing other aggregations at substation level and at residential level can be found in the Technical Section of the SmartHG project website: http://smarthg.di.uniroma1.it/technical-section/, where information are supplied in different languages, namely English, Russian, and Danish.

In what follows, with demand we mean consumption (loads) minus production (photovoltaic in our test-beds), both at substation and at residential level, and with aggregated we mean the sum at substation level of all single demands or consumption.

3.1 Tables

Table 3.1 shows for each test-bed the number of measurements gathered from deployed sensors and the number of measurement collected through historical data supplied to the SmartHG project.

Table 3.2 shows for each test-bed the number of sensors deployed in all houses, both from Develco Products and from Panoramic Power.

Table 3.3 shows for each house in each test-bed the number of sensors deployed, divided by producer (between Develco Products and Panoramic Power) and type of appliance connected (entertainment, food preparation, heating and cooling, lighting, machinery, home appliances, ...).

Test-bed	**Sensor Measurements**	**Historical Measurements**	**TOTAL**
Svebølle, Denmark	149,292	678,528	**827,820**
Central District, Israel	144,252	0	**144,252**
Minsk, Belarus	0	3,409,132	**3,409,132**
TOTAL	**293,544**	**4,087,660**	**4,381,204**

Table 3.1: Number of measurements gathered from SmartHG test-beds

Houses		**Gateways**		**Sensors**	
Test-bed	**Quantity**	**Producer**	**Quantity**	**Producer**	**Quantity**
Svebølle, Denmark	25	Develco Products	25	Develco Products	62
		Panoramic Power	25	Panoramic Power	246
Central District, Israel	19	Panoramic Power	25	Panoramic Power	299
Minsk, Belarus	268	-	0	-	0
TOTAL	**44**		**75**		**607**

Table 3.2: Deployment (high-level) at SmartHG test-beds

House		Sensors categorised by producer and sensed appliance type							
		Develco Products	Panoramic Power						
Test-bed	**ID**	**Entertainment**	**Food Preparation**	**Heating and Cooling**	**Home Appliances**	**Lighting**	**Machinery**	**Miscellaneous**	**Main Meters**
Svebølle, Denmark	1	4	3	2	2	0	0	0	3
	2	2	4	1	2	0	0	0	3
	3	4	4	0	1	0	0	0	3
	4	0	3	8	2	0	0	0	3
	5	4	4	3	2	0	0	0	3
	6	4	4	3	2	0	0	0	3
	7	2	3	3	5	0	0	0	3
	8	4	4	3	2	0	0	0	3
	9	4	4	3	2	0	0	0	3
	10	3	4	3	2	0	0	0	3
	11	0	4	3	2	0	0	0	3
	12	3	3	0	1	0	0	0	3
	13	1	3	0	2	0	0	0	3
	14	4	3	0	2	0	0	0	3
	15	4	3	0	1	0	0	0	3
	16	0	4	0	2	0	0	0	3
	17	1	3	0	3	0	0	0	3
	18	3	4	0	2	0	0	0	3
	19	4	4	0	2	0	0	0	3
	20	0	3	1	1	0	0	0	3
	21	0	4	3	2	0	0	0	3
	22	4	1	0	2	0	0	0	3
	23	4	5	0	2	0	0	0	3
	24	1	3	0	1	0	0	0	3
	25	2	3	0	1	0	0	0	3
Denmark Total		**62**	**87**	**36**	**48**	**0**	**0**	**0**	**75**
Central District, Israel	112	0	1	7	6	3	0	0	6
	113	0	2	4	4	3	2	0	6
	114	0	1	7	4	3	0	0	9
	115	0	3	3	1	3	0	0	1
	116	0	0	0	0	0	0	5	1
	117	0	3	4	2	1	0	5	3
	118	0	1	3	4	0	0	0	3
	119	0	0	1	1	0	0	0	1
	120	0	0	0	0	1	0	0	3
	121	0	0	3	0	3	0	3	3
	122	0	1	2	2	0	0	2	6
	123	0	2	8	1	0	0	0	9
	124	0	1	15	5	3	0	0	6
	125	0	1	11	6	0	0	2	9
	126	0	3	8	2	13	1	1	3
	127	0	0	3	0	0	0	0	3
	128	0	2	3	0	0	0	0	10
	129	0	0	3	3	0	3	0	3
	130	0	1	2	6	0	0	1	0
Israel Total		**0**	**22**	**87**	**47**	**33**	**6**	**19**	**85**
Minsk, Belarus	131-398	0	0	0	0	0	0	0	0
TOTAL		**62**	**109**	**123**	**95**	**33**	**6**	**19**	**160**

Table 3.3: Deployment (house level) at SmartHG test-beds

3.2 Charts

Figures 3.1, 3.2 and 3.3 show the distribution of users as for the annual demand for Svebølle, Central District and Minsk test-bed, respectively. In particular, each bar of the chart represents the percentage of residential users whose annual demand falls within a certain range of kWh.

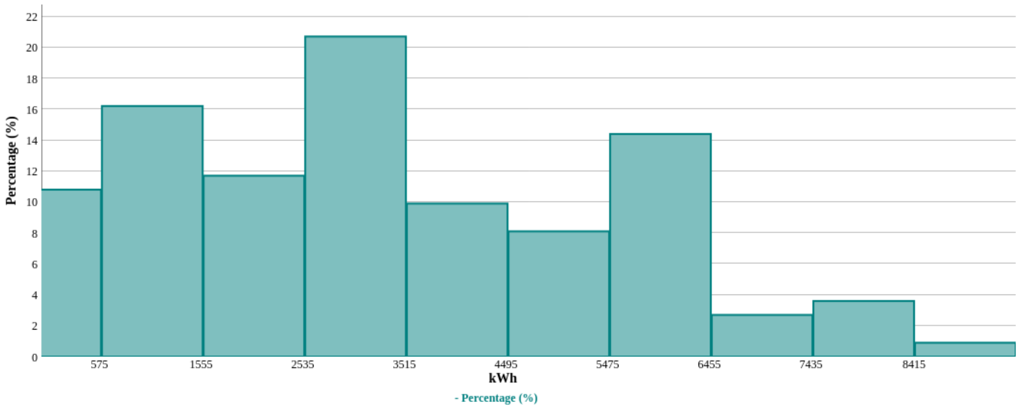

Figure 3.1: Distribution of users for annual energy demand (Svebølle)

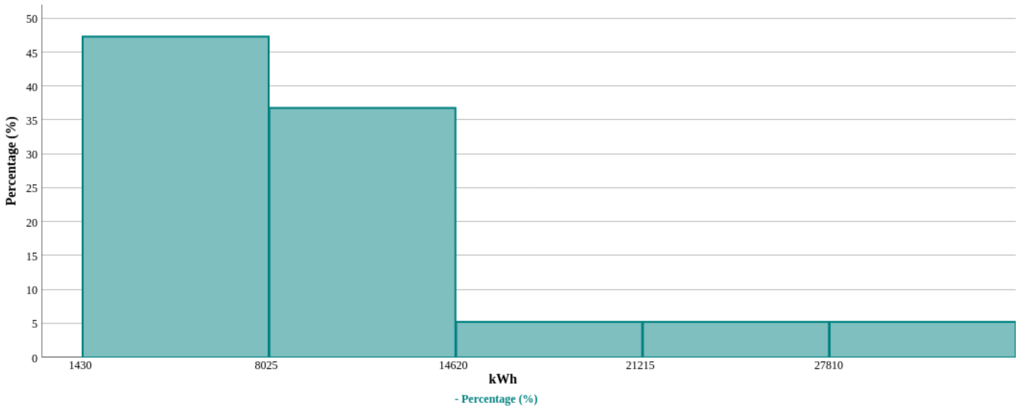

Figure 3.2: Distribution of users for annual energy demand (Central District)

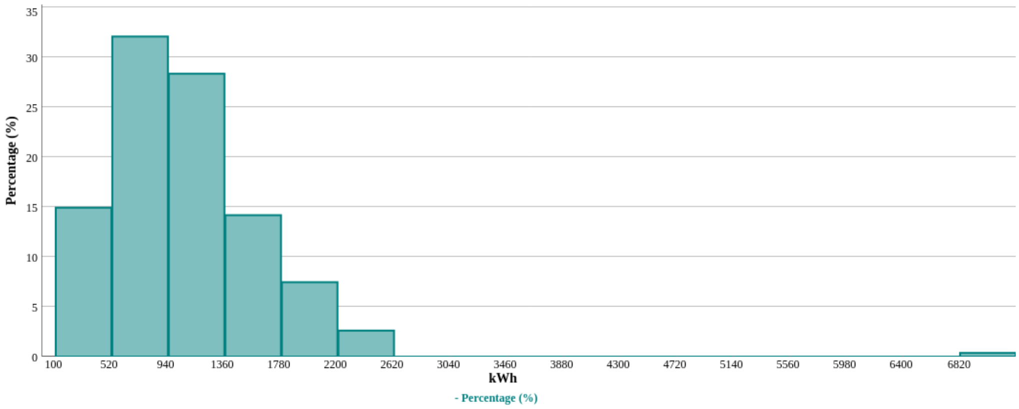

Figure 3.3: Distribution of users for annual energy demand (Minsk)

Figures 3.4 and 3.5 show the proportion of user consumption for each kind of appliance, where 100% corresponds to the overall consumption in the whole period for Svebølle and Central District test-bed, respectively. In Minsk test-bed we monitor only the main consumption of residential building and not the appliances.

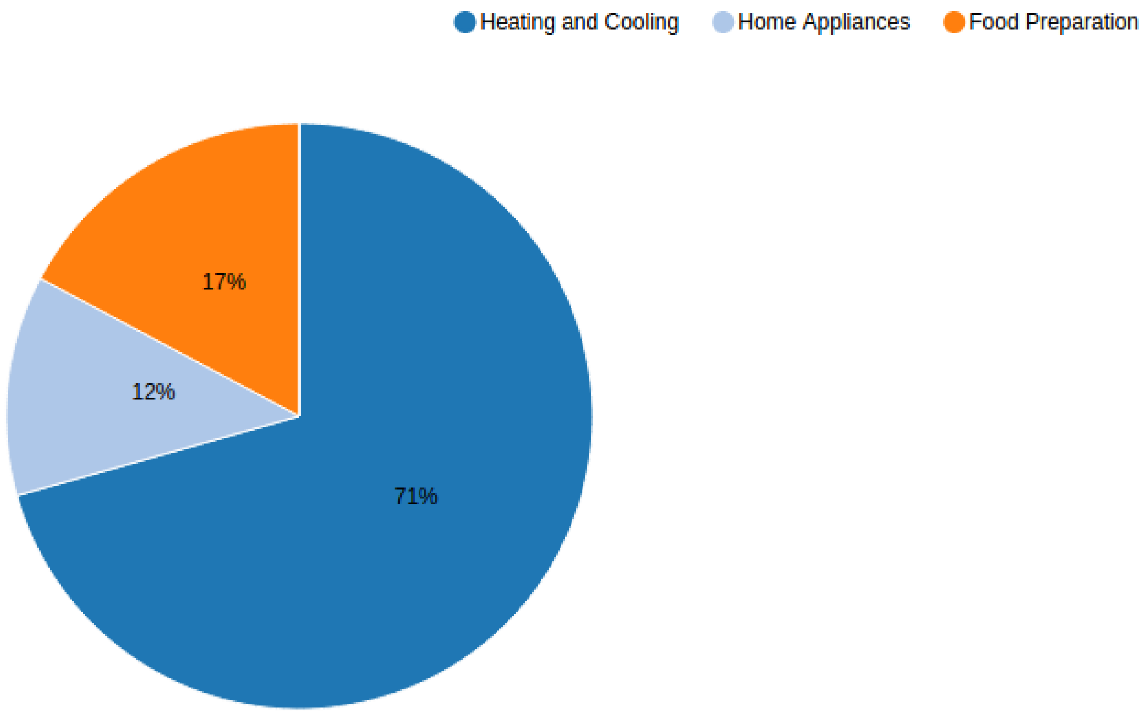

Figure 3.4: Proportion of aggregated consumption per kind of appliance (Svebølle)

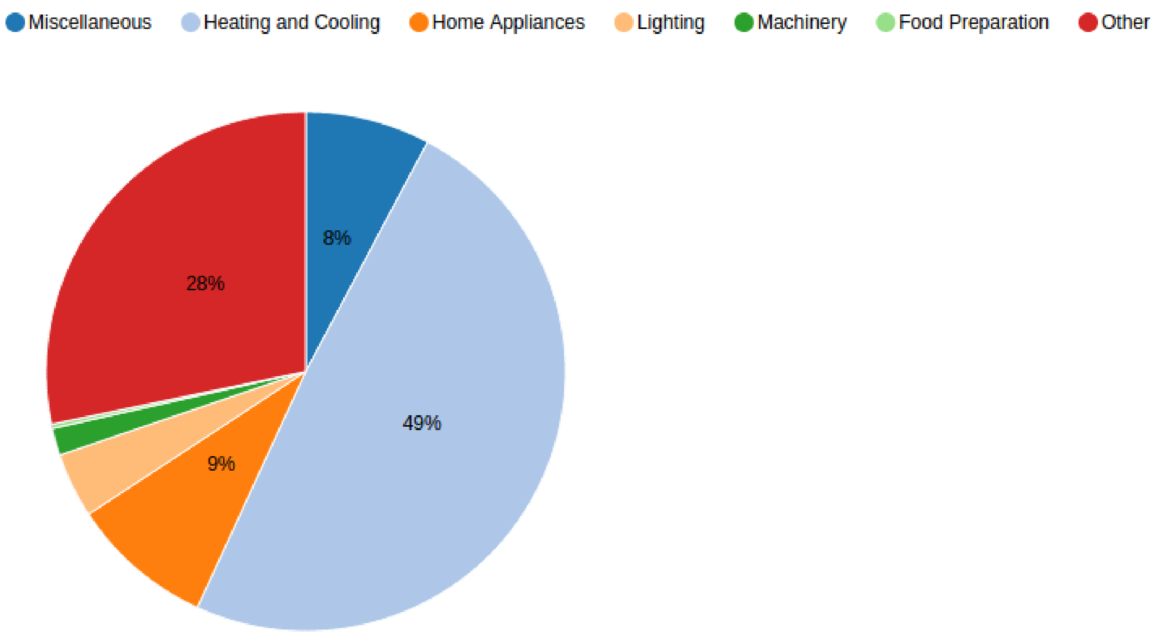

Figure 3.5: Proportion of aggregated consumption per kind of appliance (Central District)

Chapter 4

Hardware Devices

The devices deployed in SmartHG test-bed have been described in the second year deliverables, but for the sake of completeness, in this chapter we report such description.

4.1 Develco Products Smart Meters

Develco Products provided (see Figure 4.1):

- Smart Plugs that can both act as meters and as relays. This means that the consumer is capable of diagnosing the exact energy consumption from every connected appliance in his home. He will be aware of how much energy is used on different times of the day/week/month/year, and he will be able to switch appliances on/off remotely. The smart plugs can easily be installed by an untrained user and do not require any installation costs.
- Gateways that will handle the wireless ZigBee [1] network, control devices, collect data, and transmit data to the Database and Analytics (DB&A).
- User interface for turning on/off all appliances at the same time. This unit is a battery driven device that has two LEDs that are controlled from the server or the local controller. The LEDs can be used for indicating anything to the end user (defined by the backend software).
- Temperature sensors. These units are battery driven and equipped with a ZigBee module which makes them capable of reporting temperature to the gateway and thereby to the DB&A.

Figure 4.1: Develco Products smart meters

4.2 Panoramic Power Sensors

Panoramic Power provided (see Figure 4.2):

- PAN10 sensors to monitor loads up to 63 Amperes, max cable diameter 7mm.
- PAN12 sensors to monitor loads up to 225 Amperes, max cable diameter 17mm.
- Bridges that deliver energy information from the sensors every 10 seconds.

Figure 4.2: Panoramic Power sensors

4.3 Home Energy Controlling Hub (HECH) kit

AU provided Home Energy Controlling Hub (HECH) kits (see Figure 4.3), composed by:

- Raspberry Pi board

- Develco Products Smart Meters (ZigBee devices and gateway, see Section 4.1)
- USB stick
- Internet cable
- Power supply

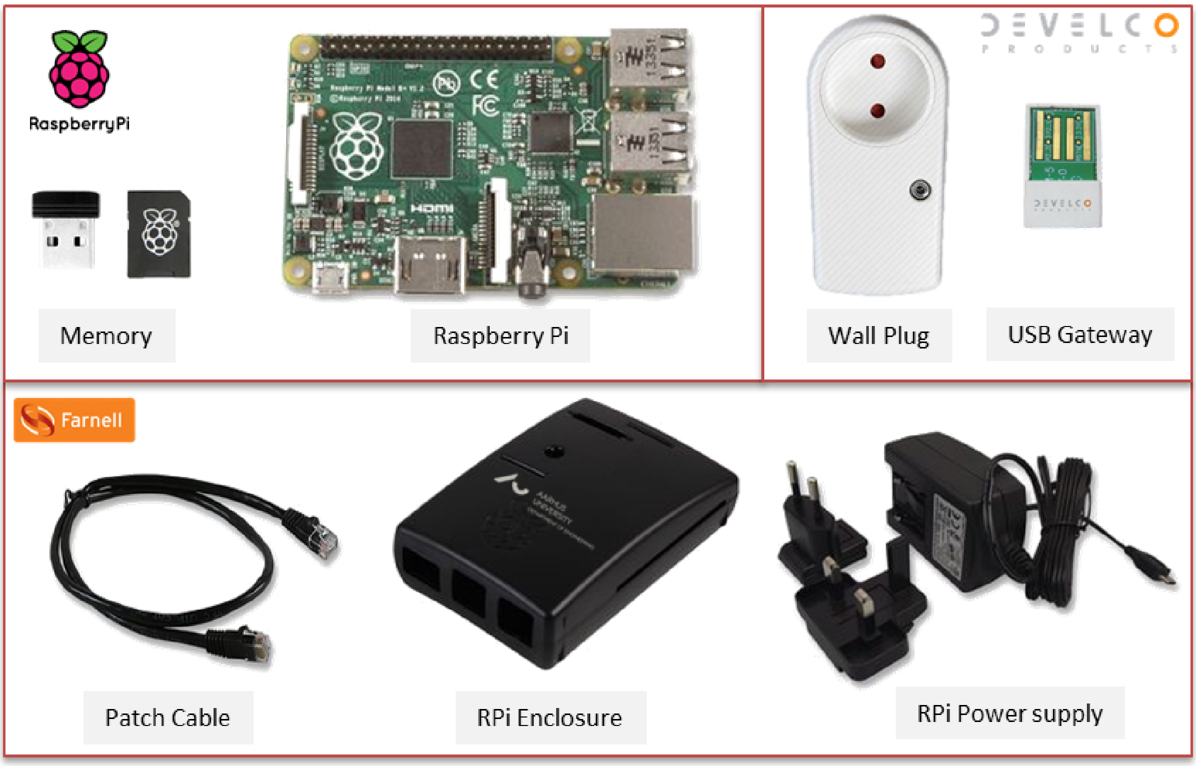

Figure 4.3: Home Energy Controlling Hub (HECH) kit

Chapter 5

Sensor Interfaces

The communication interface between SmartHG hardware devices collecting measurements in houses and the Database and Analytics (DB&A) service gathering collected data has been described in the second year deliverables, but for the sake of completeness, in this chapter we report such description.

5.1 Develco Products Smart Meters Interface

Figure 5.1 shows the design of communication between Develco Products smart meters (see Section 4.1) deployed in Svebølle test-bed and SmartHG Database and Analytics (DB&A).

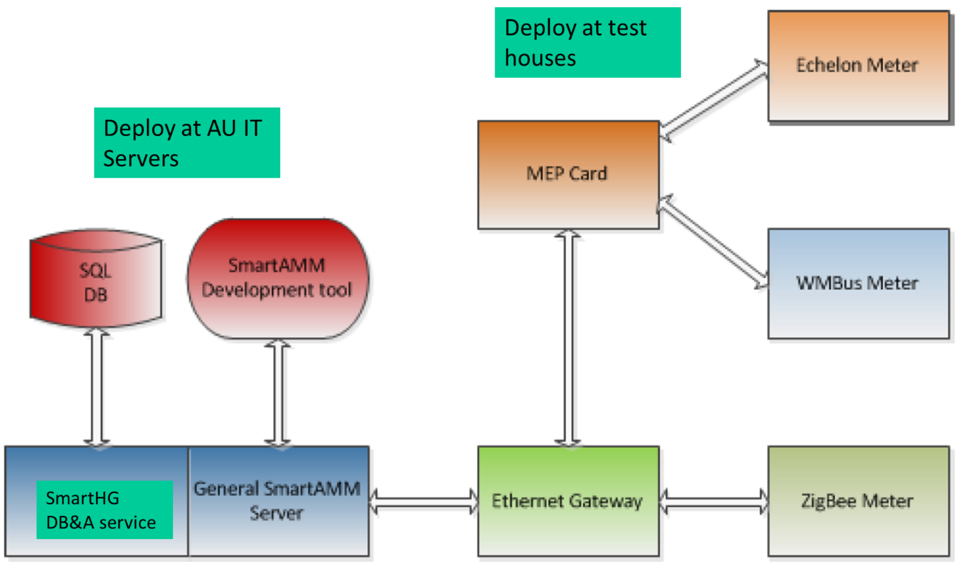

Figure 5.1: Database and Analytics (DB&A) and smart meters communication design

The smart meter interface provides the Echelon meters with ZigBee and Wireless M-Bus communication. Wireless M-Bus is intended for the readouts of meter data from water meters via the electricity meter. The ZigBee communication will be used for Home Intelligent Automation Service (HIAS) and load control. The meter interface, so-called MEP card, is designed as a drawer that can be inserted in the meter by the consumer himself without involving any electricians or installation contractors. Echelon meters (see Figure 5.2) are already installed in all homes in the Svebølle test area.

Figure 5.2: Echelon main meter

The heart of the system is a gateway that will handle the wireless ZigBee network, control devices, collect data, and transmit such data to the DB&A from where the data will be available to the users. The gateway is connected to an existing Internet router and provides thereby full access to all ZigBee devices in the household. Different applications can access the system via different interfaces on the server side.

5.2 Panoramic Power Sensors Interface

Panoramic Power sensors (see Section 4.2) deployed in all SmartHG test-beds send the data gathered from monitored appliances in the houses to Panoramic Power servers, via Panoramic Power bridge. All data are then sent to SmartHG Database and Analytics (DB&A) and shown on the Panoramic Power dashboard (see Chapter 10), where only registered users can access them.

5.3 Home Energy Controlling Hub (HECH) Interface

The Home Energy Controlling Hub (HECH) (see Section 4.3) acts as a gateway between ZigBee and the RESTful interface of the SmartHG Database and Analytics (DB&A). In the houses in which HECH kit is installed, data will flow to DB&A through the HECH.

Chapter 6

Svebølle (Denmark) Test-Bed

The main motivation for deployment of home devices in private homes in Svebølle (Kalundborg Municipality) is to support the SmartHG project with real data from real homes. Kalundborg Municipality participates in a wide range of sustainability projects, supporting the utility infrastructure and industries. The SmartHG project gives to Kalundborg Municipality the possibility to involve citizens in these activities, which support the municipality brand as the Green Industrial Municipality [2]. Taking part in the SmartHG project has been a kick start for Kalundborg Municipalities for establishing the Village Svebølle as a Living Lab for testing smart grid and wi-fi related devices in private homes. Figure 6.1 shows one of the houses involved in the Svebølle test-bed.

Figure 6.1: Svebølle involved home

6.1 Deployment and Maintenance Status

Sensors and smart meters have been deployed in 25 houses in Svebølle, as planned, by SEAS qualified electricians (see Figures 6.2 and 6.3 and for an example of installed sensors, gateway and bridge), who will take also in charge the maintenance of installed devices.

As shown in Table 3.1, in Svebølle test-bed we gathered 149,292 measurements from sensors deployed and 678,528 historical measurements.

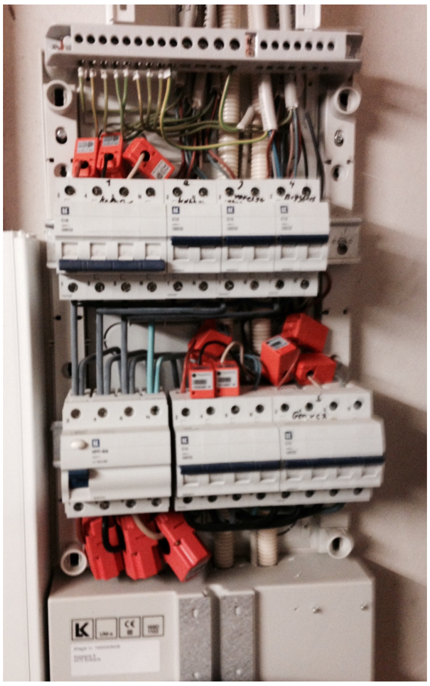

Figure 6.2: Sensors deployed in Svebølle

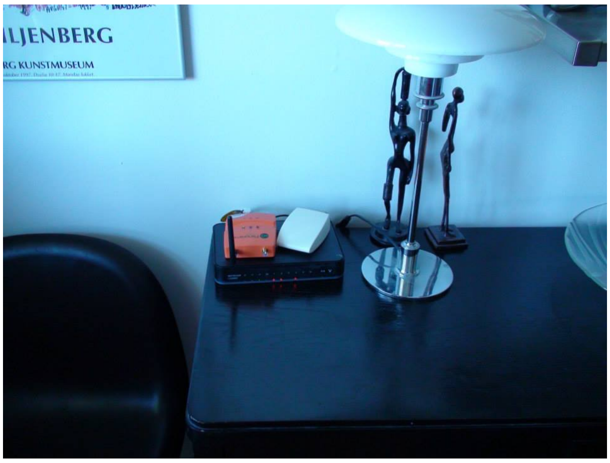

Figure 6.3: Gateway and bridge deployed in Svebølle

As shown in Table 3.2 (high-level) and Table 3.3 (house level), in Svebølle test-bed we deployed 25 bridges and 25 gateways, 62 smartmeters, 246 sensors, 50 temperature sensors and 2 smart switches.

In particular, for one house we have also plugged heat pump to one of such smart switches. We have then tested with success communication between our software infrastructure and smart switch in order to turn heat pump on and off.

Four homes have been further equipped with Home Energy Controlling Hub (HECH) kit. This allowed us to further assess the effectiveness of SmartHG Energy Bill Reduction (EBR) service, which uses inside temperature information to control heat pumps.

Data from monitored houses are available in SmartHG Database and Analytics (DB&A) and showcased in the Panoramic Power Dashboard (see Chapter 10). Some (anonymized) statistics and analytics on such data are shown in the Technical Section of the SmartHG project website (see Chapter 3) where information are supplied in different languages, namely English, Russian, and Danish.

The sensors available in all houses participating in the test-bed allowed us to measure all uncontrollable inputs (e.g., energy consumption as well as energy production from PhotoVoltaic (PV) panels, if any) for all houses in the test-bed. This allowed us to faithfully reproduce in IMDEA Smart Energy Integration Lab (SEIL) energy usage/production of each home and to experiment with different energy storage strategies for homes.

Maintenance of home devices in private homes in Kalundborg Municipality is important to secure a smooth running of the test-bed, and to secure that test homes are staying in the project until its end, and to gather valuable data. In Svebølle, we established a hotline, where test home representatives can call or mail if any problems. The hotline is running 7 days a week. To succeed the process, we found it necessary to promise to react also during weekend and holydays, and it has showed to be useful. The feedbacks from the test homeowners are positive. Dismantling of devices are planned to take place after the end of the project to give the longest possible test period. At the end of the project, every participant will get a short status on the results of the tests.

6.2 Distribution System Operator Interface

In this section we describe SmartHG generic interface towards Distribution System Operators (DSOs) (Section 6.2.1) along with our preliminary evaluation of the possibility of exploiting the Common Information Model (CIM) open standard to provide an interface towards DSOs (Section 6.2.1) whose control centre software is based on CIM.

6.2.1 SmartHG generic interface towards DSOs

All SmartHG Grid Services provide a web based interface towards DSOs. Such an interface is independent from the software used by the DSO in the control centre and it is based on exchange of text files (namely, in CSV format) defining inputs and outputs for the SmartHG Grid Services. More specifically, to see and download the data gathered from test-beds, the DSO can just access SmartHG Database and Analytics (DB&A). To run the Demand Aware Price Policies (DAPP) service in order to compute a price policy, a DSO can upload demand data and operational constraints through the web interface provided by the DAPP service (see Figures 6.4 and 6.5). To run the Price Policy Safety Verification (PPSV) service in order to evaluate robustness of a price policy, a DSO can upload the needed data through the web interface provided by the PPSV service (see Figure 6.6). Finally, a DSO can access the EDN Virtual Tomography (EVT) service by uploading to the EVT service website the electrical network topology (see Figure 6.7).

The above approach can be used to interface with *any* DSO, since it does not depend on the software used by the DSO to manage its control centre. We only require the relevant data (e.g., electricity demand) can be provided in a CSV format, which can be done by any control centre software.

6.2.2 Exploiting CIM interface towards DSOs

In order to ease integration of software from many vendors and to decrease maintenance costs, many DSOs are in the process of moving towards control centre software based on the CIM open standard. This process is, of course, independent from SmartHG. However, in view of SmartHG exploitation plan towards DSOs, it is worth to evaluate such an

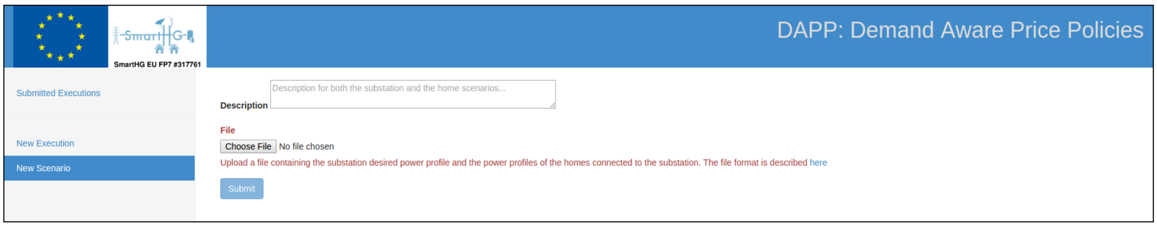

Figure 6.4: Demand Aware Price Policies (DAPP) service interface - Submitting a new scenario

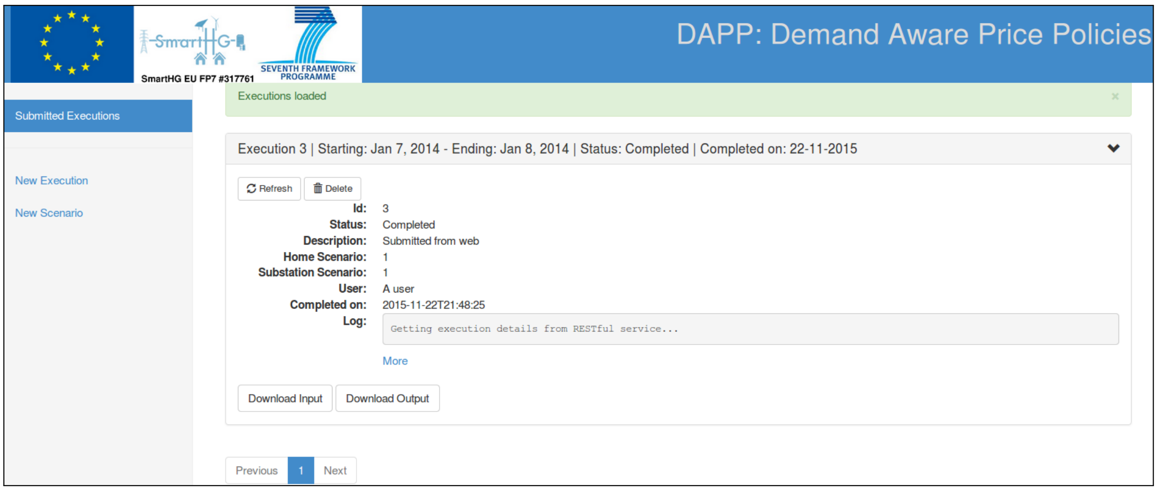

Figure 6.5: Demand Aware Price Policies (DAPP) service interface - Checking submitted tasks

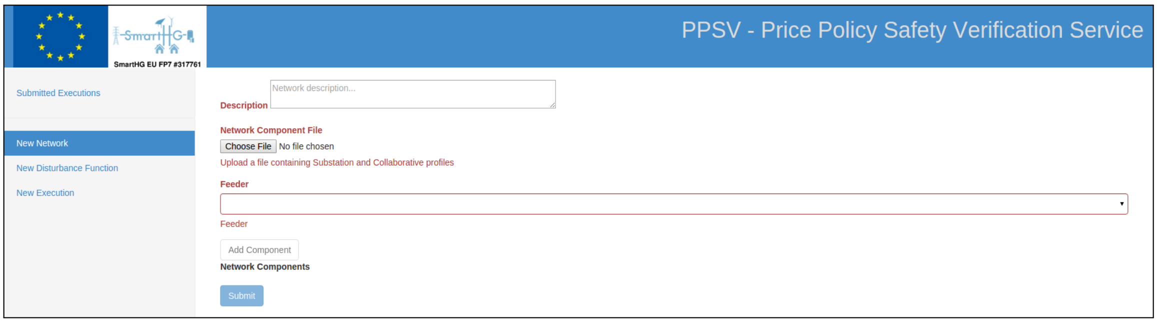

Figure 6.6: Price Policy Safety Verification (PPSV) service interface - Submitting a new network

opportunity. In fact, a CIM based interface towards a DSO may facilitate adoption of SmartHG services, since they will integrate seamlessly with DSO software infrastructure. Accordingly, during our third year of activity we explored with SEAS-NVE (and thus focusing on Svebølle test bed) the possibility offered by CIM. It is important to note that the target DSOs here are those that, for their own reasons (unrelated to SmartHG), have (or will have) a CIM based control centre software. All other DSOs can use the generic interface described in Section 6.2.1.

During the third year, the SmartAMM software and the SmartHG DB&A service, deployed at AU, have been optimised and maintained, to be up and running in a more stable way. The four deployed Home Energy Controlling Hubs (HECHs) allowed us to test communication on this open platform directly from Develco Products smart-plugs to

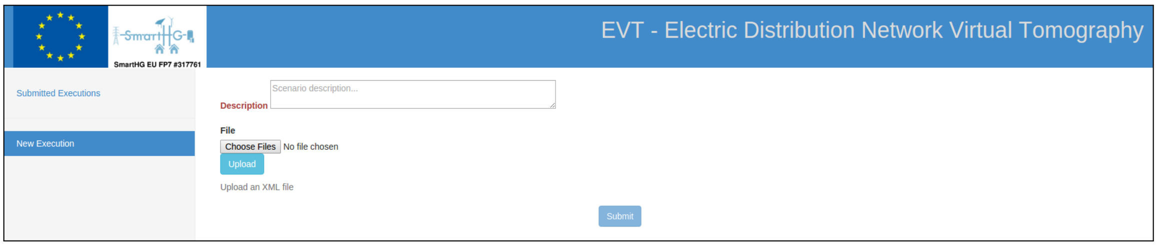

Figure 6.7: EDN Virtual Tomography (EVT) service interface - New Execution

SmartHG DB&A and Intelligent Automation Services (IASs) services.

After the third year of the SmartHG project, the "Grid Analyse System" from SEAS-NVE has been integrated with the SmartAMM. Figure 6.8 shows and example of a display of the "Grid Analyse System".

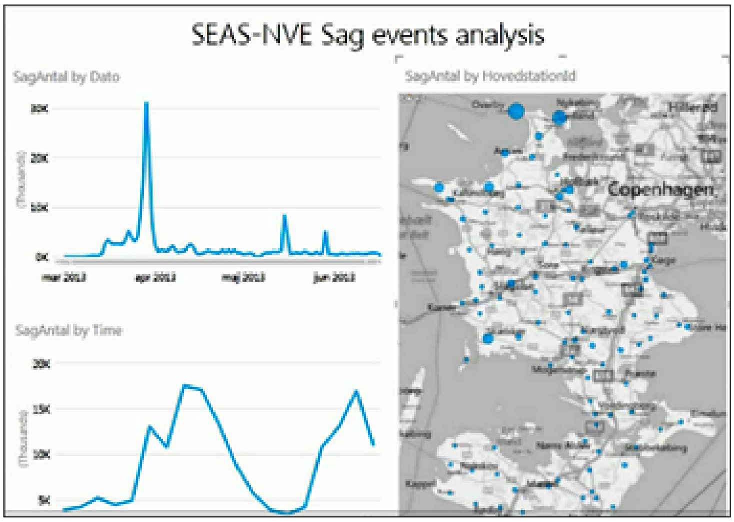

Figure 6.8: Example of a display of the Grid Analyse System of SEAS-NVE

Data from the SmartAMM is transferred to the Enterprise Service Bus (ESB). The Service-Oriented Architecture (SOA) nature of the ESB will provide utilities with an interoperable framework for intra-Enterprise communications between the real-time utility operational applications such as Supervisory Control And Data Acquisition (SCADA). This integration allows SmartHG from the field trial in Kalundborg to be integrated into the DSO system.

For application layer interoperability between the DSO network at SEAS-NVE and SmartHG, subsets of the CIM standards have been addressed. In particular, the CIM data model from the IEC 61970 (EMS, control center), IEC 61968 (DSO); and IEC 61850 (Substation equipment & sensors) have been investigated. As a result, smart meter data and EVT data has been integrated with the "Grid Analyse System".

The older version of the SCADA system from PSI, used by SEAS-NVE, is unfortunately not fully CIM compatible and an upgrade to the new version is needed for a more complete CIM integration. Hence, in order to provide compatibility between the DSO system interface and SmartHG, a mapping between customised DSO system objects (aka. NetTelligence) and CIM objects was made (see Table 6.1).

Overall, the analysis of CIM based integration with the DSO platforms reveals several challenges that need to be overcome for a full deployment. The overarching risk for an

NetTelligence Domain	NetTelligence Entity	CIM Domain	CIM Entity	CIM Entity description
Metering	Metering point	Metering	UsagePoint	Logical or physical point in the network to which readings or events may be attributed. Used at the place where a physical or virtual meter may be located; however, it is not required that a meter be present.
Metering	Meter end device	Metering	Meter	Physical asset that performs the metering role of the usage point. Used for measuring consumption and detection of events.
Metering	Energy consumption measurement	Metering	MeterReading	Set of values obtained from the meter.
Metering	Power quality event	Metering	EndDeviceEvent	Event detected by a device function associated with end device.
Metering	Meter diagnostic event	Metering	EndDeviceEvent	Event detected by a device function associated with end device.
Customer	Net installation	Metering	UsagePoint	Logical or physical point in the network to which readings or events may be attributed. Used at the place where a physical or virtual meter may be located; however, it is not required that a meter be present.
Customer	Premises	Customer	ServiceLocation	A real estate location, commonly referred to as premise.
Customer	Agreement	Customer	CustomerAgreement	Agreement between the customer and the service supplier to pay for service at a specific service location. It records certain billing information about the type of service provided at the service location and is used during charge creation to determine the type of service.
Customer	Customer	Customer	Customer	Organisation receiving services from service supplier.
Distribution power grid	10/0.4 kV substation	Core	Substation	A collection of equipment for purposes other than generation or utilization, through which electric energy in bulk is passed for the purposes of switching or modifying its characteristics.
Distribution power grid	10/0.4 kV substation	Wires	PowerTransformer	An electrical device consisting of two or more coupled windings, with or without a magnetic core, for introducing mutual coupling between electric circuits. Transformers can be used to control voltage and phase shift (active power flow).A power transformer may be composed of separate transformer tanks that need not be identical.A power transformer can be modelled.

Table 6.1: Mapping between SEAS-NVE information objects of the Grid Analyse System and CIM objects.

deployment is the added cost of software system integration. A DSO Information and Communications Technology (ICT) strategy for a future development should take into account the risk of possible interoperability problems for the CIM implementation. On the other hand, the DSO may benefit from a minimised vendor lock-in when following the path towards CIM compliance and DSO will achieve future gains such as lower operational cost from an improved standard integration between internal systems and with external services.

The design of such a CIM based interface between SmartHG services and DSOs is described in Chapter 6 of D4.3.1. In such a design, special emphasis has been put on the EndDeviceControl element of the CIM. Furthermore, we define an XML Schema for the basic CIM message structure, analyse a graphical representation of the EndDeviceEvent message, and provide a set of supporting tools for modelling with CIM and for the generation of XML based CIM messages. Finally, we describe a prototyping activity that demonstrates the used CIM elements to model two types of information messages: recommendation and warning messages, that were agreed between IMDEA and SEAS-NVE project partners.

Chapter 7

Minsk (Belarus) Test-Bed

Two multi-floor apartment buildings in the Fruzenski district of Minsk (Belarus) are selected as testbed for the SmartHG project.

Frunzenski district of Minsk was founded on April 17, 1951 due to the rapid post-war development of the city. It is the largest district in the north-west area of the capital, having a surface of 4,300 ha with 133 streets, alleys and driveways. In Frunzenski district live more than 373,000 people.

The two multi-floor apartment buildings are located on Belskogo street 2 and Burdeinogo street 8 (see Figure 7.1).

Figure 7.1: Buildings involved in Minsk test-bed

The building in Belskogo street 2 includes 153 flats and that in Burdeinogo street 8 includes 116 flats. Furthermore, each building is served by two transformers. Each transformer has primary voltage of 10kV, secondary voltage of 400V and nominal power of 1000kVA.

Currently, in the Minsk test-bed there are no energy generators based on renewable sources, although the Minsk administration has plans to equip the city with a district heat pump and a wind farm.

7.1 Deployment and Maintenance Status

Due to problems with Belarusian customs, it has not been possible to deliver Panoramic Power sensors and bridges (see Section 4.2) to SmartHG Minsk test-bed as planned. In order to meet our goal of having two different test-beds as a recovery plan we deployed a test-bed in Central District (Israel), see Chapter 8. However, from Minsk test-bed we used 3,409,132 historical measurements (see Table 3.1) about main consumption for each apartment for the time interval from April 2014 till July 2015, with granularity 1 hour.

Some (anonymized) statistics and analytics on such data are shown in the Technical Section of the SmartHG project website (see Chapter 3) where information are supplied in different languages, namely English, Russian, and Danish.

7.2 Distribution System Operator Interface

Interfacing between SmartHG grid services and Minsk Distribution System Operator (DSO) (MinskEnergo) is based on the generic interface outlined in Section 6.2.1. Since from Minsk we only use historical data such an interface is basically used to exchange such data with Minsk DSO.

Chapter 8

Central District (Israel) Test-Bed

As a recovery plan for the delay in the deployment of Minsk test-bed due to customs problems with Belarus, we decided to have a test-bed in Central District (Israel). This allows us to gather data from two test-beds, as planned.

Panoramic Power monitors consumption of houses in the Central District (mainly large private houses) by summer 2015. Those houses have been used as a (new and unplanned) SmartHG test-bed, allowing SmartHG to use a wider set of residential scenarios. Figures 8.1 and 8.2 show two of the houses involved in the Central District test-bed.

Figure 8.1: Central District involved home #1

Figure 8.2: Central District involved home #2

8.1 Deployment and Maintenance Status

Sensors have been deployed in 19 houses in Central District, out of the 13 homes planned, by qualified electrician who will take also in charge the maintenance of installed devices.

As shown in Table 3.1, in Central District test-bed we gathered 144,252 measurements from sensors deployed.

As shown in Table 3.2 (high-level) and Table 3.3 (house level), in Central District test-bed we deployed 25 bridges and 299 sensors.

Home owners receive weekly reports on their electrical consumption, as well as a new mobile App allowing them to monitor their consumption from their mobile phones.

Data from monitored houses are available in SmartHG Database and Analytics (DB&A) and showcased in the Panoramic Power Dashboard (see Chapter 10). Some (anonymized) statistics and analytics on such data are shown in the Technical Section of the SmartHG project website (see Chapter 3) where information are supplied in different languages, namely English, Russian, and Danish.

8.2 Distribution System Operator Interface

A Distribution System Operator (DSO) is not directly involved in the Central District test-bed. However, as for Minsk test-bed, data and functionalities are made available to a DSO through the SmartHG webservices as outlined in Section 6.2.1.

Chapter 9

IMDEA Smart Energy Integration Lab

Experiments at IMDEA Smart Energy Integration Lab (SEIL) have been mostly completed during our second year. During the third year, interfaces of SmartHG services with SEIL have been further improved. For sake of completeness here we describe the current status of IMDEA SEIL test bed.

9.1 Introduction

The main goal of IMDEA Smart Energy Integration Lab (SEIL) (Figure 9.1) test bed within SmartHG is to allow us to experiment with actuation of home batteries. In fact, carrying out such an activity in the homes in our test beds would raise safety issues. To this end, we proceed as follows.

We record electricity demand and local generation data from the homes in our test bed as well as Plug-in Electric Vehicle (PEV) data from the Danish project “Test-an-EV”. We then drive IMDEA SEIL converters to emulate loads, generators and PEV using such data.

Finally, we use SmartHG Home Services (namely Energy Bill Reduction (EBR)) to control SEIL batteries. In this way, we can use IMDEA micro grid to experiment with actuation of home batteries and PEVs as if the homes in our test beds were equipped with a PEV and a battery.

Finally, IMDEA SEIL test bed allows us also to evaluate integration of the Home Energy Controlling Hub (HECH) with SmartHG Home Services by running the EBR on the HECH and interfacing it with IMDEA SEIL devices.

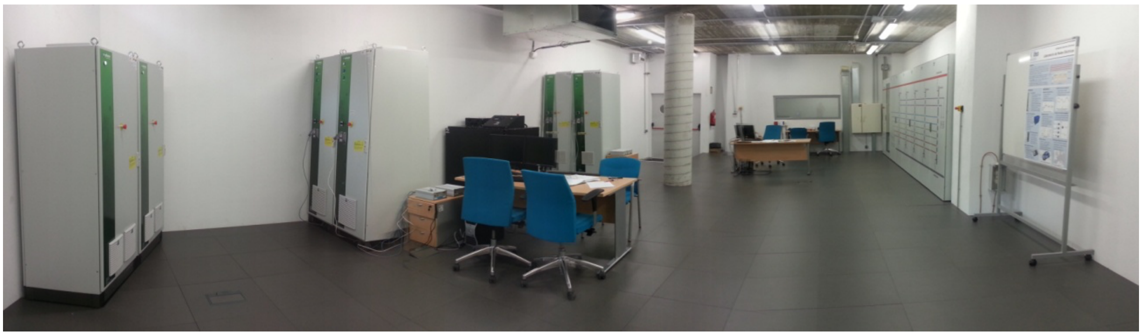

Figure 9.1: Smart Energy Integration Lab at IMDEA

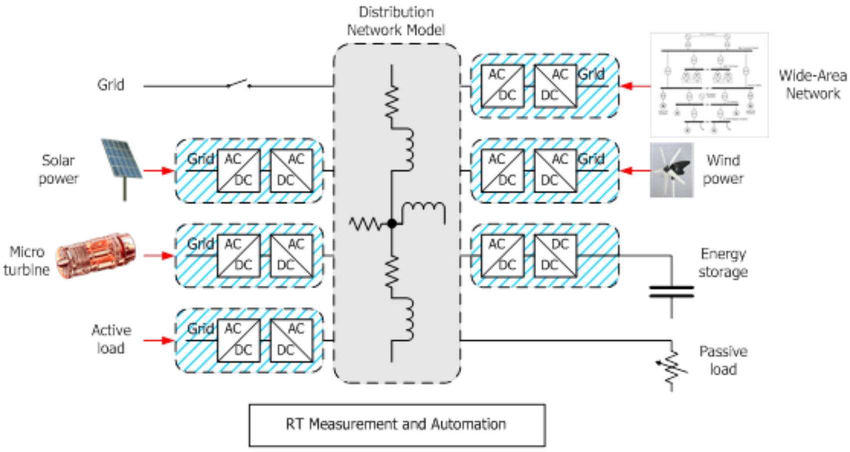

Figure 9.2: Description of Smart Energy Integration Lab at IMDEA.

9.2 SEIL Architecture

Electrical Systems Unit at IMDEA has created a test environment specifically designed for research, development and testing of control algorithms in energy systems and micro-grids. This environment (see Figure 9.1) named "Smart Energy Integration Lab (SEIL)" has the goal of accelerating the process of control design and development necessary for connecting energy resources to electricity networks.

The approximate lab capacity for power processing is 210kVA and it is formed by a set of power electronics converters, resistive loadbanks, 47.5kWh battery system, distribution panels along with monitoring and control systems. This platform allows analysis, development and testing of realistic scenarios for energy integration in both AC and DC networks and also operation of distribution power networks, islanded networks and micro-grids. The results obtained from this test environment are more reliable and accurate than any model based computer simulation. Table 9.1 describes the main facilities available at SEIL, Figure 9.2 summarises their usage in our setting and Figure 9.3 outlines the 2-level SEIL hierarchical control infrastructure.

What distinguishes SEIL is its flexibility in implementation of control algorithms and easy access to all test and management data from any part of the network. The IMDEA lab microgrid is capable of recreating a large number of different events that occur in

Components	Description
Configurable AC distribution system	Distribution panels with 5 independent busbars and contactor control
Converters	6 AC/DC and 1 DC/DC converters
Inverters	4 x 15kVA three-phase power inverters 2 x 75kVA three-phase power inverters
Configurable loads	2 x 30kW balanced and unbalanced, programmable resistive loadbanks (configurable loads)
Battery system	47.5kWh Li-Ion battery system with Battery Management System (BMS)
Battery charger	90KW Bidirectional, wide bandwidth, programmable battery charger
Independent monitoring and control system	2-level hierarchical control (see also Figure 9.3): – Top: SCADA system based on National Instruments Technology – Bottom: 4 industrial PCs with RT operating systems

Table 9.1: IMDEA SEIL infrastructure.

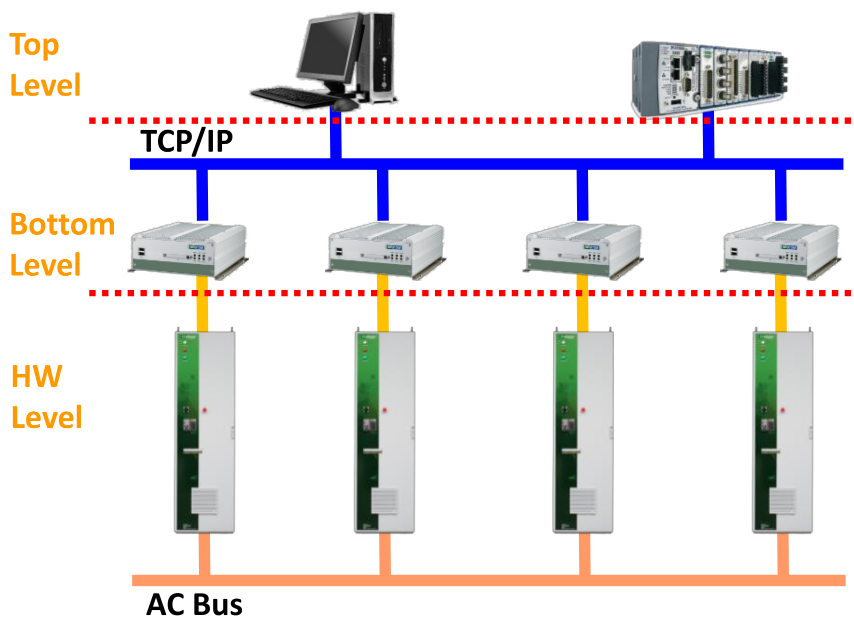

Figure 9.3: SEIL hierarchical control infrastructure.

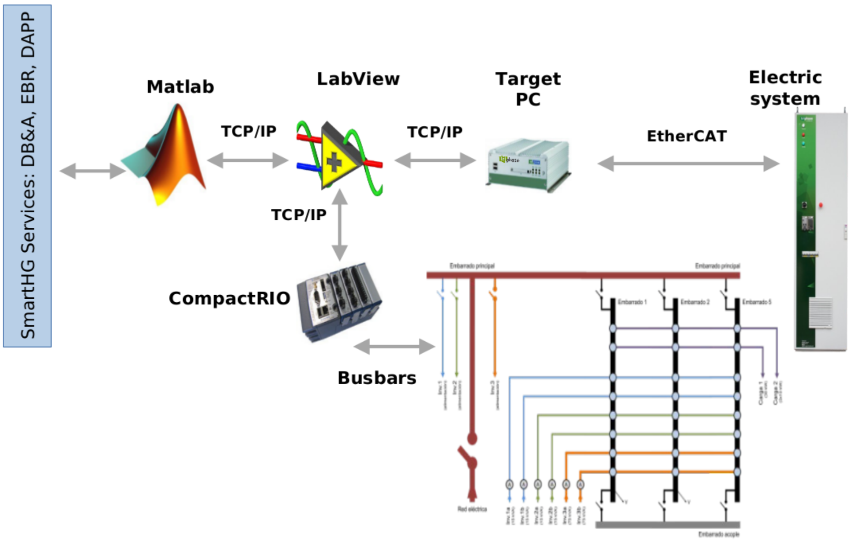

Figure 9.4: Interaction between SmartHG Home Services and SEIL devices.

real power networks and, therefore, represents a useful tool when it comes to research, development and implementation of energy management algorithms. For example, the lab network is capable of emulating at the same time a generation and load mix consisting of various wind, photovoltaic and conventional generators and passive and active loads all together connected to a wide area network whose dynamic is emulated in real-time. The role for the power converters acting as energy resources in such a network is simply defined by assigning a different control block to each of them. In addition to this, the battery system installation offers all the flexibility needed for the development of management algorithms for future power network.

Figure 9.4 outlines the interaction between SmartHG Home Services (Home Intelligent Automation Service (HIAS)) and SEIL devices. Control algorithms for power inverters are programmed via Matlab Simulink and code generation tools and are then executed in real-time on industrial PCs. Real-time data exchange provides access to all control variables and parameters during the test. In this way the desired flexibility in reproducing real dynamic characteristics of any energy source, generator or load is achieved. The monitoring and control system allows an independent, remote, real-time access to laboratory resources including the network reconfiguration, control of contactors and connection to the external power grid. Moreover, by harnessing the potential of the communication network installations, any centralised or decentralised management control algorithm can be implemented.

9.3 Energy Bill Reduction Test Architecture and Methodology

Energy Bill Reduction (EBR) service was evaluated in Smart Energy Integration Lab (SEIL) by using power converters to reproduce real demand and generation profiles recorded in other SmartHG test-bed sites and also to provide actuations on battery storage and Plug-in Electric Vehicle (PEV) that were not available in any of the project

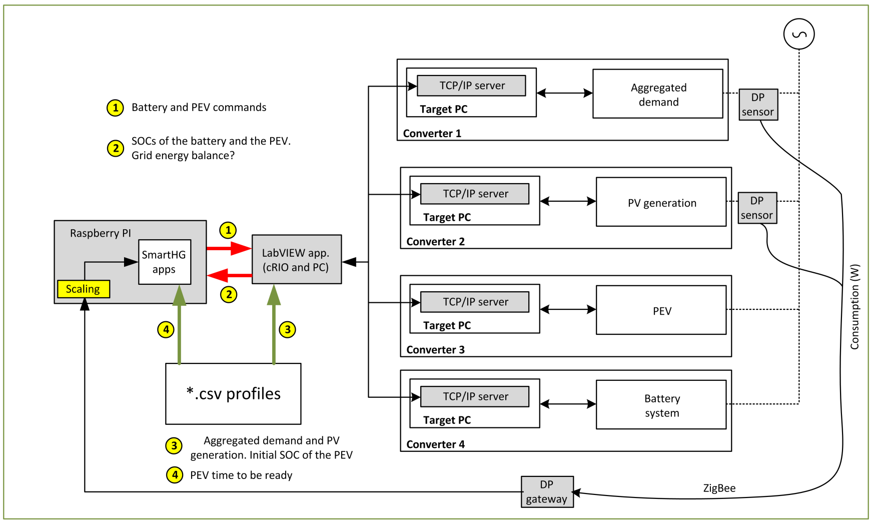

Figure 9.5: Control schema for SmartHG Home Services evaluation at Smart Energy Integration Lab.

test-beds. The real PEV battery profiles from the Danish project "Test-an-EV" were used as the reference for the PEV demand.

Figure 9.5 outlines the test bed architecture we used to evaluate SmartHG Home Services (namely, EBR) at SEIL whereas Figure 9.6 outlines how LabView is used to interface SmartHG Home Services to SEIL hardware. The Raspberry PI control platform (Home Energy Controlling Hub (HECH)) hosted the EBR algorithm, Database and Analytics (DB&A) and SmartAMM services and used the real sensors and the gateway to receive the measurements of home demand and PhotoVoltaic (PV) generation in the same way as it would have done in a real home. The HECH was then interfaced to the SEIL control platform based on LabView that had two main roles: to replay the demand and PV recorded profiles and to relay the charge-discharge information for the battery storage and PEV control. In this way the lab test-bed allowed the evaluation of EBR in the same way as if the tests were applied in one of the real homes equipped with real PEV, battery systems and HECH. Finally, Figure 9.7 outlines how the converters in IMDEA's SEIL were used to represent the home demand, PV generation, battery storage and PEV.

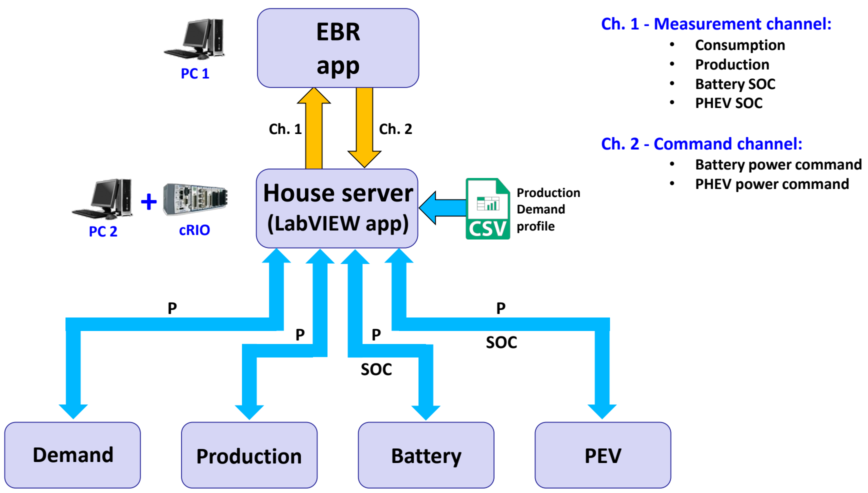

Figure 9.6: Interfacing SmartHG Home Services with Smart Energy Integration Lab devices.

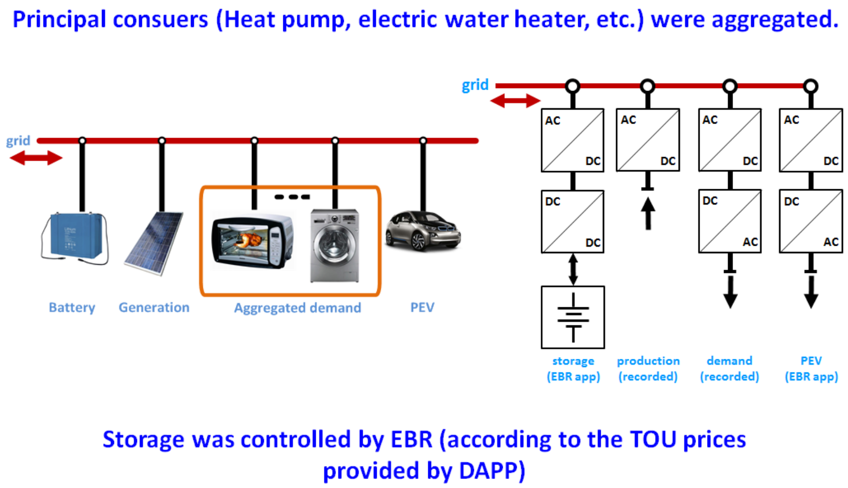

Figure 9.7: Usage of converters for EBR evaluation at SEIL.

Chapter 10

Data Showcase

All data gathered by sensors and smart meters deployed in the SmartHG test-beds are stored in the SmartHG DB&A and are showcased in the Panoramic Power PowerRadar™ dashboard. The Panoramic Power dashboard is used by both the homeowners involved in SmartHG and the project partners to view the energy use of the individual homes monitored in the project's test-beds. Only users with private and secure username and password can log in to the Panoramic Power dashboard.

For this reason, we create a public showcase in the project website, which contains some anonymized screenshots from the dashboard and general information about deployed hardware and test-beds data. Further details about project showcase are available in Deliverable D7.3.3 - Project Showcase on Industrial Web-site.

Chapter 11

Conclusions

Twenty-five houses are monitored in the Svebølle test-bed out of the 25 planned. Nineteen houses in the Central District area are monitored, out of the 13 planned. In Minsk test-bed deployment of sensors has not taken place, due to problems with Belorusian customs. From Minsk test-bed we used historical data about main consumption for each apartment. Table 11.1 summarises the planned and current hardware deployment on SmartHG test-beds. Data gathered from those sites are available for homeowners and project partners on the Panoramic Power dashboard (private and secure username and password are needed to log in). Statistics and analytics on such data aggregations at substation level and at residential level can be found in the Technical Section of the SmartHG project website: http://smarthg.di.uniroma1.it/technical-section/, where information are supplied in different languages, namely English, Russian, and Danish.

Test-bed	Planned			Current		
	Monitored houses: appliances and main	Monitored flats: only main	Hardware deployment	Monitored houses: appliances and main	Monitored flats: only main	Hardware deployment
Svebølle (Denmark)	25		250 sensors 25 bridges 65 smartmeters 25 gateways 5 HECH 50 temperature sensors 2 smart switches	25		246 sensors 25 bridges 62 smartmeters 25 gateways 4 HECH 50 temperature sensors 2 smart switches
Minsk (Belarus)		25	78 sensors 6 bridges 1 smartmeter 1 gateway			
Central District (Israel) *Recovery Plan*	13		140 sensors 13 bridges	19		299 sensors 25 bridges

Table 11.1: Test-bed planned and current deployment status

Chapter 12

List of Acronyms

BMS Battery Management System 29

CIM Common Information Model 18

DAPP Demand Aware Price Policies 18

DB&A Database and Analytics 31

DSO Distribution System Operator 26

EBR Energy Bill Reduction 30

EDN Electric Distribution Network

ESB Enterprise Service Bus 20

EVT EDN Virtual Tomography 18

HECH Home Energy Controlling Hub 31

HIAS Home Intelligent Automation Service 30

IAS Intelligent Automation Service 20

ICT Information and Communications Technology 22

PEV Plug-in Electric Vehicle 30

PPSV Price Policy Safety Verification . . . 18

PV PhotoVoltaic . . . 31

SCADA Supervisory Control And Data Acquisition . . . 20

SEIL Smart Energy Integration Lab . . . 30

SOA Service-Oriented Architecture . . . 20

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