• FINAL PUBLISHABLE SUMMARY •

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Chapter 1

Executive Summary

The SmartHG project develops a set of open yet secure economically viable *software services* pursuing the following (possibly conflicting) objectives: (a) Support the DSO in optimising Electric Distribution Network (EDN) operations; (b) Reduce energy costs for residential users; (c) Reduce CO2 emissions.

SmartHG approach consists of a two-tier hierarchical control schema. At the top tier, the DSO sets operational constraints for the EDN and gets from the SmartHG Platform (*Grid Services*) an *individualised price policy* for each residential user. At the bottom tier, the SmartHG Platform (*Home Services*) monitors and control home devices (namely, energy storage devices) to comply with the user price policy.

SmartHG technology supports both a Demand Response (DR) like approach, where each user adjusts his habits so as to comply with the given individualised price policy, as well as a Direct Load Control (DLC) like approach, where home energy storage devices (such as home batteries and Plug-in Electric Vehicles (PEVs)) are used to comply with the given price policy in a way fully transparent to the residential user.

SmartHG technology *virtually* pulls together residential users so that they can provide (*and being paid for*) useful services (e.g., peak shaving, arbitrage, etc.) to DSOs or to electricity retailers.

We evaluated SmartHG effectiveness on three test beds: Kalundborg (Denmark), Central District (Israel) and Minsk (Belarus). Using data gathered from such test beds, below we summarise the advantages for DSOs, electricity retailers and residential users that adoption of SmartHG technology may bring.

The benefits provided by SmartHG individualised price policy technology to the EDN, and thus to the DSO, are: 1) Increasing the *demand load factor* of more than 18% with respect to a flat price policy and of more than 35% with respect to to a global price policy (because of *rebounds*), thereby providing a *peak shaving* effect considerably better than the one offered by a *global* price policy; 2) Decreasing low voltage violation in the grid; 3) Decreasing network line thermal MVA limit violations; 4) Decreasing network line losses (e.g., of about 2% with respect to a global price policy).

The benefits provided by SmartHG to electricity retailers mainly consist in the possibility of effectively exploiting distributed home energy storage to buy energy when its price is low in the day-ahead market (*arbitrage*). By using SmartHG Home Services, we can achieve a reduction in the energy cost from 3% to 19%.

Finally, SmartHG can bring benefits also to the environment, by allowing electricity retailers to buy energy when its CO2 footprint is small. This allows a reduction in CO2 emissions from 3% to 15%, depending on the scenario considered.

Chapter 2

Project Context and Objectives

In this section we outline the motivations behind the SmartHG project (Section 2.1) along with SmartHG objectives (Section 2.2)

2.1 Context

Demand-Response is at the very heart of the Smart Grid idea. Thus, unsurprisingly, gathering real-time data on energy usage and exploiting such data for intelligent automation has been widely explored for commercial and industrial buildings as well as for residential homes. However, while for *energy eager* buildings, such as commercial or industrial ones, such an approach has generated business opportunities, as witnessed by the many companies providing energy services for such customers (indeed, four such companies, i.e., ATANVO, DEVELCO Products, Panoramic Power, Solintel, belong to SmartHG consortium), the situation is not that bright for residential homes.

In fact, intelligent automation for residential homes currently faces the following obstacles:

- The energy saving that a single residential home can achieve is quite modest when compared to those achievable by energy eager users such as commercial or industrial buildings. As a result, even the investment in (non-mandatory) monitoring equipment can be hard to justify, let alone investments for intelligent automation.
- Because of the small economical returns, today residential homes are not a very appealing business opportunity for companies working on energy saving products or services.
- A Distribution System Operator (DSO) typically focuses on optimising Electric Distribution Network (EDN) operations. In such a case, again, the energy figure of a single residential home is too small to be of direct interest for a DSO.

In summary, today we face a *lack of a sound business case*, which may prevent the development and widespread uptake of Information and Communications Technology (ICT) solutions that can un-tap the potentials of the energy saving opportunities stemming from intelligent automation exploiting energy usage and generation data from residential homes.

This motivates SmartHG plans to overcome such a state of affairs by developing a system that will be appealing to residential home users and DSOs.

The rationale is that, in such a situation, DSOs can become customers for companies developing energy services. Considering that DSOs, unlike residential homes, are *interesting* customers for such companies, we have that such an approach brings a benefit to all actors involved. Thus, by exploiting residential home energy usage data, *low-value Home Services* are offered to each residential home and *high-value Grid Services* to the DSO. This approach can *bring economical benefits to all stakeholders*.

2.2 Objectives

SmartHG develops software services that, by exploiting the energy usage data from residential homes, provide *intelligent automation services* to residential home users as well as to Distribution System Operators (DSOs).

The rationale is that SmartHG Home Services (Home Intelligent Automation Services, HIASs) will provide benefits to individual citizens by helping them to minimise their energy costs (*local* optimisation), whereas SmartHG Grid Services (Grid Intelligent Automation Services, GIASs) will support the DSO in optimising Electric Distribution Network (EDN) management (*global* optimisation).

Furthermore, development of SmartHG Grid Services introduces new interesting business opportunities for companies providing energy-saving software at the grid level, whereas SmartHG Home Services will open opportunities for companies providing energy services to electricity retailers.

To foster sustainability of the envisaged approach, we need to guarantee that the software services developed in the project can be used as *building blocks* on which *further services* can then be developed. For this reason, one of the fundamental objectives that this project pursues is the definition of open protocols for the envisaged Home and Grid services as well as for the data gathering hubs (sensors, gateways, etc.) deployed in residential homes.

Summing up, SmartHG aims at developing a set of open yet secure economically viable software services pursuing the following (possibly conflicting) objectives:

- Support the DSO in optimising EDN operations
- Reduce energy costs for residential users
- Reduce CO2 emissions.

Chapter 3

Main Scientific and Technical Results

We provide a short description of the SmartHG *Software Platform* (Section 3.1), of the test beds we used to evaluate such a platform (Section 3.2) and of SmartHG main achievements (Section 3.3) towards the planned objectives, i.e.,: develop economically viable open software services aiming at optimising EDN operations, reduce electricity costs and reduce CO2 emissions.

3.1 SmartHG Platform

We provide a brief overview of the SmartHG Platform. The aim of such a description is to clarify how *demand awareness* from the field data is achieved and exploited for *smart* energy management.

The *SmartHG Platform* (Figure 3.1) consists of a set of integrated *software services* supporting management of the Electric Distribution Network (EDN) (*SmartHG Grid Services*) as well as of the home devices (*SmartHG Home Services*) along with a communication infrastructure enabling reliable and secure communication among such services.

SmartHG approach consists of a two-tier hierarchical control schema. At the top tier, the Distribution System Operator (DSO) sets operational constraints for the EDN and gets from the SmartHG Platform (*Grid Services*) a *power profile* (i.e., time dependent power constraints) for each residential user. At the bottom tier, the SmartHG Platform (*Home Services*) monitors and controls home devices in order to keep at each time the home power demand within its power profile. In the following, we provide a short description of SmartHG Grid Services (Section 3.1.1), Home services (Section 3.1.2) and of

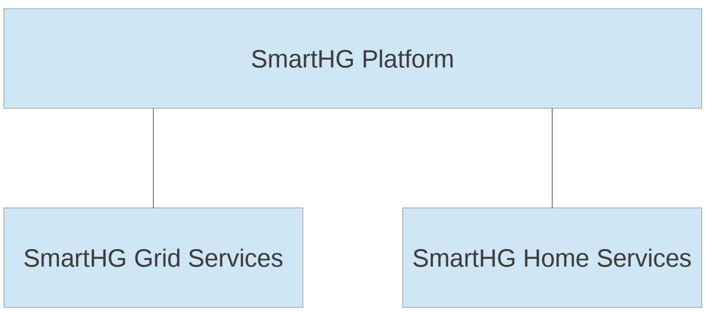


Figure 3.1: The SmartHG Platform and its main Services.

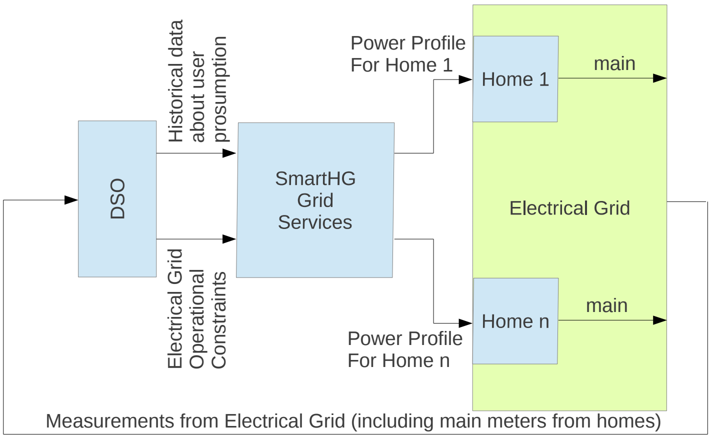


Figure 3.2: SmartHG Grid Services.

the communication infrastructure supporting open yet secure communication among such services (Section 3.1.3).

3.1.1 SmartHG Grid Services

SmartHG *Grid Services* (Grid Intelligent Automation Service (GIAS)) implement SmartHG platform top tier control loop whose role is that of supporting the DSO in keeping EDN hardware, in particular transformers, within its operational bounds. This, of course, depends on the energy demand. Accordingly, SmartHG Grid Services try to steer energy demand from residential users (by suggesting *power profiles* to follow) so that the resulting *aggregated demand* (i.e., the sum of the electricity demand from all residential users considered) drives EDN devices in such a way that EDN operational constraints are met. This is summarised in Figure 3.2.

SmartHG Grid Services attain their goals through three specific services:

- The EDN Virtual Tomography (EVT) service, supporting the DSO in computing operational constraints for each substation of interest.
- The Demand Aware Price Policies (DAPP) service, supporting the DSO in computing a *demand-aware power profile* for each user connected to a given substation.
- The Price Policy Safety Verification (PPSV) service, supporting the DSO in checking *robustness* of user power profiles with respect to user deviations, since power profiles are proposed to users that receive incentives to follow them, but are not directly enforced by the DSO.

In the following we shortly describe such services.

3.1.1.1 EDN Virtual Tomography

For each substation to be controlled by the SmartHG Grid Services, the DSO provides (to the SmartHG Grid Services) historical data about the aggregated energy demand at the substation. From such data and the EDN topology, the EVT service can estimate the EDN state also where sensors are not actually deployed. On such a basis, by simulating different EDN operational scenarios, the EVT service can suggest operational constraints for the substation of interest. EVT rests on the *PowerWorld* simulator (www.powerworld.com) to carry out its computations.

3.1.1.2 Demand Aware Price Policies

To ensure that a substation aggregate demand meets the constraints computed by the EVT service, we need that the electricity demand of each user connected to such a substation meets, in turn, suitable constraints.

The classical approach is providing a *global price policy* (e.g., defining low-price power bounds at each time slot) offering *incentives* to users that move away their electricity demand from peak times. Such a policy, besides the well known *rebounds* problems, may also unnecessarily compress the electricity demand. Furthermore, it may be hard to follow for users whose electricity consumption *habits* are far away from those entailed by the price policy. Using energy storage systems to automate *Demand Response (DR)* does not actually solve the problem, since a power profile quite different from that of the user requires a battery with a large capacity to be followed. This has the risk of making the approach not viable from an economic point of view.

To overcome such obstacles SmartHG approach is that of computing *demand aware* power profiles, so that each user gets a *power profile* (i.e., power bounds on each time slot) that is as close as possible to his/her current demand pattern. This basically minimises the battery capacity needed to follow such a power profile (i.e., it minimises the *flexibility* required to the user).

Given power constraints for a substation and historical data on user demand at the substation, the DAPP Grid Service computes, for each user connected to the substation, a power profile to follow for the next day. Accordingly, the DSO will run the DAPP service each day.

DAPP models the problem of computing *demand aware* power profiles as a *Mixed-Integer Linear Programming (MILP)* problem and rests on CPLEX (from IBM) to solve it. For a substation with a few hundreds of users, running DAPP on a Linux desktop computer takes just a few tens of seconds.

3.1.1.3 Price Policy Safety Verification

SmartHG Home Services will operate user home devices so that the power constraints provided to the user by DAPP are met. However a user may optimise energy storage management also with respect to to other goals, namely minimising energy cost (rather than just electricity distribution cost). It is well known that these may be conflicting goals. Accordingly, even with an automatic system as the one envisaged by SmartHG, user demand may deviate from the power profile suggested by SmartHG Grid Service DAPP. Accordingly, we need to make sure that, even if some user deviates from the DAPP proposed power profile, the aggregate demand does not exceed given safety constraints. This is done by the PPSV Grid Service by using *Statistical Model Checking* techniques to estimate the probability distribution of values for the aggregate demand power. PPSV computation is quite heavy and requires days of computations on a cluster of about two hundreds Linux cores. Fortunately, PPSV needs only to be run when a new set of residential users joins the system.

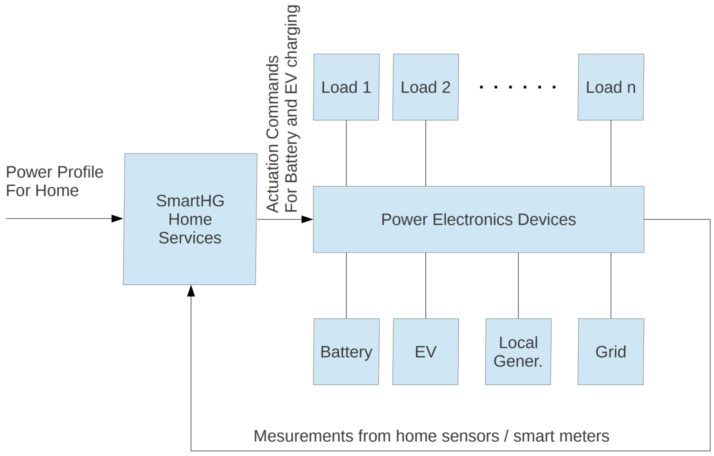


Figure 3.3: SmartHG Home Services.

3.1.2 SmartHG Home Services

SmartHG *Home Services* (Home Intelligent Automation Services, HIASs) implement SmartHG Platform bottom-tier control loop, whose role is that of supporting each residential user in following the power profile proposed by the DSO (and computed by the SmartHG Grid Services in our setting). The SmartHG platform is fully automatic from a residential user perspective. That is, no involvement is expected from the user. Home demand steering is achieved by controlling energy storage devices (such as batteries or Plug-in Electric Vehicles (PEVs)) at home premises. This is summarised in Figure 3.3.

SmartHG Home Services attain their goals through three specific services:

- The Energy Usage Modelling and Forecasting (EUMF) service, whose goal is to model user electricity consumption so as to provide (short term) forecasting on future consumption.
- The Energy Usage Reduction (EUR) service, whose goal to model home thermal behaviour so as to forecast (short term) electricity demand from electrical heating (namely, heat pumps in our case).
- The Energy Bill Reduction (EBR) service, whose goal to control charge and discharge of home energy storage devices so as to meet the time-dependent power constraints (the home *power profile*) provided by the DSO (and computed by SmartHG DAPP Grid Service).

In the following we shortly describe such services.

3.1.2.1 Energy Usage Modelling and Forecasting

Of course, effective planning of home energy storage charge/discharge requires forecasting of future energy needs for the home. We note however that the SmartHG Home Service (EBR) that controls energy storage devices is based on a *receding horizon* approach, and thus we only need a short time (a few hours) prediction on home energy demand, which is what EUMF provides.

3.1.2.2 Energy Usage Reduction

The EUR service takes as input data about home heat pump Coefficient of Performances (COPs) as well as sensor readings about home inside and outside temperature and heat pump consumption. Then, using the electrical analogy of heat conduction, EUR estimates thermal insulation and thermal capacity of the home. From such data, EUR then estimates the decay rate time of the home temperature. This, in turn, allows us to estimate when the heat pump will be turned on again thereby improving our estimation about future home energy demand.

3.1.2.3 Energy Bill Reduction

The EBR service takes as input: the power profile to be followed, energy costs, CO2 footprint of energy, economic values of CO2 emissions along with measurements from home sensors. Such measurements include: home main meter, status of batteries and PEV, local generation (if any). EBR returns a charge/discharge plan (for a few hours ahead) for the home storage devices. EBR rests on EUMF and EUR to a compute a short term (a few hours) forecasting of the home energy demand. EBR computes its actuation plan using a *receding horizon* approach thereby solving a MILP problem to compute the next charge/discharge action. EBR runs on a home device, namely Raspeberry PI in our project, thus we do not use CPLEX to solve the above MILP, but rather the GNU GLPSOL solver. EBR solves the MILP computing the next action within a few seconds on a Raspeberry PI.

Note that no data about home usage of appliances need to be sent outside the home in our two-tier approach. Indeed, once the power constraints from the DSO are received, SmartHG Home Services can work even without Internet connection (power constraints will not be updated then) making them, as a matter of fact, an *autonomous system*.

Experimentation with energy storage devices cannot be done at the home premises for economic as well as safety reasons. Accordingly, SmartHG uses a Micro grid to experiment with actuation. Namely, a dedicated test facility at IMDEA Smart Energy Integration Lab (SEIL) where: we drive Micro grid loads using data recorded from SmartHG sensors at home test-beds and we drive Micro grid batteries using data from PEV usage recorded from the Danish project Test-an-EV as well as EBR commands. This allows us to carry out experiments with actuation much as if we were in one of the homes in our test-beds equipped with a PEV and a battery.

3.1.3 SmartHG Communication Infrastructure

This section presents SmartHG communications infrastructure and shows the interactions between the home devices, Database and Analytics (DB&A), and DSO. Figure 3.4 shows the main building blocks of such an infrastructure. Home Area Network (HAN) transmits/receives metering/actuating data of the home devices to/from the cloud services via Internet connection. SmartHG services and the DSO access such data and analyse it.

Figure 3.5 shows a detailed deployment of the project main devices and its services. It shows how the interactions between the services and the devices are occurring and which communication technologies are using. For instance, a washing machine sends its power consumption measurements to the home ZigBee gateway. A Raspberry Pi based kit called Home Energy Controlling Hub (HECH) allows the gateway to communicate with the database via an internal server called SmartAMM (*Smart Advanced Management*

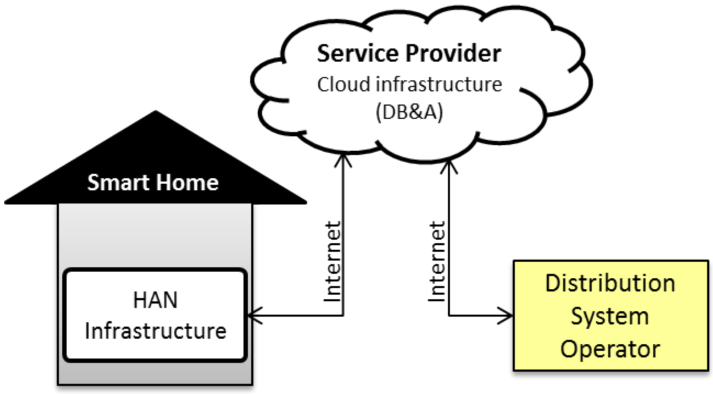


Figure 3.4: Communication infrastructure concept.

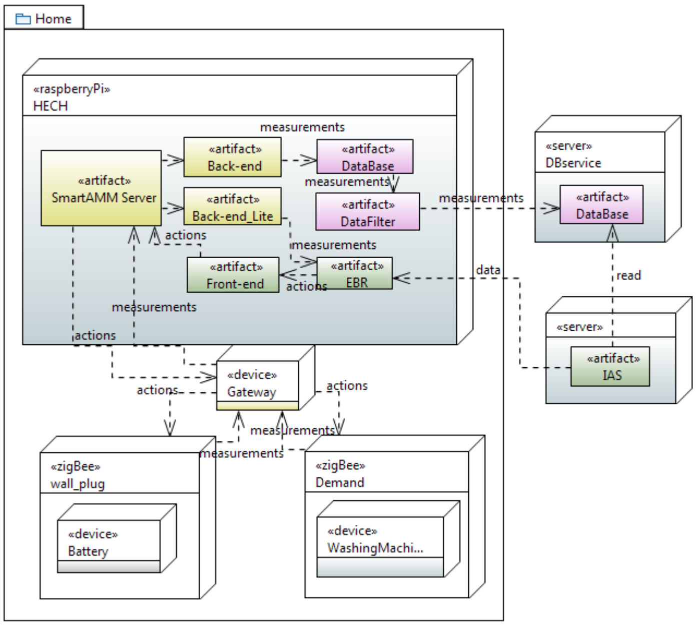


Figure 3.5: Deployment diagram of the communication infrastructure.

Module). The server is developed by SmartHG partner DEVELCO and it uses back-end tools to handle the received/transmitted data. In this project, we have developed a back-end to filter only the desired data and post them to the DB&A. Services such as EBR send actuating commands to the home devices (e.g., batteries) via the SmartAMM server.

3.1.3.1 Home Area Network

The HAN is a dedicated network connecting home devices. Within SmartHG, HAN devices are communicating with the SmartHG services via DEVELCO home automation middleware called SmartAMM. The SmartAMM Communication System consists of two core components: the *Communication Service Provider* (CSP) and the SmartAMM API (API). The CSP is handling the communication with the remote SmartAMM gateways, and the API library is used by both the CSP and optionally systems wishing to utilise the CSP. In the project, we have customised an API of the server backend to handle the

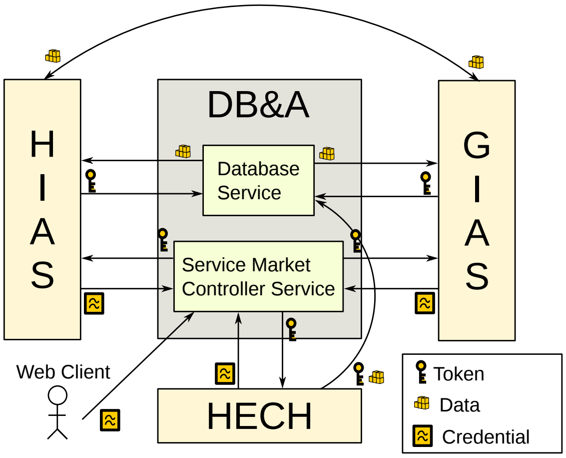


Figure 3.6: High-level representation of the communication paths for the access control and the data dissemination for the DB&A service.

metering home devices telegrams and post them to the DB&A.

3.1.3.2 Database and Analytics

Metering data represents the main asset for the stakeholders in a smart grid, and therefore it is crucial for the communication infrastructure how this is handled. In the SmartHG ecosystem, the DB&A is responsible for storing and disseminating metering data, while ensuring authentication and access control. The DB&A is divided into two REpresentational State Transfer (RESTful) web services: a SmartHG Market Controller (SMC) web service that is aware of service locations and verifies the authentication and authorisation; a database service that provides analytic views of the metering data.

This division allows the SMC service to act as a proxy for accessing services, and thereby making all other services exchangeable. Furthermore, it allows existing commercial partners in the energy metering sector to exchange data with the database service. Data obtained from proprietary solutions can be reused in our ecosystem, thus facilitating integration without breaking any proprietary constraints. For example, within SmartHG we have integrated within DB&A data from Panoramic Power sensors as well as from DEVELCO smart plugs.

Figure 3.6 illustrates the interconnection between the HECH, the SmartHG Home Services (HIASs) SmartHG Grid Services (GIASs).

The HECH is preloaded with a shared secret and the location of SMC service. It retrieves information about the location of the database service and gets a token, allowing it to post to the database service. Meta information (e.g., association between a submeter and an appliance) and metering data from the residential houses are posted to the database service through the RESTful API.

SmartHG Home and Grid Services are able to request access either directly to the raw metering data or by requesting analytic representations, e.g., consumption aggregation on substation level using the same token system as the HECH. Similarly, SmartHG Home and Grid Services can exchange data from each other through the SMC service authorisation system.

3.1.3.2.1 Service Market Controller The SMC is an authentication and authorisation server for three stakeholders of the system; the HECH that supplies the metering data to other services, the services that want to access each others' data, and the web clients accessing the services directly as seen in Figure 3.6. It is based on the OAuth2 authorisation framework with a shared authentication scheme built on top. The authorisation process between the client and resource service are carried over an established HTTPS connection with HTTP redirects. This increases both interoperability and horizontal scale by being RESTful compliant. The OAuth2 scheme only assumes the clients follow the HTTP protocol, thus facilitating both web browser clients and service clients to operate equally without extending it with additional client support.

Access delegation to the database service is based on self-contained tokens that are exchanged when the authenticity of the requesting client is verified by SMC service. The tokens define the scope of access and are time-limited. Expired tokens can be refreshed automatically within an expiration time set by its owner.

3.1.3.2.2 Database Service The database service is an exchangeable self-contained RESTful web service. It supports the operations and added value for the SmartHG Grid and Home Services by providing common analytic views of the measurement data. These include: 1) Aggregation views (e.g., weekly, monthly and yearly) of the consumption and production data on residential home level with a given time interval and granularity; 2) Data quality indicator on residential home level given a tolerance time span that detects missing data within a given time interval; 3) Interval filtering for time and value on meter port level; 4) Generation of condensed datasets on appliance level with a fixed sampling period.

The views are provided as RESTful representations on URI endpoints (e.g., https://dbservice.org/energy_consumption/), while the filtering capabilities are set through URI query parameters (e.g., https://dbservice.org/?key1=value1&key2=value2).

3.1.3.2.3 Implementation Considerations Both the SMC service and database service are implemented as Python-based web applications in the Django Web Framework and RESTful toolkit. The Python language allows for integration with existing open source web applications, and thereby shrinks development time, but it comes with a performance penalty. The slow performance is compensated by using Gunicorn (http://gunicorn.org) as web server for hosting the web application, and Nginx (http://nginx.org) as a reverse proxy for delegating the burden of processing the SSL/TLS encryption in HTTPS and delivering the static content. Nevertheless, processing the analytic views can be time consuming, thus, in order to avoid processing on-request, the database service has a background caching system that independently processes common views before they are requested (a sort of *speculative execution*).

3.1.3.3 Distribution System Operator

The DSO interacts with the SmartHG services through DB&A using the provided RESTful APIs. A customisation of the Common Information Model (CIM) is used to ensure interoperability between SmartHG services. The CIM is an open standard for representing power system components and networks and has been documented in the IEC 61970 series and the IEC 61968 series. The SmartHG infrastructure uses CIM to provide a data exchange format for service provisioning, hereby bridging the gap between the SmartHG

Test-bed	Sensor Measurements	Historical Measurements	Total
Kalundborg, 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**
Kalundborg, 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.

infrastructure and the Information and Communications Technology (ICT) systems running at DSO premises.

3.2 Test-Beds

In this section we provide some statistics about the data gathered from SmartHG test beds and describe the devices deployed in the participating homes.

3.2.1 Test Bed Data Analytics

SmartHG has gathered data from three test beds: Kalunborg (Denmark), Central District (Israel), Minsk (Belarus). In Kalunborg and Central District we installed sensors, whereas in Minsk we only gathered historical data. Table 3.1 shows the number of measurements gathered from our test beds.

We installed two kind of sensors: wireless self-powered current sensors from Panoramic Power, smart plugs and temperature sensors from Develco Products. All kind of sensors send their data to Internet through a gateway. Table 3.2 summarises the number of sensors and gateways installed.

Finally, Table 3.3 shows how many home appliances have been monitored in our test beds using the above mentioned sensors.

	Sensors categorised by producer and sensed appliance type							
	Develco Products	Panoramic Power						
Test bed	**Entertainment**	**Food Preparation**	**Heating and Cooling**	**Home Appliances**	**Lighting**	**Machinery**	**Miscellaneous**	**Main Meters**
Kalundborg, Denmark Total	62	87	36	48	0	0	0	75
Central District, Israel Total	0	22	87	47	33	6	19	85
Total	**62**	**109**	**123**	**95**	**33**	**6**	**19**	**160**

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

Figure 3.7: Develco Products Sensors and Gateways.

3.2.2 Hardware Devices

We provide a short description of the devices installed in our test beds.

Develco Products devices (see Figure 3.7) installed in our test beds comprise: a) Gateways enabling communication (via ZigBee) between smart plugs, sensors and Database and Analytics (DB&A); b) Smart Plugs, sending data (via ZigBee) to gateways, acting as meters (for current, voltage and power) as well as switches; c) User interface for turning on/off appliances through smart plug switches; d) Temperature sensors, sending data (via ZigBee) to gateways.

Panoramic Power devices (see Figure 3.8) installed in our test beds comprise: a) Sensors to monitor loads up to 63 Amperes, max cable diameter 7mm (PAN10 model); b) Sensors to monitor loads up to 225 Amperes, max cable diameter 17mm (PAN12 model); c) Bridges delivering energy information from the sensors every 10 seconds.

Figure 3.8: Panoramic Power devices.

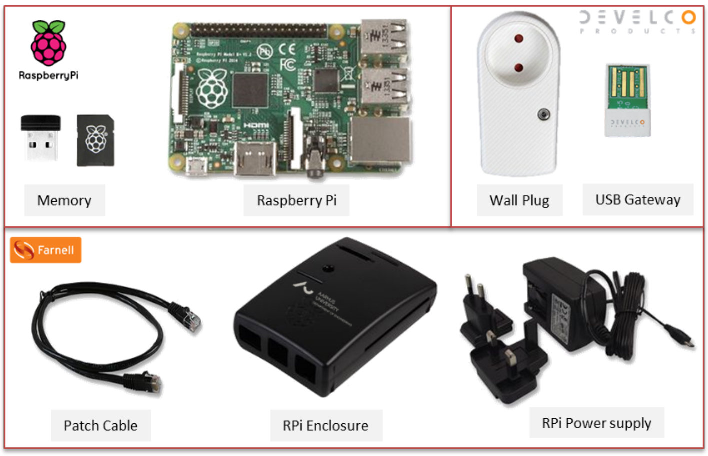


Figure 3.9: Home Energy Controlling Hub (HECH) kit

To enable communication between home devices and SmartHG open protocol architecture we developed a Home Energy Controlling Hub (HECH) kit (see Figure 3.9), consisting of: a) Raspberry Pi board; b) Develco Products Smart Meters (ZigBee devices and gateway); c) ZigBee gateway; d) USB stick; e) Internet cable; f) Power supply.

3.2.3 Sensor Interfaces

We outline the communication interface between SmartHG hardware devices collecting measurements in houses and the DB&A service enabling communication between SmartHG services and home devices.

Figure 3.10 shows the design of communication between Develco Products smart meters deployed in Kalundborg test bed and DB&A.

The smart meter interface provides the Echelon meters with ZigBee and Wireless M-Bus communication. The meter interface, so-called MEP card, is designed as a drawer that can be inserted in the meter by the user himself without involving any electricians or installation contractors. Echelon meters (see Figure 3.11) are already installed in all homes in the Kalundborg test area.

The heart of SmartHG home system is a gateway that handles the wireless ZigBee

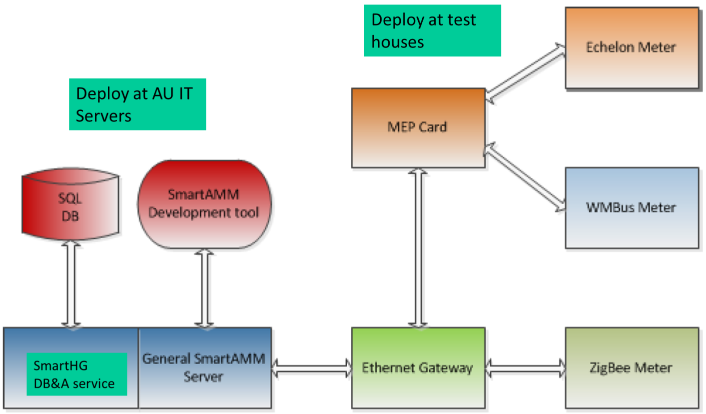


Figure 3.10: Database and Analytics (DB&A) and smart meters communication design.

Figure 3.11: Echelon main meter.

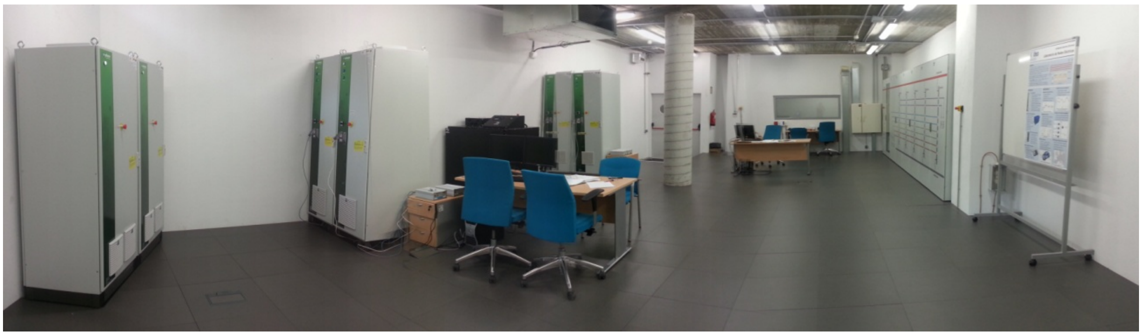


Figure 3.12: Smart Energy Integration Lab at IMDEA

network, controls devices, collects data, and transmits such data to DB&A from where the data are available to users. SmartHG 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.

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

The Home Energy Controlling Hub (HECH) acts as a gateway between ZigBee and the REpresentational State Transfer (RESTful) interface of DB&A. In the homes in which the HECH kit is installed, data will flow to DB&A through the HECH.

All data gathered by sensors and smart meters deployed in the SmartHG test-beds are stored in the theproject DB&A and are showcased in the Panoramic Power PowerRadar dashboard.

The Panoramic Power dashboard is used by both the home owners involved in SmartHG and the project partners to view the energy use of the individual homes monitored in the project test beds. Only users with private and secure username and password can log in to the Panoramic Power dashboard.

For this reason, we have created a public showcase in the project website, which contains some anonymised screenshots from the dashboard and general information about deployed hardware and test-beds data.

3.2.4 IMDEA Smart Energy Integration Lab

IMDEA Smart Energy Integration Lab (SEIL) has been used to carry out experiments with the SmartHG Home Services involving energy storage. Here we shortly describe such a facility.

The *Electrical Systems Unit* at IMDEA has created a test environment, Smart Energy Integration Lab (SEIL), specifically designed for research, development and testing of control algorithms in energy systems. This environment (see Figure 3.12) has the goal of accelerating the process of designing systems connecting energy resources to electricity networks.

The approximate lab capacity for power processing is 210 kVA and it is formed by a set of power electronics converters, resistive loadbanks, a 47 kWh battery system, distribution panels and monitoring and control systems. This platform allows analysis, development and testing of realistic scenarios for energy integration in both AC and DC networks and

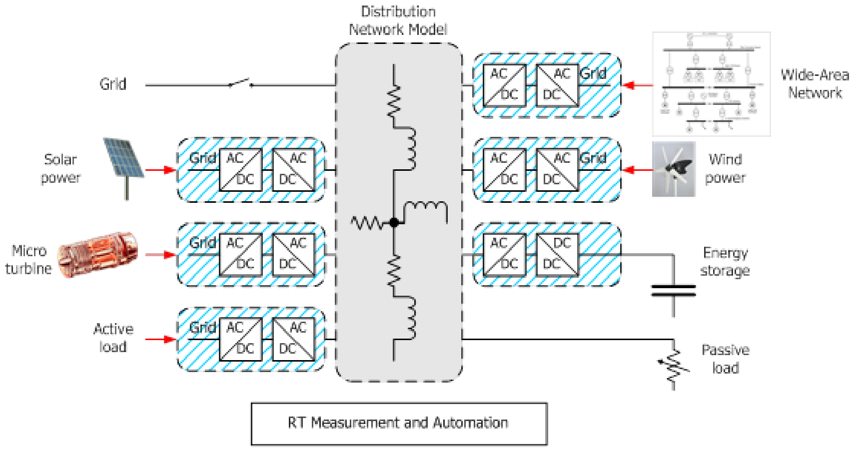


Figure 3.13: Smart Energy Integration Lab at IMDEA.

also operation of distribution power networks, islanded networks and microgrids. The results obtained from this test environment are more reliable and accurate than any model based computer simulation. What distinguishes this laboratory is its flexibility in implementation of control algorithms and simple access to all test and management data from any part of the network. The lab microgrid is capable of recreating a large number of different events that occur in 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.

The SEIL consists of (see Figure 3.13): a) four 15 kVA three-phase power inverters; b) two 75 kVA three-phase power inverters; c) industrial PCs with RT operating systems; d) two 30 kW balanced and unbalanced, programmable resistive loadbanks; e) a 47.5 kWh Li-Ion battery system with BMS; f) a 90 kW bidirectional, wide bandwidth, programmable battery charger; g) distribution panels with 5 independent busbars and contactor control; h) independent monitoring and control system.

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.

3.3 Main Achievements

3.3.1 Optimising EDN Operations

The main goal of SmartHG Grid Services is to optimise Electric Distribution Network (EDN) operation by:

- Supporting the Distribution System Operator (DSO) in computing a *power profile* (i.e., lower and upper limits to the average power in each 1-hour time slot) for any EDN substation, so that operation of the whole EDN is optimised.
- Supporting the DSO in computing a *power profile* for each residential user so that in each time slot the aggregate demand of all users connected to a given substation is within the substation power profile computed above.

In this section we outline the operational benefits provided by SmartHG to the EDN (and thus to DSOs), whereas the following sections will focus on the economic benefits provided by SmartHG to electricity retailers, residential users as well as on the environmental benefits (namely, reduction of CO2 emissions) provided to the society as a whole.

3.3.1.1 Grid Scenarios

In order to evaluate the individualised price policy approach and the SmartHG Grid Services and to demonstrate the potential benefits to the DSO, a number of scenarios were developed. These used recorded smart meter data from the Kalundborg test bed, along with information from a SEAS-NVE demand flexibility study, and a Danish study on Plug-in Electric Vehicle (PEV) integration (https://www.clever.dk/test-en-elbil). These scenarios apply both “global" and “individualised" price policies to each of the 1400 residential users connected to the Kalundborg Medium Voltage (MV) network and compare the results in terms of the ability of each Time of Usage (ToU) price policy to reduce demand peaks and improve the network load factor (e.g., the overall ratio of average demand to maximum demand).

It should be noted that, even with very strong price ToU incentives for demand-shifting, such as those used in the SEAS-NVE study, the amount of demand flexibility from residential users is limited.

However, two technologies which are expected to grow significantly and influence future electricity distribution networks, electricity storage and PEVs, are also examined in the scenarios. Energy storage technologies offer much greater possibilities for shifting the electricity demand, and it is widely expected that the cost of such technologies will continue to decrease in the near future, making storage accessible to a wide range of users, including domestic consumers. In addition, PEVs can significantly alter the demand profiles, and create significant congestions in the EDN if not managed appropriately.

Hence, scenarios have been developed in which the residential homes are equipped with batteries and PEVs, allowing us to examine potential future scenarios with greater user flexibility in response to ToU pricing. The final scenarios used in the analysis are provided below.

- **Base Case** The results calculated using the actual recorded data from the network for the two-year period from September 2012 to September 2014. All users received a fixed (i.e., flat) electricity price during this period.

- **Scenario 1a** All residential users in the case study network from SEAS-NVE receive the same ToU price designed to shift demand away from the peak hours (i.e., a “global” price policy). Households do not have energy storage or PEV.
- **Scenario 1b** All residential users receive the individualised ToU price policy proposed by the Demand Aware Price Policies (DAPP) service. Households do not have energy storage or PEV.
- **Scenario 2a** All residential users receive the same “global" ToU price policy designed to shift demand away from the peak hours. 50% of the households (randomly-selected) are equipped with both energy storage in the form of a Tesla PowerWall battery (with 7 kWh capacity and 2 kW power rate). and a PEV (with 16 kWh capacity and 13 kW power rate). The PEV data used in this study was taken from actual vehicle charging data from the “Test-an-EV” Danish project.
- **Scenario 2b** All residential users receive the individualised ToU price policy proposed by the DAPP service. 50% of the households (randomly-selected) are equipped with both energy storage and a PEV as in Scenario 2a.

The results have shown that the use of global Demand Side Management (DSM) price policies can cause synchronisation of user demand patterns, reducing load diversity and creating undesirable “rebound” effects. It was shown that the individualised price policy approach proposed in SmartHG has several advantages over a global policy approach, in that it can reduce the magnitude of the demand peaks, and flatten the overall system demand profile. Some of the practical benefits of this are simulated in a distribution network operations context, where it was shown that the individualised price policy can increase the load factor, and improve voltage and line loading conditions, and reduce network losses, compared to a global DSM price signal.

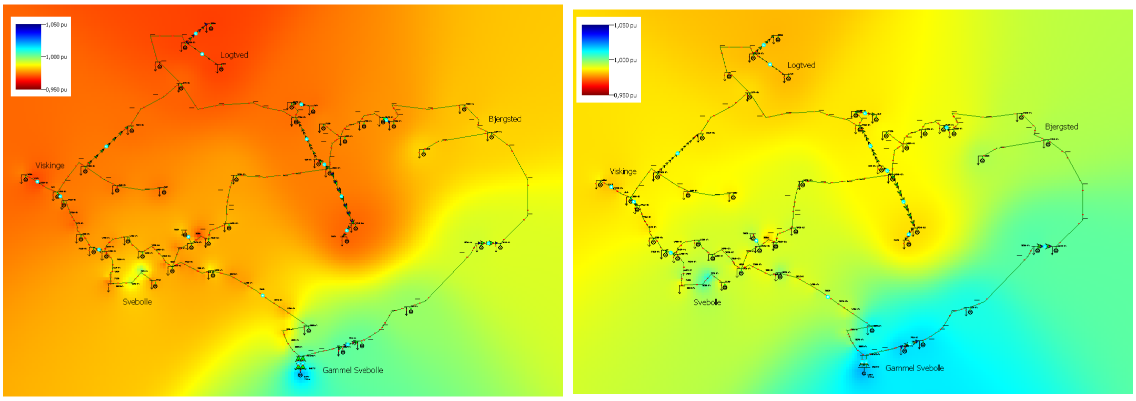
3.3.1.2 Supporting Grid Configuration

SmartHG Grid Services can support (through the state estimation features provided by the EDN Virtual Tomography (EVT) service) the DSO operator managing the EDN. This will be illustrated with an example from our Kalundborg test bed.

One of the scenarios simulated showed a low voltage issue at the most electrically distant part of the Kalundborg network (Logtved). According to the EU standards for public distribution systems (EN50160 and EN61000), voltage magnitude limits throughout all points in the Low Voltage (LV) and MV networks should remain within ±10% of nominal (taken as 10-minute average of the Root Mean Square (RMS) voltage). There are also other specific limits around temporary under- and over-voltages that are not considered here.

Due to the fact that there may be a considerable voltage drop along LV feeders, particularly on long lines in rural areas, the DSO may wish to tighten the limits at the feeder head, or secondary (10:0.4kV) substation to e.g. ±3%, since voltage is generally worse at the feeder extremities. In general, the DSO will set nominal voltages higher than $1.0 p.u.$ particularly at full-load, in order to provide more headroom for voltage drop and to reduce network RI^2 losses. In this example, the primary substation voltage set-point is $V = 1.02 p.u.$ and tap ratio is 1.0125 (+2 taps).

Figure 3.14a shows the PowerWorld Simulator output for the above described scenario, where low voltages occur in parts of the network which are further from the primary



(a) Before corrective actions. (b) After corrective actions.

Figure 3.14: EVT technical evaluation (Kalundborg scenario).

substation. The warnings/alarms and corrective actions generated by the EVT are given below:

- **Warning/alarm**: Voltage below 0.97$p.u.$ at Bus 46, Bus 47 and Bus 48.
- **Recommendation**: Adjust transformer taps at primary transformer (50:10kV) by +2 $(2 * 0.00625)$ to increase voltage throughout the network.

Figure 3.14b shows the PowerWorld Simulator output for the above described scenario, after the corrective action recommended by EVT has been taken, where the voltage has reached a normal level throughout the system.

3.3.1.3 Increasing Demand Load Factor

Effectiveness of the attained peak shaving is typically measured using the *load factor*, that is the ration between the average aggregated demand and its peak value. The greater the load factor the flatter the demand.

Our simulation results on the considered scenarios show that SmartHG individualised price policies can improve the load factor up to 18% with respect to the flat price policy case and up to 35% with respect to the global price policy case. This shows that indeed a global price policy, because of rebounds, can worsen the situation. Below we provide further details.

The aggregate load factors, calculated across all residential customers, are provided in Tables 3.5 and 3.6. These were calculated for typical “Winter peak" and “Summer minimum" days, and also for the “overall" case, which calculates the total load factor over the two years of the simulation.

The global price policy (Scenarios 1a and 2a) increases the magnitude of demand peaks, reducing load factors, whereas the individualised price policy flattens the demand profiles and increases load factors (Scenarios 1b and 2b).

The load factors in the “Overall" case (final rows of Tables 3.5 and 3.6) are much lower than the Winter peak/Summer minimum day cases, since the “Overall" values represent the average load factor calculated over the entire two year period, considering all of the seasonal variations during this time.

Scenario	Price policy	PEV	Energy Storage System (ESS)
Base Case	flat rate	No	No
1a	global	No	No
1b	indiv	No	No
2a	global	50%	50%
2b	indiv	50%	50%

Table 3.4: Scenarios characteristics summary.

Load Factor	Base Case	Scenario 1a	Scenario 1b
Winter Peak	0.7054	0.6164	0.8017
Summer Min	0.6205	0.5794	0.6257
Overall	0.3327	0.2897	0.3933

Table 3.5: Scenario 1 Aggregated Load Factors.

Load Factor	Base Case	Scenario 2a	Scenario 2b
Winter Peak	0.7116	0.6176	0.8124
Summer Min	0.5927	0.5280	0.7038
Overall	0.3471	0.3084	0.4415

Table 3.6: Scenario 2 Aggregated Load Factors.

This increase in load factors due to the application of individualised price policies would have clear benefits for the DSO. This would reduce the amount of energy to be purchased from the wholesale market during expensive peak hours, and the flatter load profiles would result in less instances where the network is overloaded, potentially reducing network maintenance and upgrade costs and allowing deferral of network investments.

3.3.1.4 Reducing Network Low Voltage Violations

In our distribution network case study voltages lower than 0.97 are recorded as voltage violations. High voltage events are not considered in the study, nor are events involving network faults and planned/unplanned outages, which would affect the voltage profiles. Voltage violations are summarised in Table 3.7. These results show that several voltage violations occur in both the Base Case and Scenario 1a and 2a (global price policy) cases. These low voltages occur during time of peak loading, in the parts of the network with the greatest electrical distance from the primary substation. In the individualised price policy simulations, Scenarios 1b and 2b, there were no violations, due to the reductions in peak loading.

No. Low Voltages (> 0.97 $p.u.$)	Base Case	Global Price Policy	Individual Price Policy
Scenario 1	2	2	0
Scenario 2	2	2	0

Table 3.7: Summary of Low Voltage Violations.

No. Overloads (> 100 %)	Base Case	Global Price Policy	Individual Price Policy
Scenario 1	3	6	0
Scenario 2	3	18	2

Table 3.8: Summary of Line Thermal MVA Limit Violations.

3.3.1.5 Reducing Line Thermal MVA Limit Violations

The impacts on power flows throughout the MV network were also analysed. Table 3.8 shows the results for the number of overloads (MVA flow > 100 % of line rating) in each case. We can see that SmartHG individualised price policy approach considerably reduces the number of limit violations (that can actually increase when using a global price policy).

3.3.1.6 Reducing Network Line Losses

Simulation based analysis of the total losses in the MV test case network shows that the individualised power profiles from SmartHG Grid Services produce between 1.5% and 2.3% lower line losses than those of the global price policy case.

3.3.2 Reducing Electricity Costs and CO2 Emissions

In this section we present (Low Voltage) substation level evaluation results on using SmartHG services to reduce: residential user demand peaks (Section 3.3.2.2), electrical energy costs (Section 3.3.2.3), CO2 emissions (Section 3.3.2.4). Finally, Section 3.3.2.5 presents results on combining such possibly conflicting objectives. Section 3.3.2.1 outlines the scenarios we will be considering.

3.3.2.1 Residential User Scenarios

Table 3.9 shows some relevant data about our three test beds: Kalundborg, Central District and Minsk.

In our evaluation we use, as day-ahead electricity prices, those from DK2 area of Nord Pool Spot (http://www.nordpoolspot.com) in all test beds, thus simulating the condition in which all users from our test beds are in Denmark (but have different electricity demand patterns from those in Kalundborg). This allows us to evaluate SmartHG services on user demand with different profiles. To each home in our test beds, we add to the electricity

	Kalundborg	Central District	Minsk
Number of households	186	18	268
Average electricity demand (MWh)	7.78	8.44	4.91
Average historical energy cost (EUR/MWh)	102.70	77.54	88.61
Average battery capacity per MWh of annual consumption (kWh/MWh)	0.71	0.28	0.15
Average battery power rate per MWh of annual consumption (kW/MWh)	0.16	0.06	0.04
Average battery amortised (over 10 years) cost per MWh of annual consumption (EUR/MWh)	9.60	3.77	2.04

Table 3.9: Summary data about our test beds.

Configuration ID	Description
BU	Home Battery, PEV at home can only be charged and charge is not controlled by SmartHG services.
BC	Home Battery, PEV at home can only be charged and charge is controlled by SmartHG services.
BD	Home Battery, PEV at home can be charged and discharged and both are controlled by SmartHG services.
PC	No home battery, PEV at home can only be charged and charge is controlled by SmartHG services.
PD	No home battery, PEV at home can be charged and discharged and both are controlled by SmartHG services.

Table 3.10: Energy storage configurations considered in our evaluation for electricity cost reduction.

consumption data the electricity consumption due to one of the PEVs from the data gathered through the Danish project *Test-an-EV* (https://www.clever.dk/test-en-elbil). Table 3.9 shows the average (over one year, among test bed households) energy cost per MWh.

For each home, battery capacity and power rate are computed by the SmartHG Home Services (namely, Energy Bill Reduction (EBR)) so as to maximise user saving on energy cost. Table 3.9 shows capacity, power rate and amortised (over 10 years) cost per MWh of annual consumption chosen by EBR for the batteries to be installed in the average home of our test beds.

For each test bed, we consider five energy storage configurations as outlined in Table 3.10. Note that scenarios BD and PD in Table 3.10 both use PEV as a *home energy storage* device (e.g., as in the project Storage4All http://www.smartgridrendement.nl/nieuwe-diensten/dienst-7).

3.3.2.2 Reducing Demand Peaks

The benefits provided to the grid by SmartHG distributed control (through individualised power profiles) have been described in Section 3.3.1. The objective of this section is to compare SmartHG distributed control approach with a centralised one.

We measure the congestion level of a given substation through the *substation utilisation factor*, defined as the ratio between the annual aggregate energy demand from users and the maximum energy that the substation can provide in one year without ever exceeding its nominal power.

The following figures show statistics about effectiveness of SmartHG Grid Services.

Figure 3.15a shows how the peak shaving effectiveness changes with the substation utilisation factor. For each substation utilisation factor value considered we have a group of 3 vertical bars. The first bar in each group shows historical data about the percentage of annual energy consumption that *exceeds* the substation power limit (*peak energy percentage*). The second bar in each group shows the same data when SmartHG Grid Services are used to manage user demand in order to keep, as much as possible, the substation power level below its nominal value. Finally, the third bar in each group shows the same data when centralised storage (with capacity and power rate equal, respectively, to the sum of capacities and power rates of the energy storage devices installed at homes) is used to flatten the aggregated demand. Although a distributed storage approach has many advantages with respect to a centralised one (e.g., a *pay-as-you-go* schema is possible and there is no *single-point-of-failure*), it will always be less efficient than a centralised one. From Figure 3.15a we can see that, as for flattening user demand, thanks to the control strategy provided by SmartHG Grid Services, SmartHG distributed storage is only slightly less effective than a centralised energy storage approach.

Another measure of effectiveness worth considering for peak shaving approaches based on distributed storage is the *peak shaving capacity*, that is the ratio between the energy moved away from the peak and the storage capacity used to achieve such a peak shaving. Comparing peak shaving capacities of different approaches tells us how effectively the available storage is used. This is modelled by the *peak shaving efficiency*, that is the ratio between the peak shaving capacity when using SmartHG and (as a reference) the peak shaving capacity when using centralised storage (as described above).

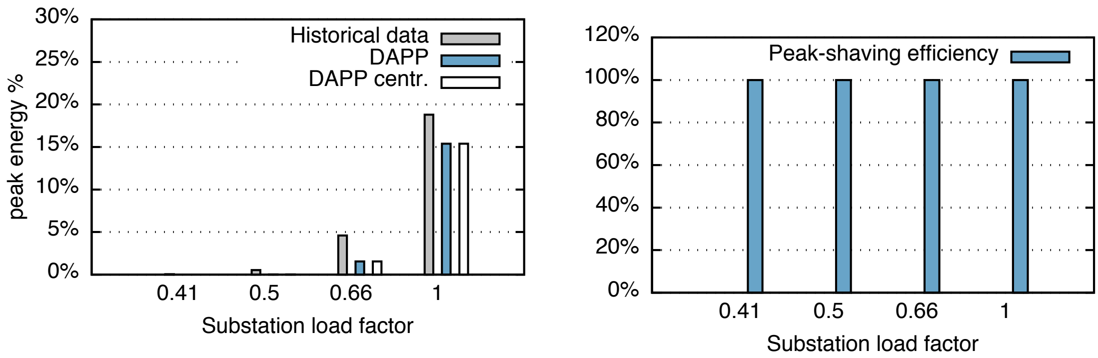
Figure 3.15b shows the peak shaving efficiency attained under 4 different values for the substation utilisation factor. It can be observed that in all cases the achieved peak shaving efficiency is about 1, which means that, as for storage use, the SmartHG distributed storage approach is basically as effective as a centralised energy storage approach.

3.3.2.3 Reducing Electrical Energy Cost

In this section we summarise the economic benefits enabled by the SmartHG Home Services technology.

The SmartHG platform enables saving on the energy costs by leveraging on price differences during the day. That is, we can buy electricity when its price is low, store it and then use it when the electricity price is high (*arbitrage*).

Using the day-ahead electricity prices for the Denmark (DK2) market from the Nord Pool Spot (http://www.nordpoolspot.com/) we can compute electricity costs from our historical data. Figure 3.16 shows the percentage saving on energy cost provided by SmartHG Home Services.



(a) SmartHG peak shaving effectiveness wrt. a centralised approach.

(b) SmartHG peak shaving efficiency.

Figure 3.15: SmartHG distributed energy storage approach vs. a centralised approach.

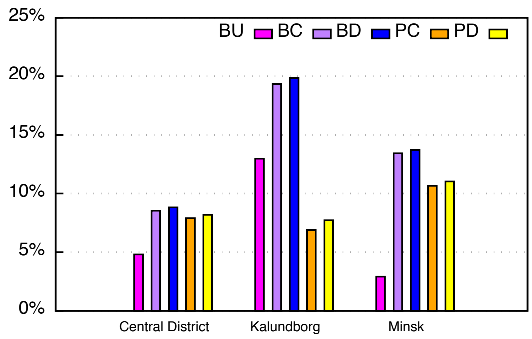


Figure 3.16: Average percentage reduction on energy cost enabled by SmartHG Home Services for all the 5 home storage configurations in our test beds.

3.3.2.4 Reducing CO2 Emissions

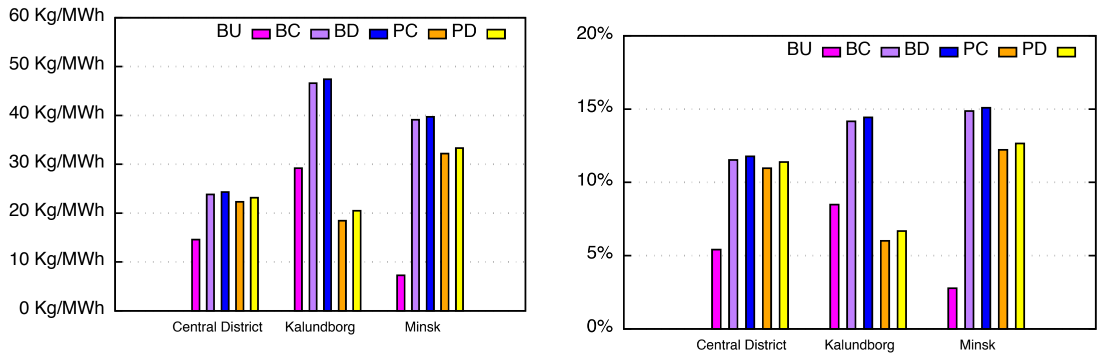
Using SEAS data for Denmark market, we can compute CO2 emissions from historical data. On such a basis, in this section we summarise the environmental benefits provided by the SmartHG Home Services technology for each home storage configuration in Table 3.10.

Figure 3.17a shows the average (among all test bed users) reduction in CO2 emissions for each MWh of annual electricity consumption provided by SmartHG Home Services. Figure 3.17b shows the average (among all test bed users) percentage reduction in CO2 emissions provided by SmartHG Home Services.

3.3.2.5 Pursuing Peak Shaving along with Energy Cost reduction

This section describes effectiveness of SmartHG services in pursuing the following conflicting objectives: flatten the energy demand according to the requirements received by the SmartHG Grid Services, decrease energy cost (by using energy when it is less expensive) reduce CO2 emissions (by using energy when its production requires less CO2).

Figure 3.18a shows effectiveness (with respect to the substation utilisation factor) of SmartHG Home Services in attaining peak shaving. For each substation utilisation factor value considered, we have a group of 7 bars. The first bar shows the percentage of peak energy when SmartHG is not used (i.e., historical data). The second bar, shows



(a) Average CO2 emission reduction per MWh of annual household electricity consumption.

(b) Average percentage CO2 emission reduction.

Figure 3.17: Statistics about CO2 emission reduction for each scenario in our test beds.

the percentage of peak energy when SmartHG Home Services only pursue the objective of flattening energy demand. The remaining 5 bars show the percentage of peak energy when SmartHG Home Services take into account all objectives (flattening energy demand, minimise energy cost, minimise CO2 emissions) under the 5 home storage configurations described in Table 3.10.

Figure 3.18b shows effectiveness (with respect to the substation utilisation factor) of SmartHG Home Services in reducing electrical energy cost when also pursuing the goal of keeping demand within the power profile provided by SmartHG Grid Services (namely, DAPP). We focus on scenarios where the substation is moderately-to-heavily loaded (namely, utilisation factor having values 0.66 and 1). For each considered substation utilisation factor value we have a group of bars showing the average percentage reduction on energy cost (thanks to *arbitrage*) provided by SmartHG Home Services for our 5 home storage configurations.

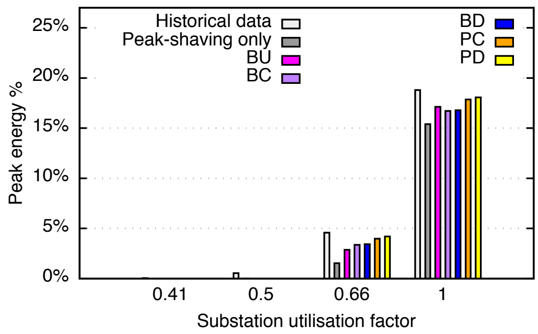
Comparing Figure 3.18b with Figure 3.16, we see, as to be expected, that pursuing also the objective of meeting power profiles (from DSO) decreases the saving on energy cost. This gives also a way to estimate the *incentives* the DSO should offer to residential users in order to motivate them in using SmartHG Home Services to follow the power profiles provided by the DSO (through DAPP).

Figure 3.18c shows effectiveness (with respect to the substation utilisation factor) of SmartHG Home Services in reducing CO2 emissions. For each utilisation factor value considered, we have a group of bars showing the average CO2 emissions (kg) per MWh of annual consumption, as entailed by SmartHG (when taking into account all objectives), for our 5 home storage configurations.

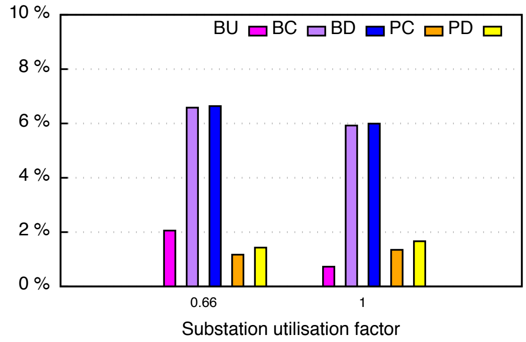
Finally, Figure 3.18d shows the average percentage of CO2 emissions reduction as entailed by SmartHG (when taking into account all objectives), for our 5 home storage configurations.

3.3.3 Openness and Security

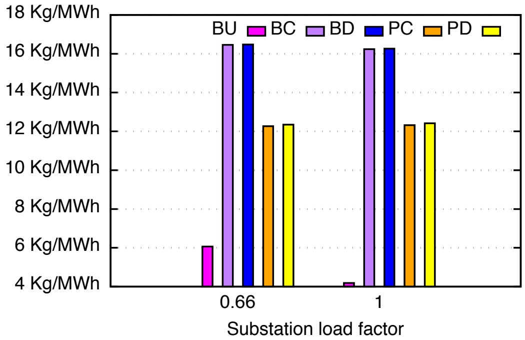
SmartHG relies on open as well as secure protocols to support communication among SmartHG subsystems, services as well as to interface with external systems. In this section we shortly outline the main achievements as for SmartHG communication infrastructure.



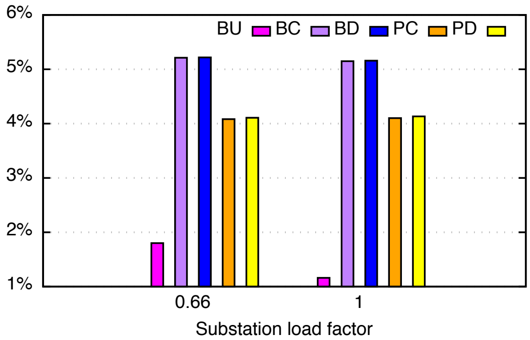
(a) Peak shaving provided by SmartHG services.



(b) Average percentage energy cost reduction provided by SmartHG Home Services.



(c) Reduction of CO2 emissions entailed by SmartHG Home Services.



(d) Percentage reduction of CO2 emissions entailed by SmartHG Home Services.

Figure 3.18: Pursuing peak shaving along with energy cost and CO2 emissions reduction using SmartHG services.

3.3.3.1 Communication Between SmartHG Services

An open protocol supporting communication among SmartHG intelligent automation services have been designed. Such a protocol includes a *Service Market Controller* (SMC) Service to support security policies for all SmartHG intelligent automation services.

3.3.3.2 User Data Storage

Data storage is supported through SmartHG Database and Analytics (DB&A) service. Accordingly, data from sensors are stored in DB&A. DB&A open interface allows us to store data from sensors of different kind and from different companies (e.g., Panoramic Power and Develco in our test beds). DB&A allows SmartHG services to access data through an open REpresentational State Transfer (RESTful) interface. DB&A addresses security and privacy issues by using an access control system compliant with the *Service Market Controller* (SMC) service using *JSON Web Tokens* (JWTs) in the authorisation procedure in the *OAuth 2.0* (OAuth2) protocol.

3.3.3.3 Communication with the DSO

Communication with the DSO is implemented using the *Common Information Model (CIM)*. CIM is a powerful overall integration framework, which has historically grown and continuously improved in order to meet the latest requirements from DSO. CIM models have been developed to handle the communications between DSOs and SmartHG services in a standard manner. The model follows IEC 61968 standard and shows the data and message exchange models.

3.3.3.4 Home Energy Controlling Hub

SmartHG home device to store data and manages sensors and actuators is the *Home Energy Controlling Hub (HECH)*. SmartHG HECH consists of a Raspberry PI running Linux that hosts a local (home) version of the DB&A and implements all the protocols needed to support secure communication with SmartHG services. Using the HECH a residential user may keep storing data from sensors while at the same time preventing unauthorised accesses to such data.

3.3.3.5 Interfacing Home Devices

SmartHG provides a specific open service, named *DBservice*, to support secure communication through with home devices (e.g., sensors and actuators). Shortly, *DBservice* on one side allows home devices to securely store data in the HECH and on the other side allows SmartHG services (who have the right to do so) to exchange data with the HECH. We note that remote access to the HECH is carefully controlled within SmartHG, since unauthorised access to the HECH from outside may allow reading of the user energy data, modification of such data and even modification of the control policies running on the HECH.

Chapter 4

Potential Impact, Main Dissemination Activities and Exploitation of Results

4.1 Potential Impact

In this section we outline the potential impact of the technology developed within SmartHG project. We focus on impact towards residential electricity prosumers, Distribution System Operators (DSOs), electricity retailers, Information and Communications Technology (ICT) companies, the whole society, and the environment.

4.1.1 Impact Towards Residential Electricity Prosumers

Although sensing and actuation technology supporting Demand Response (DR) is widely available, only big electricity consumers (such as commercial or industrial users) can indeed take advantage of it by saving on their electricity costs.

SmartHG makes DR economically viable also for residential electricity users, by enabling them to provide *peak shaving* and *arbitrage* services to, respectively, DSOs and electricity retailers. This is attained by coordinating electricity demand from residential users, so that their *combined impacts* on the Electric Distribution Network (EDN) adds-up (since none of them would have any alone) in order to effectively provide the requested service. DSOs and electricity retailers will then pay for such a service with discounts on the electricity distribution and/or energy tariffs.

Data gathered from our test-beds show that adoption of the SmartHG approach can yield to residential users an annual saving on electricity costs from 6% to 8%, depending on how much the DSOs *needs* a peak shaving service. Note that such a gain comes in a *transparent* way to the residential user, that is no change of habits is required.

4.1.2 Impact Towards DSOs

DSOs agree that the widely expected higher diffusion of PhotoVoltaic (PV) technology, Plug-in Electric Vehicles (PEVs) and heat-pumps will stress the EDN and will call for increased EDN capacity in the mid-term. This in turn will make new investments on the grid necessary. A centralised approach (e.g., energy storage at the substation level) is not always feasible because of economic (high upfront cost with uncertain future demand to pay it back), physical (space, positioning, etc. may be issues) and, last but not least, regulatory (it is not always possible to place a storage system on the network) issues.

The SmartHG project offers a distributed control approach to residential user demand where home energy storage systems are managed from SmartHG services in order to support self-consumption (e.g., from PV) and provide a *peak shaving* service to the DSO as well.

This benefits residential users (as seen in Section 4.1.1) and helps DSOs in meeting future electricity distribution demand without violating the EDN operational constraints, thereby deferring grid investments.

Data gathered from our test beds show that the benefits provided by SmartHG individualised price policy technology to the EDN, and thus to the DSO, are: 1) increase of the *demand load factor* of more than 18% with respect to a flat price policy and of more than 35% with respect to to a global price policy (because of *rebounds*), thereby providing a *peak shaving* effect considerably better than the one offered by a *global* price policy; 2) reduction of low voltage violations in the grid; 3) reduction of network line thermal MVA limit violations; 4) reduction of network line losses (e.g., of about 2% with respect to a global price policy).

4.1.3 Impact Towards Electricity Retailers

The recent liberalisation occurred in many EU countries in the residential electricity market is producing an ever-growing competition among electricity retailers. Such a competition rests on two main pillars: competitive tariffs and innovative energy services offered to the residential users.

The adoption of the SmartHG Platform allows electricity retailers to achieve a competitive advantage on both such pillars.

SmartHG allows retailers to exploit home-deployed batteries to reduce energy costs leveraging on energy price (*arbitrage*) and by trading reduction of CO2 emissions. This, in turn, allows them to offer competitive electricity tariffs to their customers (thus fostering increase of their market share) and also to increase their returns.

Data gathered from our test-beds show that adoption of the SmartHG platform can yield to electricity retailers a reduction in the energy cost ranging from 3% to 19%.

4.1.4 Impact Towards ICT Companies

One of the main features of SmartHG service-based architecture is the *openness* of the service interfaces. SmartHG services in fact interact using *open protocols* with a REpresentational State Transfer (RESTful) interface. This enables composing services to create new services and promotes an open market of energy services that ICT companies can develop in a synergistic way, well beyond those developed in the SmartHG framework. Taking also into account the ongoing processes to standardise communication with home devices, we think that SmartHG open protocol approach will foster a market of energy related ICT services, thereby creating new opportunities for (old and new) ICT companies.

For example, along those lines, Aarhus University is in the process of creating a start-up based on the device (HECH) they developed within the SmartHG project, whereas SOLINTEL has opened a company in Hongkong China (CNES International) focusing on Smart grid and energy efficiency.

While being based on open protocols, SmartHG architecture guarantees security of data, since energy data are a precious source of information about users. Indeed, companies offering smart sensors and home automation hardware are already collecting such data, as such devices typically upload energy data to their private clouds. The result is that users do not precisely know which of their personal energy data is disclosed and for which purpose.

The SmartHG approach enables an open and secure market for energy data of residential users. Energy data are stored securely in the Home Energy Controlling Hub (HECH) at home, under the full control of the residential users. Users can decide which of their data to disclose (via SmartHG open protocols) to which service provider, by exploiting SmartHG secure data access policies. Indeed, such an energy data market is a key enabler for the energy service market discussed above. In fact, development of new energy services by composing and building on existing services relies, among other things, on the possibility of implementing data access policies that adequately protect user ownership of energy data.

4.1.5 Environmental Impact

Resting on SmartHG technology, electricity retailers can manage home storage devices (home batteries and PEV in our test-beds) to save on energy costs by buying energy when its price is low and by trading reduction of CO2 emissions (by buying electricity when its CO2 footprint is low). As a result, pulling (*virtually*) together demand from many residential users, besides the economic benefits the electricity retailer may also provide a benefit for the environment and for the whole society.

Data gathered from our test-beds show that using SmartHG technology allows a reduction in CO2 emissions ranging from 3% to 15%, depending on the scenario considered.

4.1.6 Impact Towards the Whole Society

Besides, of course, the environmental impact outlined in Section 4.1.5, we see the following benefits for the whole society: employment opportunities and energy efficiency awareness for citizens.

As for *employment opportunities*, we note that SmartHG open services will foster the development of new services building on those available. We expect that this will lead to the creation of many new jobs in the ICT and energy sectors.

As for *energy awareness*, we note the following. SmartHG test beds consists of 44 homes (in Kalundborg and Central District) along with 268 apartments in Minsk. About one thousand citizens where involved in such test-beds. Through such an experience, many of them gained awareness of SmartHG technology and, more in general, of the energy efficiency issues driving the ICT for the energy sector. This happened through our reports sent by email as well as through private conversations. We think that such an awareness is important in order to keep citizens somehow acquainted with the energy research agenda and of the motivations behind it.

More specifically, resting on SmartHG experience, Kalundborg Municipality has increased its competences in supporting projects as a demonstration site (in Svebølle) supporting public and utility services in villages and rural districts. Indeed, Smart Village Svebølle is now a reality. Three other projects are now using Svebølle as a living Lab: Lighting Metropolis (Danish project), URB GRADE (FP7), and a third project funded directly by SEAS-NVE, establishing an LP-WAN network to monitor energy usage. In the end, participating in the SmartHG project has given to Kalundborg Municipality valuable competences, that will be used in planning the future of the Municipality.

4.1.7 Attaining the Potential Impact

Of course, as always for technology, the realisation of the potential impact of SmartHG rests on the actual uptake of the developed technology.

In the last months we have witnessed a booming in the market of home energy storage systems for residential usage. Increasingly efficient home batteries are being produced and sold by big players (e.g., Tesla, Mercedes-Benz, Enphase).

Such a steadily growing interest of big players in home energy storage systems on one side supports deployment of SmartHG technology (that heavily exploits home energy storage systems), and on the other side witnesses market readiness for SmartHG technology and fosters its uptake.

We think indeed that, to some extent, such a recent booming in home energy storage systems is the strongest endorsement we may get from the market at this stage about the technology developed within the SmartHG project since, independently, many big commercial players are heading towards the same direction SmartHG is.

4.2 Main Dissemination Activities

During the project lifetime (October 2012 – September 2015), SmartHG project carried out various dissemination activities aimed at promoting its research to the widest and varied audience possible. The Dissemination Plan was released at Month 6 and provided guidelines for dissemination activities by project partners, by presenting information on the dissemination strategy of the project, the aim of the dissemination actions, the communication and dissemination tools to be used, and the activities and mechanisms for information exchange with various stakeholders.

Key dissemination tools and activities conducted by the project are described below.

4.2.1 Project Website

The public website (http://smarthg.eu) was made available in October 2013 (month 13 of the project) and it has been used as an important dissemination channel, describing project activities and outcomes, such as latest news, articles, presentations, internal and external documents. In May 2015 (Month 32 of the project) the public website has been completely redesigned to provide our visitors (energy distributors, retailers, residential users or simple onlookers) with an easier way to learn about SmartHG aims, services, and benefits. The website will be maintained at least 5 years after the project ends.

The statistics as of September 2015 are as shown in Table 4.1.

4.2.2 Logo, Power Point and LaTeX Templates

A logo was created to establish an identity for the project. Templates for Power Point and LaTeX presentations and deliverables were designed to ensure a visual identity to SmartHG material.

4.2.3 Artefacts

Dissemination artefacts produced by the project (and available in the public website) include: 1 poster, 3 leaflets (English and Danish), 3 sets of project presentation slides.

	Value
Published pages	60
Sessions	6866
Users	4383
Pageviews	26 066
Pages/Session	3.80
New visitors	63.84%
Visits from Europe	54.91%
Visits from America	21.20%
Visits from Asia	9.80%

Table 4.1: Some statistics about the SmartHG website.

4.2.4 Social Media

Twitter and Facebook account were activated in August 2013 (Month 11 of the project). LinkedIn account and group were activated in May 2015 (Month 32 of the project). All social media accounts of the project are accessible from the project website.

The statistics as of September 2015 are: 380 followers on Twitter, 240 likes on Facebbok, 55 connections on LinkedIn.

4.2.5 Newsletter

A total of 11 Newsletters were published during the project period, highlighting project activities, outputs and upcoming events. The newsletters have been sent to all who subscribed for the newsletter on the website. At the end of the project there were 60 subscribers.

4.2.6 Project Workshop

The "Kalundborg – Smart Energy 2015" workshop was held in Kalundborg, Denmark, on 5–6 May 2015. During this workshop, SmartHG consortium had the opportunity to broadly disseminate the concepts and results of the projects to scientists, energy distributors, retailers, interested people in industry, residential users, citizens, politicians, students and press.

4.2.7 Publications

4.2.7.1 Scientific Publications

The project produced a total of 26 scientific peer reviewed publications. The list of scientific (peer reviewed) publications is shown in Template A1 of "Use and dissemination of foreground" part of the final report.

4.2.7.2 Magazine and Newspaper Publications

SmartHG has appeared online on: Pan European Networks: Government magazine and Energi magazine, the news magazine from the Danish energy trade association Dansk

Energi.

4.2.7.3 Online Appearance

SmartHG has appeared online on: The Horizon 2020 Projects webpage, Panoramic Power Blog in the post "Energy Productivity: Leading the Way in the EU", 2GreenEnergy website in the article "Energy Efficiency Initiatives in Sustainable Cities", Madri+d, a Spanish news portal promoting science, R&D and innovation.

4.2.8 Participation in Events

During the project lifetime, members of the SmartHG consortium participated in 17 conferences, 7 workshops, 4 fairs and 4 other international and national events (28 of these events took place in Europe, 2 in Asia and 2 in America). These events have been an opportunity to disseminate the project results as well as to undertake networking and cooperation activities with other projects, to identify and use synergies between research projects, and to figure out the requirements and relevant topics for future research and collaborations. Successful partnerships have been established with FP7 projects ADVANCED, URB-Grade, SEMIAH, SiNGULAR, INCREASE, Linear, CONTREX and VIMSEN.

The list of dissemination activities is shown in Template A2 of "Use and dissemination of foreground" part of the final report.

4.3 Exploitation of Results

In this section we outline our plans for the exploitation of the SmartHG Platform. We envision two main exploitation directions: one towards electricity retailers (Section 4.3.1), to enable savings on the electrical energy cost (*arbitrage*), and one towards Distribution System Operators (DSOs) (Section 4.3.2), to support *peak-shaving* of the aggregate electrical demand.

4.3.1 SmartHG Exploitation Plan Towards Retailers

Presently, the electrical energy retail market is quite competitive, with retailers working hard to attract customers by offering competitive electricity prices as well as energy services. Retailers are thus quite interested in technologies that may allow them to attract new customers. Accordingly, we regard our exploitation plan towards retailers as a *short term* exploitation opportunity, since the market appears ready for it.

Figure 4.1 summarises our SmartHG exploitation plan towards electricity retailers. First of all, the retailer offers to residential users an electricity tariff consisting of a service fee along with a discount on the energy component of the electricity tariff. In exchange of the service fee, the electricity retailer installs at the user premises all the needed SmartHG devices, namely: sensors, Raspberry PI running SmartHG software and the required energy storage systems. By using SmartHG Home Services, the retailer will manage such home devices in order to get lower energy prices enabling the discount on the energy tariff mentioned above.

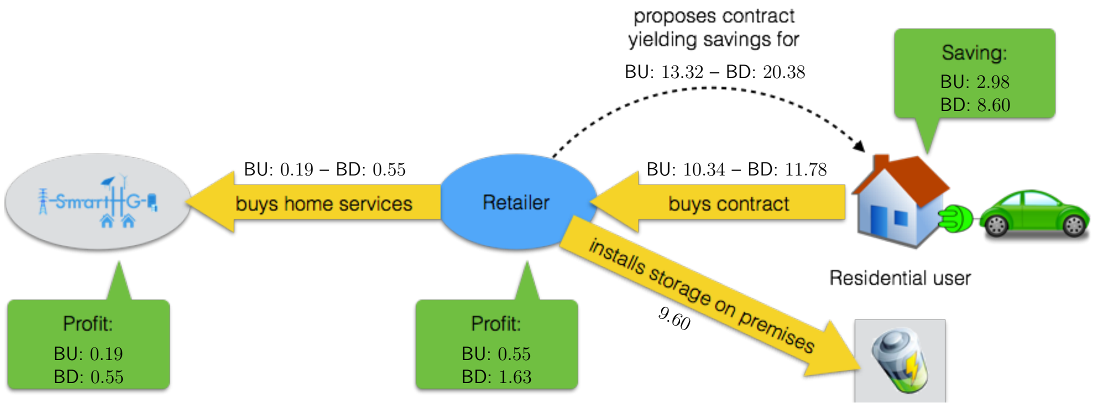


Figure 4.1: SmartHG Home Services Exploitation Schema (EUR/MWh).

Figure 4.1 considers two possible scenarios: one where the user Plug-in Electric Vehicle (PEV) is not controlled by SmartHG Home Services (*BU scenario*) and one where the PEV is controlled (charge as well as discharge) by SmartHG Home Services (*BD scenario*).

This approach on one side allows the retailer to pay for the devices installed at home premises while obtaining some gain and, on the other side, provides to residential users a money saving of about 80% of the net energy cost saving. Note that, to harvest such a saving, residential users do not need to worry about time dependent tariffs, since, by paying a device management fee, they receive a discounted flat tariff.

4.3.2 SmartHG Exploitation Plan Towards DSOs

While all DSOs agree that at some point in the future the distribution network will be stressed to the point that the saving from the SmartHG technology due to peak shaving will be interesting, it is not obvious that this is indeed the case now, also taking into account the reduction in electricity consumption triggered by the economic crisis. Accordingly, we regard our exploitation plan towards DSOs as a *medium term* exploitation opportunity.

Figure 4.2 summarises our SmartHG exploitation plan towards DSOs. The DSO offers a tariff (to which users may subscribe) that has a discount on electricity distribution *if* the user average power in any time slot meets DSO given time dependent power limits (*power profile*). Such a tariff depends on how important is for the DSO that most users follow the suggested power profile.

In Figure 4.2 we assume that DSO decides to provide a 20% discount on the electricity distribution component of the electricity tariff to residential users following the proposed power profiles. With the electricity distribution cost in our scenario being about 120 EUR/MWh (tax included), this means a discount of 24.00 EUR/MWh. In turn, the DSO will pay SmartHG Grid Services for computing power profiles for all participating residential users.

An electricity retailer can offer to a residential user an *ancillary* service helping him to follow the power profile proposed by the above mentioned DSO special tariff. To this end the retailer will install at the user premises all the needed SmartHG devices, namely: sensors, Raspberry PI running SmartHG software and the required energy storage systems. To pay for such an hardware infrastructure as well as for the management service provided, the retailer will charge to residential users a service fee (per MWh).

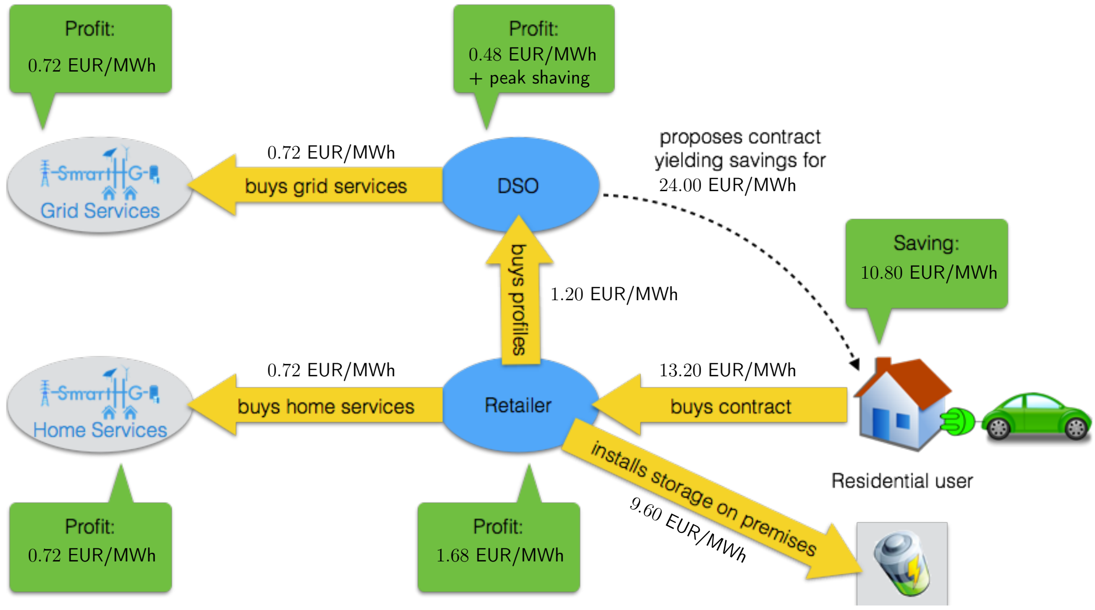


Figure 4.2: SmartHG Grid Services Exploitation Schema.

The electricity retailer, in turn, will use the collected fee to pay for: the energy storage devices installed at the user premises, the services received from SmartHG Home Services, the services received from the DSO.

Chapter 5

Public Website and Relevant Contact Details

This section contains the address of the project website and relevant contact details.

5.1 Address of the SmartHG Project Website

SmartHG Project Website is accessible at http://smarthg.eu and at http://smarthg.di.uniroma1.it.

5.2 Relevant Contact Details

The sections below show contact details of the project coordinator as well as of each SmartHG partner.

5.2.1 Project Coordinator

Enrico Tronci
Sapienza University of Rome
Computer Science Department
Via Salaria 113, 00198 Rome, Italy
Email: tronci@di.uniroma1.it
URL: http://mclab.di.uniroma1.it
Phone: +39 0649918361
Fax: +39 068541842

5.2.2 Sapienza University of Rome (UNIROMA1)

Sapienza University, one of the largest universities in Europe, has a long standing experience in participation and coordination of European Projects. Its Computer Science Department has about 40 faculties, 15 Ph.D. Students and 5 Post-Docs covering most of subjects in mainstream computer science. The project has been carried out by the Model Checking Research Lab of the department. The lab, led by Prof. Enrico Tronci, focusses on model-checking-based algorithms and tools for the automatic verification and synthesis of mission- or safety-critical systems.

Role in the project: UNIROMA1, the project coordinator, has focussed on the design and development of model-checking-based software services to compute price policies and to formally verify their safety.

Contact Person: Enrico Tronci, Email: `tronci@di.uniroma1.it`

5.2.3 Aarhus University (AU)

Aarhus University was founded in 1928. It has 34 000 students (about 15 000 Master's degree students and 1600 Ph.D. students), about 550 postdoctoral scholars, and 6000 employees (2009/2010). Its four faculties cover the entire spectrum of basic, applied, and strategic research, and provide research-based advice to the authorities. In 2011, AU was number 79 at the QS World University Ranking (the second highest Scandinavian ranking) and number 125 on the Times Higher Education World University Ranking. Internationalisation is part of the university mission and it is continuously strengthened through a series of initiatives which increase the international research partnerships and the number of international students. The Department of Engineering (ENG) is part of the Faculty of Science and Technology and will contribute to the research undertaken in SmartHG.

Role in the project: AU is responsible for system integration in the Home Area Network (HAN) and has developed and integrated a control-hub/home-hub prototype including interoperable communication protocols, the needed proxy functions and application for data collection in the smart home/building.

Contact Person: Rune Hylsberg Jacobsen, Email: `rhj@iha.dk`

5.2.4 IMDEA Energy Institute (IMDEA)

IMDEA Energy Institute is a Research Centre created by the Regional Government of "Comunidad de Madrid" to develop world-class R&D on clean and renewable energy. The Scientific Programme of IMDEA has been outlined with the aim of contributing to the future establishment of sustainable energy systems. Its mission is to strengthen and have a significant impact on R&D activities across the energy themes by bringing together high quality researchers, providing them with excellent infrastructures and promoting their close collaboration with the industrial sector, in all cases within an international framework.

Role in the project: Inside SmartHG, IMDEA has provided contributions in energy-demand modelling, demand-side management, power-network management.

Contact Person: Milan Prodanovic, Email: `milan.prodanovic@imdea.org`

5.2.5 A. V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus (HMTI)

The A. V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus is a leading research centre, whose main concern is the investigation of fundamental and applied problems and incorporation of outcomes of research studies into various branches of the national economy. HMTI is a top organisation on energy policy development and rational use of energy in Belarus. In particular, the staff at HMTI has an active role in the development of the Energy Program of Belarus which will last until 2030. HMTI is involved in domestic and international projects in nuclear physics and nuclear energy, thermophysics, fluid dynamics and heat-mass transfer, energy system development and planning, fuel balance and energy mix, energy saving technologies and energy efficiency, environmental protection and monitoring.

Role in the project: The contribution of HMTI is the development of methodologies for physical and mathematical modelling of energy processes in buildings. Systems based on those models can serve as home energy controlling hubs that collect real-time data on energy consumption, data from smart household appliances and enable intelligent automation. Moreover, HMTI has developed a methodology and an integrated system for the effective monitoring and management of energy in buildings, leveraging geographic information systems and decision-support systems with smart energy grids functionality.

Contact Person: Sergei Levchenko, Email: `sergei.levchenko@hotmail.com`

5.2.6 ATANVO GmbH (ATANVO)

ATANVO GmbH is a Germany-based SME company, registered in 2002 at the court of Stuttgart-Baden-Wuerttemberg. The company is active in the field of research, development and engineering of grid-based services as energy management, telecommunication and power generation.

Role in the project: ATANVO main focus is on design, development and evaluation of Energy Usage Modelling and Forecasting (EUMF) and Energy Usage Reduction (EUR) Intelligent Automation Services (IASs).

Contact Person: Juergen Unfried, Email: `j.unfried@atanvo.de`

5.2.7 Panoramic Power (PANPOW)

Panoramic Power provides an innovative Energy Management System (EMS) that enables enterprises and organisations to reduce their operational and energy expenses. PANPOW helps customers improve their energy efficiency using a breakthrough power flow visibility platform. PANPOW has invented a series of low cost, wireless, self-powered sensors engineered to allow rapid, non-invasive installation, with minimal to no-disturbance of daily operations. This first of its kind technology provides visibility to energy consumption at the individual circuit level, enabling rapid, non-invasive installation. Low cost sensors allow building retrofits with minimal expense, while a no-maintenance design enables installation with zero disruption to building operations. An integrated, cloud-hosted data management service offers customers a broad set of applications such as energy savings, failure prediction and preventive maintenance, load optimisation and sub-metering. Advanced Business Intelligence and Analytics capabilities are supported to allow a high level view of the high volume of collected data, as well as benchmarking within or across organisations. Panoramic Power Energy Management Solution is a fully-installed, fully-integrated service that enables our customers to acquire complete visibility of their operation power flow and achieve informed, high-level decision making.

Role in the project: PANPOW contributed with the definition, design, and development of communication protocols and software APIs and web-services to collect energy data from different sources using different protocols, and communicate the data to the group in a single standard API. PANPOW has developed analytics algorithms to aggregate and analyse the highly granular real-time energy data. PANPOW has provided its asset level energy management platform and sensor hardware, and helped facilitate them for the demonstration of the project. Finally, PANPOW has implemented a showcase for the Database and Analytics (DB&A) data gathered from the project test-beds.

Contact Person: Adi Shamir, Email: `adi@panpwr.com`

5.2.8 Solintel (SOLINTEL)

SOLINTEL (Spain) focuses on energy efficiency improvement of processes and products to be applied in different fields and on the development of high performance materials. Its goal and strategy is to apply a whole new analysis technique to improve energy efficiency and to reduce greenhouse gas emission from facilities and production processes. This is done through the constant monitoring, optimisation and integration of new compatible technologies and low-energy-consumption innovative materials. SOLINTEL has a large experience in the application of Computational Fluid Dynamics in the modelling of industrial processes and equipments, in fluid mechanics, turbulence, heat transfer and other related physical and chemical phenomena.

Role in the project: SOLINTEL has developed algorithms to forecast energy production and consumption, based on local data monitoring and collection. Distributed energy networks are subject to grid faults, since they have lower inertia than national grids. To avoid this situation, an islanding optimised design and a fault detection frequency-based system is developed, and new algorithms with specific tools and dynamic simulations are implemented to recreate different scenarios. The aim is to guarantee a rapid response to manage the energy transfers within a district avoiding problems in line capacity and voltage levels.

Contact Person: Xiugang He, Email: `xiugang.he@solintel.eu`

5.2.9 SEAS-NVE (SEAS)

SEAS-NVE is a modern utility company with proud traditions. Our supply area covers 6878 mq2, and uses 27 000 km wires. SEAS-NVE provides value to their members within three business areas: 1) Energy grid: operation, maintenance, and the 3-in-one-project; 2) Energy sale: sale, customer service, and energy consultancy; 3) Fibre-optic Internet: establishment, and sale. SEAS-NVE, to ensure delivery security in a multi-supplier scenario, is in the process of establishing a SmartGrid, which can hold a more flexible electricity production (even local production at consumers end) and the increasing amounts of fluctuant renewable energy (such as wind turbines). In 2009–2011, we are installing new intelligent electricity meters that in the future also form an important part of the SmartGrid, which entails a better utilisation of the electricity. SEAS-NVE is a sort of broker who purchases electricity on the electricity exchange at the best possible price, which is then sold to our private customers. SEAS-NVE has engaged in various product developments recently, for instance we have developed an actual climate-friendly electricity product: GlobalEnergi. Energy consultancy is connected to the sale of energy. Making our members conscious of their consumption and how they may reduce it, we manage to save 68.3 million kWh in 2009. We co-operate with municipalities to replace outdoor lighting if they so desire. We are at the forefront when it comes to the most modern and energy-saving outdoor lighting systems. SEAS-NVE sponsors local and regional initiatives/organisations/associations and activities that are in line with our values and mission to give value to our members.

Role in the project: SEAS-NVE has contributed in the following activities: 1) Head of installation and field management; 2) Project developer; 3) Business developers; 4) Commercialisation experts; 5) Carry out analyses and feasibility studies; 6) Funding Financing and commercialisation; 7) User of the development.

Contact Person: Lars Elmegaard, Email: `LEN@seas-nve.dk`

5.2.10 Kalundborg Municipality (KAL)

Kalundborg Municipality, with its about 50 000 inhabitants, is a Danish public entity, a local government with an elected ruling body: a city council of 31 members. As a municipality we both enact, implement and pass local regulations within the framework of the Municipal laws as defined within the jurisdiction of the Ministry of Interior. KAL is a law enforcing body implementing national and EU laws transposed into national and thereupon local legislation. Also the municipalities act upon those laws locally by ascertaining and monitoring that laws are implemented in conformity with the ministerial Acts. Moreover, KAL is a scrutinising entity reassuring that irregularities do not occur and manage these when they are identified. Finally KAL is proactive with regards to taking local initiatives promoting business development and thereby preparing for new business opportunities in partnership with industry and research institutions in compliance with rule of law namely Directive on Public Procurement.

Role in the project: KAL is a demonstratorium for the research project deploying its own assets for that purpose alongside catalysing private dwellings to enter the project as test bed. Also its spatial planning and asset management are corner stones with regard to being a Smart City revolving around the strategic energy plan of the Kalundborg Municipality.

Contact Person: Johan Ib Hansen, Email: `johan.ibhansen@kalundborg.dk`

5.2.11 Minskenergo (MINSKENG)

Minskenergo is an energy company based in Minsk, Belarus. The company is primarily involved in generating heat and electricity, which is supplied to residential and industrial customers in the region. Moreover, the company owns and operates five co-generation plants and a steam power plants. This includes Minsk Hydro Power Station (HPS-2), Minsk HPS-3, Minsk HPS-4, Minsk HPS-5, Zhodinskaya HPS, Minsk heating networks and regional electric networks. The installed electric power capacity of MINSKENG amounts to 1814 MW. Furthermore, the company holds more than 60 thousand km of electric networks for distribution and transmission of energy. Besides providing electric service in the region, the company also consists of power lines linking the Republic with the power of the Russian Federation and the Baltic States.

Role in the project: MINSKENG has led the case study in Minsk and brought into the project its experience in power and heat generation and distribution.

Contact Person: Yuriy Mishuk, Email: `Mishuk_YE@minskenergo.by`

5.2.12 Develco Products A/S (DEVELCO)

Develco Products is a small Danish company specialised in communication systems for Smart Metering combined with Home Automation. The company provides products for sensoring, me- tering, and load control, among these relays, sensors, meter interfaces, and gateways. Develco Products has deep and long-standing expertise in wireless communication.

Role in the project: DEVELCO has contributed to the SmartHG project by: delivering hardware for energy monitoring and load control, standardising the communication with the backend server, and upgrading from IPv4 to IPv6

Contact Person: Henning Maerkedahl, Email: `hma@develcoproducts.com`

Chapter 6

List of Acronyms

CIM Common Information Model 27

COP Coefficient of Performance 8

DAPP Demand Aware Price Policies 19

DB&A Database and Analytics 40

DLC Direct Load Control 1

DR Demand Response 29

DSM Demand Side Management 19

DSO Distribution System Operator 34

EBR Energy Bill Reduction 23

EDN Electric Distribution Network 29

ESS Energy Storage System 21

EUMF Energy Usage Modelling and Forecasting 39

EUR Energy Usage Reduction 39

EVT EDN Virtual Tomography 19

GIAS Grid Intelligent Automation Service . . . 5

HAN Home Area Network . . . 38

HECH Home Energy Controlling Hub . . . 31

HIAS Home Intelligent Automation Service

IAS Intelligent Automation Service . . . 39

ICT Information and Communications Technology . . . 29

LV Low Voltage . . . 19

MILP Mixed-Integer Linear Programming . . . 6

MV Medium Voltage . . . 18

PEV Plug-in Electric Vehicle . . . 35

PPSV Price Policy Safety Verification . . . 5

PV PhotoVoltaic . . . 29

RESTful REpresentational State Transfer . . . 30

RMS Root Mean Square . . . 19

SEIL Smart Energy Integration Lab . . . 16

SMC SmartHG Market Controller . . . 10

ToU Time of Usage . . . 18