SmartHG: Energy Demand Aware Open Services for Smart Grid Intelligent Automation

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I. Introduction

The SmartHG project [1], [2] has the goal of developing economically viable *Intelligent Automation Services* (IASs), which gather real-time data about energy usage from residential homes and exploit such data for intelligent automation. Such services pursue two main goals: to minimise energy usage and cost for each home, and to support the *Distribution Network Operator* (DNO) in optimising operation of the *Electric Distribution Network* (EDN).

SmartHG goals are achieved with a hierarchical control schema where the DNO computes, for each user, an individualised energy usage profile to be followed. To this end, the DNO proposes to each user an individualised *price policy* defining costs for consumed energy as well as rewards for produced energy. As for energy consumption [production (e.g., from solar panels)], for each time slot (say each hour) the DNO price policy defines an interval of energy consumption [production] with a low cost [high reward]. Outside of such an interval the energy cost [reward] is high [low]. In order to minimise energy costs each user is advised to follow a power profile with low energy cost (for consumption) or with high energy reward (for production). Users will exploit *load shifting*, *energy storage* (e.g., batteries or plug-in hybrid electric vehicles) and *energy production* (e.g., from solar panels) to follow the energy profile proposed by the DNO.

Fig. 1 summarises the SmartHG hierarchical control schema. *Grid Intelligent Automation Services* (GIASs) support the DNO in computing, for each user and for each time slot, an effective, fair and safe energy usage profile communicated to the user by means of a price policy. *Home Intelligent Automation Services* (HIASs) support users in following their DNO suggested power profile by computing a control strategy for home appliances. Communication services support data exchange between all entities involved, namely: GIASs, HIASs, DNO, home devices. During its first year of activity, SmartHG focused on developing a first iteration of all such services and on evaluating them on available historical data.

SmartHG is currently at the second thirds of its lifetime. Until now, the overall architecture has been designed, prototyped, and evaluated on historical data showing promising results. By the end of SmartHG second year we will set up two test beds, each one of them presenting different hardware and users behavioural challenges. We will then show effectiveness of the aforementioned architecture in two demo sessions by the end of the project lifetime.

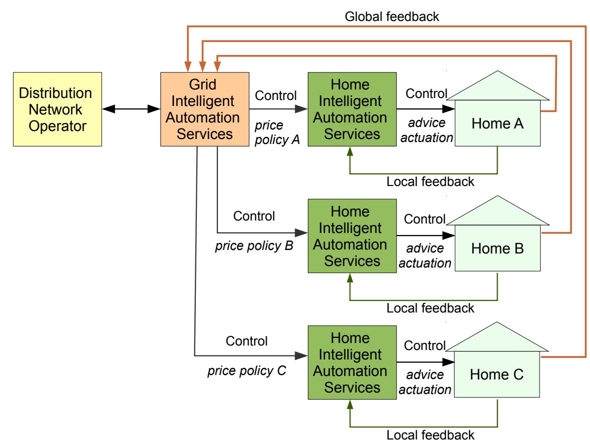

Fig. 1: The overall architecture of SmartHG project

II. SmartHG Project

Communication Infrastructure: The communication in the SmartHG infrastructure is based on the Representational State Transfer (REST) architectural style that allows home devices to communicate with the *Database & Analytics* (DB&A) service located in the cloud [3]. Home devices are hardware elements capable of participating in the Home Area Network (HAN) and compose the inter-networking of the smart home. These devices can be sensors, actuators, gateways that link communication between different types of networks. The SmartHG project deploys IPv6-compliant inter-networking technologies such as IPv6 over Low-Power Personal Area Networks (6LoWPAN) and use Smart Energy Profile version 2.0 (SEP2) as an application layer protocol for communicating with the DNO. The DB&A is the core entity for storing measurement data from the smart homes. It is implemented as a RESTful web service with a relational database as back-end of the web application.

GIASs consist of *EDN Virtual Tomography* (EVT), *Demand Aware Price Policy* (DAPP), and *Price Policy Safety Verification* (PPSV). The EVT service takes as input the EDN topology, measurements from the field and operational limits and returns alarms as well as estimates of EDN state where no sensors are available. The DAPP service takes as input the energy forecasting (from the HIAS EUMF) for all users connected to the same substation as well as safety constraints for the substation from the DNO. It returns as output, for each user and for each time slot, a power profile to be followed along with a price policy *suggesting* such a power profile. The PPSV service takes as input the DAPP power profiles and a model for the user behaviour. It returns as output the probability distribution of the aggregated demand. This allows us to assess safety (as for EDN equipment) of the DAPP computed price policy.

HIASs consist of *Energy Bill Reduction* (EBR), *Energy Usage Modelling and Forecasting* (EUMF), and *Energy Usage Reduction* (EUR). The EBR service takes as input a price policy from the DAPP service as well as models for home smart appliances, renewables and energy storage devices. EBR returns as output a scheduling for home appliances and energy storage devices that minimises the home energy bill. The EUMF and the EUR services take as input information about house structure and location, weather forecasting, and energy consumption, and return, respectively, a forecast about the energy consumption and advices on how to reduce energy usage at home.

Testbeds: *Kalundborg* (Denmark) test bed consists of 98 homes several of which equipped with photovoltaic panels or a heat pump. In total there are 134 such installations connected to the substation whose transformer has a primary voltage of 10 kV, a secondary voltage of 400 V, and a nominal power of 400 kVA. *Minsk* (Belarus) test bed consists of about 100 flats located in two multi-floor buildings consisting of, respectively, 153 and 116 flats. Each building is served by two transformers. Each transformer has a primary voltage of 10 kV, a secondary voltage of 400 V and nominal power of 1000 kVA.

A. First Year Evaluation Results

Our first year evaluation activities use SEAS-NVE historical data referring to energy consumption/production of residential homes from our Kalundborg test bed. The DB&A evaluation activities focused on testing the API to populate and retrieve such data from the database. It shows that the REST API can be effectively used to populate and read the required data from the interface.

The evaluation of the DAPP service shows that: 1) each user only needs a very modest load shifting capability in order to follow the DAPP suggested power profile; 2) if each user follows his suggested DAPP profile, the aggregated demand is almost always within the DNO suggested limits, which was not the case without using DAPP. For EVT evaluation, we built a detailed model of the Kalundborg area MV network in PowerWorld Simulator. This allowed us to create test case scenarios for the EVT service. The network model has been analysed and the most appropriate network locations for creating the test scenarios for EVT have been identified. The evaluation of the PPSV service has been performed on historical data by computing the probability distribution of the aggregated power demand when users always follow DAPP and when users follow DAPP often, but not always. Our experimental results on PPSV show how DAPP effectively moves the probability distribution of the aggregated power demand below the nominal threshold defined by the DNO.

The evaluation of the EBR service is performed on appliance models from the literature and on DAPP suggested power profiles. Our first year experimental results show that, by using EBR with a DAPP tariff, a user may save about 40% on energy cost with respect to using EBR with a traditional flat tariff. The EUMF and EUR services focused on the web mock-up and the integration with the DB&A.

III. Conclusions and Future Directions

In this paper we have presented the SmartHG project together with the main objectives and applied methodologies. The architecture is introduced and the first year results and achieved goals of SmartHG shown. The principles of interaction between Home and Grid oriented services are described and the current state of the service development reported.

Smart Energy Market is booming. By 2015, the total market will be about 420 billion dollars. Indeed, until recently, the focus has solely been on renewable energy. However, with the emerging into the commercial marketplace of *energy storage systems* and advanced, efficient conversion devices such as fuel cells, the grid is increasingly becoming a systems-based network posting significant year-on-year growth. This opens up new opportunities for SmartHG IASs, and for the communication infrastructure connecting such services.

During the second year of SmartHG project, both test beds will be equipped with sensors and a communication infrastructure for collection of energy related data. This allows us to apply all SmartHG services on current data and explore the adoption of energy storage systems within houses. Furthermore, in order to improve usability and to fully exploit our products, by the end of the second year all services will be accessible via web based services by the DNO (for GIASs) and by residential users (for HIASs).

IV. Partners

SmartHG consortium is composed of eleven partners, listed in the following, together with their countries: (i) **Università degli Studi di Roma "La Sapienza"** (Italy, Project Coordinator); (ii) **Aarhus Universitet** (Denmark); (iii) **IMDEA Energía** (Spain); (iv) **A. V. Luikov Heat and Mass Transfer Institute of the National Academy of Sciences of Belarus** (Belarus); (v) **ATANVO GmbH** (Germany); (vi) **Develco Products** (Denmark); (vii) **Panoramic Power Ltd.** (Israel); (viii) **Solintel M&P S.l.** (Spain); (ix) **SEAS-NVE Holding A/S** (Denmark); (x) **Kalundborg Kommune** (Denmark); (xi) **Minsk Republican Unitary Electronicpower Entreprise Minskenergo** (Belarus).

Acknowledgments

This research has received funding from the EU Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 317761 (SmartHG).

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