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## Swiss2G – Pilot- and Demonstration Project

An innovative concept for the decentralized  
management of distributed energy generation, storage  
and consumption and consumer acceptance

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**Mandant:**

Office fédéral de l'énergie OFEN  
Programme de recherche Réseaux  
CH-3003 Berne  
[www.bfe.admin.ch](http://www.bfe.admin.ch)

**Cofinancement:**

swisselectric research, CH-3001 Berne  
AET, CH-6501 Bellinzona  
AIM, CH-6850 Mendrisio

**Mandataire:**

SUPSI –DACD - ISAAC  
Campus Trevano  
CH-6952 Canobbio  
[www.supsi.ch](http://www.supsi.ch)

Bacher Energie AG  
Rütistrasse 3a  
5400 Baden  
[www.bacherenergie.ch](http://www.bacherenergie.ch)

**Auteurs:**

Roman Rudel, ISAAC-SUPSI, [roman.rudel@supsi.ch](mailto:roman.rudel@supsi.ch)  
Domenico Chianese, ISAAC-SUPSI, [domenico.chianese@supsi.ch](mailto:domenico.chianese@supsi.ch)  
Davide Rivola, ISAAC-SUPSI, [davide.rivola@supsi.ch](mailto:davide.rivola@supsi.ch)  
Luca Gambardella, IDSIA-SUPSI, [luca@idsia.ch](mailto:luca@idsia.ch)  
Matteo Salani, IDSIA-SUPSI, [matteo.salani@idsia.ch](mailto:matteo.salani@idsia.ch)  
Alessandro Giusti, IDSIA-SUPSI, [alessandrogiusti@idsia.ch](mailto:alessandrogiusti@idsia.ch)  
Gian Carlo Dozio, ISEA-SUPSI, [giancarlo.dozio@supsi.ch](mailto:giancarlo.dozio@supsi.ch)  
Marco Ancona, ISEA-SUPSI, [marco.ancona@supsi.ch](mailto:marco.ancona@supsi.ch)  
Diego Lunati, DSAS-SUPSI, [diego.lunati@supsi.ch](mailto:diego.lunati@supsi.ch)  
Lorenzo Sommaruga, ISIN-SUPSI, [lorenzo.sommaruga@supsi.ch](mailto:lorenzo.sommaruga@supsi.ch)  
Michael Höckel, BFH, [hkm1@bfh.ch](mailto:hkm1@bfh.ch)  
Syril Eberhart, BFH, [syрил.eberhart@bfh.ch](mailto:syрил.eberhart@bfh.ch)  
Rainer Bacher, BACHER ENERGIE AG, [rainer.bacher@bacherenergie.ch](mailto:rainer.bacher@bacherenergie.ch)

**Responsable de domaine de l'OFEN:** Dr. Michael Moser  
**Chef de programme de l'OFEN:** Dr. Michael Moser  
**Numéro du contrat de l'OFEN:** SI/500397-01, SI/500397-02

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## Résumé

The Swiss2G pilot and demonstration project is composed of a considerable number of building blocks belonging to the «real world» and the «lab world» and the overall aim of the project is to investigate a concept of a decentralized and self-regulating load management system. The first phase A - concluded to a large extent at the end of 2011- of the project was dedicated on the one hand, to the elaboration of the simulation environment at the household and grid level and of the S2G algorithm for the decentralized load management. On the other hand the 20 identified households were equipped with PV – panels and prepared to accommodate the intelligent measuring devices, developed for the purpose of the project, and the touch panels. All the equipment was successfully tested and is fully operational for implementation and demonstration in the “real world”.

Unlike the majority of the projects on smart grids the present project follows an approach based on a local and decentralized decision management for load shifting driven by the information in the single nodes and households. Preliminary results of the grid highly accurate measurements show a significant correlation between the local voltage values at household plugs and electrical loads at LV transformers. The first results of the grid simulation with the S2G algorithm, fed with the local and instantaneous voltage values, are promising and show an increasing grid stability with the growing diffusion of the S2G algorithm in the local grid.

Due to the co-financing mechanism at the beginning of 2012 we had submit again project proposal to SER. In this occasion the project design and management has been streamlined and reduced in its complexity. This led to an interruption of our activities to a certain degree and the project had to be delayed by approximately 5 months. The project periods A and B, the timeline and the tasks refer now to this proposal in line with the BFE project The challenge for the remaining period of the project - corresponding to phase B regards the implementation of the remaining smart grid components, the monitoring and acquisition of the grid and households data and the final evaluation of the impact of the algorithm under different tariff and grid stability scenarios.

## Buts du projet

The diffusion of small and decentralized energy generation units poses a considerable challenge to utilities, as grown over the last century, in not more than the next 10 to 20 years. The need to drastically reduce the CO<sub>2</sub> emissions requires the use of new energy sources, the increase in energy efficiency and the decarbonization of mobility.

The overall goal of the project is to investigate in a pilot project the technical feasibility of decentralized electric energy production, storage and consumption by combining available and new technologies in an intelligent and self-organizing system. The project intends to analyse the practical use of small energy production units in about 20 smart private households, plug-ins for storage and environmentally friendly mobility linked to the grid. This is the basic (infra-) structure of the project based on low power. This infrastructure allows to define the system parameters and to simulate the behaviour of the users and their impact on the grid on different scales of the technology diffusion.

The basic idea of the project is to optimize the control of the grid by an algorithm based on decentralized decision making with limited knowledge in an environment with selected information in the single nodes and to understand their impact on the grid, simulated by a conventional approach. Unlike the large majority of the projects on smart-grids the present project wants to show, to which extend the need of two-way communication systems capable to manage the smart grids can be reduced and the problems related to the elaboration of huge quantities of information overcome. This represents an innovative approach of the grid management based on intelligent devices with self – optimization capabilities at the level of each node (household). This leads to a decentralization of the decision processes on when to consume, store or produce energy and represents a promising option to the common management approaches for smart grids.

The design of this pilot and demonstration project is a combination of practical feasibility of technical components for the energy production and storage in real conditions in 20 households and the use of advanced optimization and simulation tools. The project is carried out by an interdisciplinary team of five institutes of SUPSI, Bacher Energy AG, a private consultancy, and the Berner FH, in co-operation with industry partners. The project covers a period of 4 years and is based in Mendrisio. In the first phase the identification of 20 households willing to participate in the pilot and demonstration project was key. The long experience of Protoscar in working with households in Mendrisio (VEL1) using a high quality multi-media communication strategy was instrumental to achieve this goal in a short time and fundamental for the dissemination of the results.

The households will be monitored during the whole period, introducing step by step a major involvement of the household. Different household profiles will be defined in order to simulate different patterns of behaviour in the optimization and simulation workpackages. The benefits for households and utilities will be analysed during the whole period.

# Travaux effectués et résultats acquis

## Household simulation environment and algorithms (IDSIA)

During phase A of the project, IDSIA developed two key components, which have been used in several experimental campaigns and provide solid foundations for phase B.

- A **sophisticated simulation environment** for groups of households including models of: different classes of electric appliances; the behavior of residents in the household; different control algorithms. The environment allows us to easily perform repeatable, quantitative experiments in many different scenarios, fully configurable with respect to the layout of the households on the low voltage (LV) network.
- A general, **decentralized control algorithm** for household appliances. The algorithm accounts for all user requirements (e.g. desired water temperature in the water heater; deadline for completing washing machine job; deadline for charging EVs), and controls appliances for meeting such requirements while at the same time optimizing one or more objectives. So far, two objectives were considered and analyzed in detail [1]: cost of energy for the users, and minimization of peaks in the LV network.

Using the above mentioned components, IDSIA is currently working in the following directions.

1. Analyzing data acquired during monitoring, with two main aims. Understanding correlations among: a) the measured voltage drops at households, and b) the overall load at the transformer.
2. Studying the algorithm's behavior in realistic scenarios. In particular, the team members are interested in how algorithms behave when using only the measured voltage as a source of information, and how to optimally exploit this information (task T2.2).

Preliminary results on these topics [2] show that some correlation exists and thus algorithms are able to significantly optimize the energy usage -- meaning that loads are shifted from periods of high transformer load to periods of low transformer load, while meeting the user requirements. Work is continuing and focusing on different parts of the Mendrisio LV network using the newly-acquired data during the first months of phase 2.

3. Extending algorithms to handle explicit peer-to-peer communication, and modeling additional, pervasive communication scenarios for quantitative comparisons (task T2.1). Preliminary results on this topic [3] show that even very limited communication abilities allow algorithms to effectively coordinate with each other and exhibit measurable performance improvements in terms of flattening the load peak curve (see Figure 1); in contrast, a pervasive communication infrastructure yields negligible incremental improvements. Current efforts are focused in modeling and evaluating additional, realistic communication scenarios.
4. Algorithm integration in real households: the algorithm implementation has been refactored to a single, self-contained library, which is being interfaced with the global framework developed by the other project partners.

The following figures describe an evaluation of several algorithm approach performances:

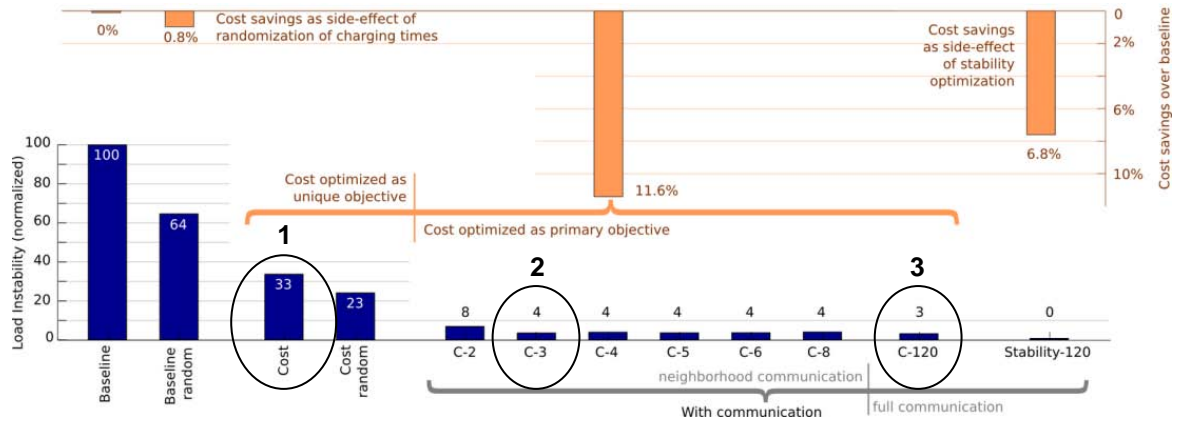


Figure 1 - Simulation results with different communication scenarios

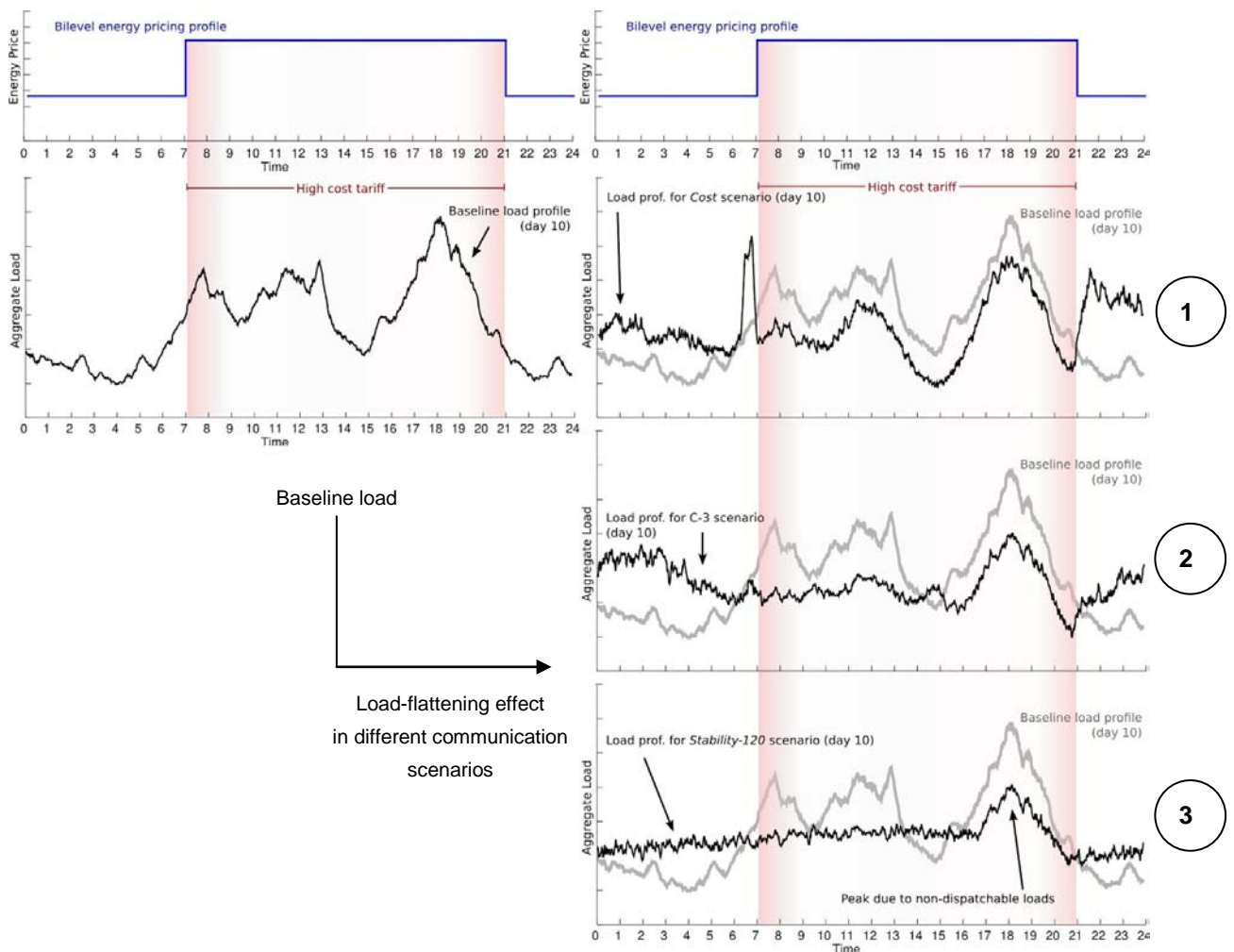


Figure 2 - Load-flattening effect w.r.t. baseline in different scenarios  
 1: cost scenario / 2: C-3 cost + stability scenario / 3: C-120 cost + stability scenario

Work is planned to continue on the main directions mentioned above. In addition, the simulation approach will be scaled up (with grid simulation tool of BFH), in order to develop aggregate models of household aggregates, which will be useful for large scale simulations.

## Tariff / pricing scenarios (DSAS)

The research activities on this work package is currently ongoing. Team members are analyzing existing literature and field experience, in order to understand the economic rational and the technical or administrative problems behind a given tariff/pricing scheme. Preliminary results are not yet available.

## Grid and household measurements (Bacher Energie AG / ISAAC / ISEA)

The **grid metering module** is an extension of the work accomplished in phase A of this project (years 2010-2011) where one full month of data has been captured successfully. In this project phase B, the measurements are extended mainly to monitor a much longer period of time and also at more locations as shown in the following figure 3.

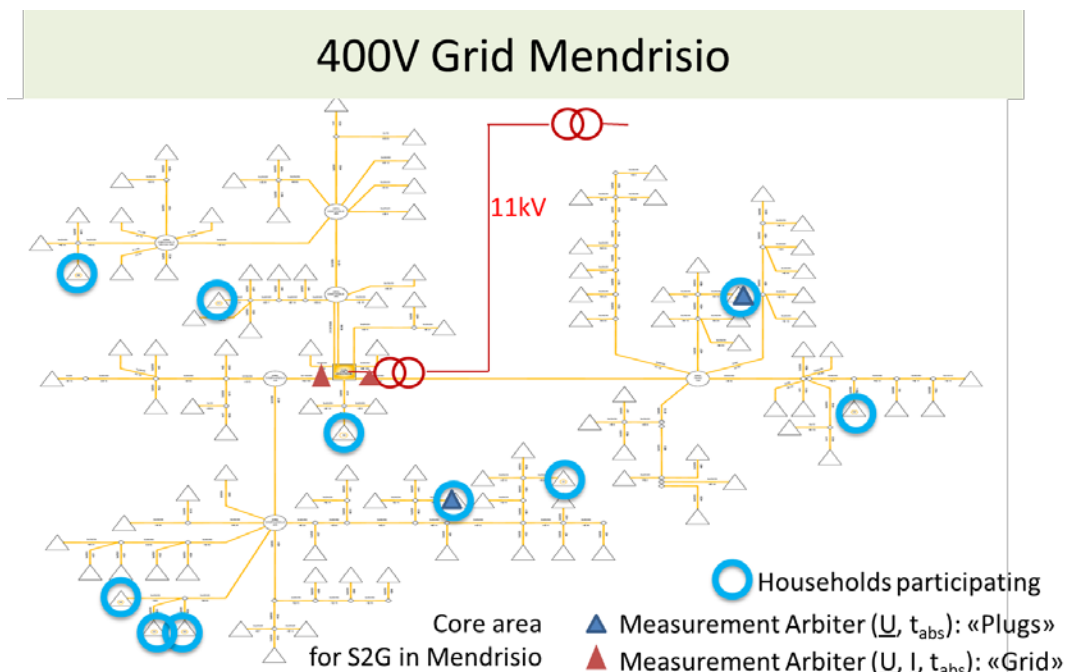


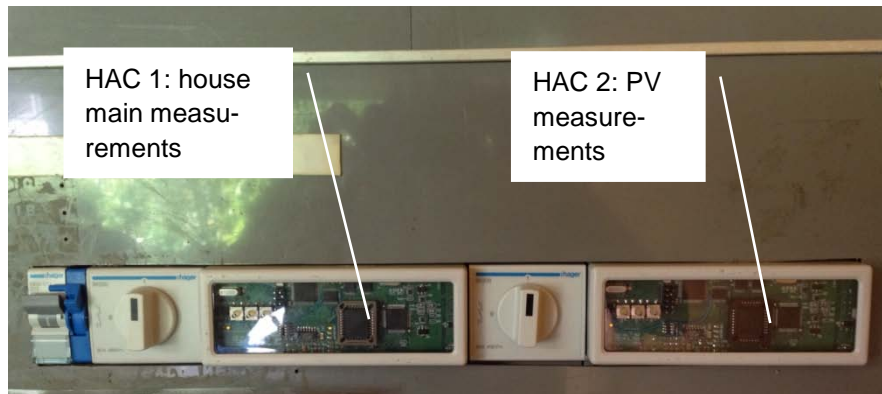
Figure 3 – Measurements points in Mendrisio “Asilo Genestrerio” neighborhood

Currently, the S2G team monitors currents and voltages at the two locations. This monitoring equipment – shown in red triangles - measures the currents leaving the transformer (shown in the middle of the above figure) towards the houses on two different radial branches, one to the right and to the lower left. In addition, we measure the voltages at two houses – shown with blue triangles - in the radial branch of the left and one in the radial branch to the right. These are the location where high-accuracy PMU-based metering of voltage and current (red triangle) and voltage only (blue triangle) is permanently ongoing.

In addition, the S2G team measures in real-time at every single location in the lower left and right radial branches and marked with the blue circle the active and reactive power generated and consumed.

Currently six houses (HH 01, 05, 06, 09, 10, 11) have been fitted with two HACs (House appliance controllers) measuring:

- house connection point to the grid;
- PV inverter output.



*Figure 4 – Example of a HAC installation*



*Figure 5 – Example of a touch panel installation*

During the last month the quality and reliability of the system has been tested and verified.

All this collected data of the various monitoring equipment must be time-matched to be ready for parallel analysis and dependency analysis with the goal to get a full picture of the critical states of the grid in very short-term intervals. Time-accuracy has been reached and verified by using a combination of GPS time signals and Network Time Protocol (NTP) signals.

Since June 2012, data is being collected and permanently stored in second intervals in a MySQL database accessible via the Web, both by FTP and Web servers.

The current interface, with restricted access to the project team, is as follows. Figure 6 shows an example as the currents in each of the three phases at the transformer leaving towards the left hand side radial branch (i.e. towards HH06, shown above).

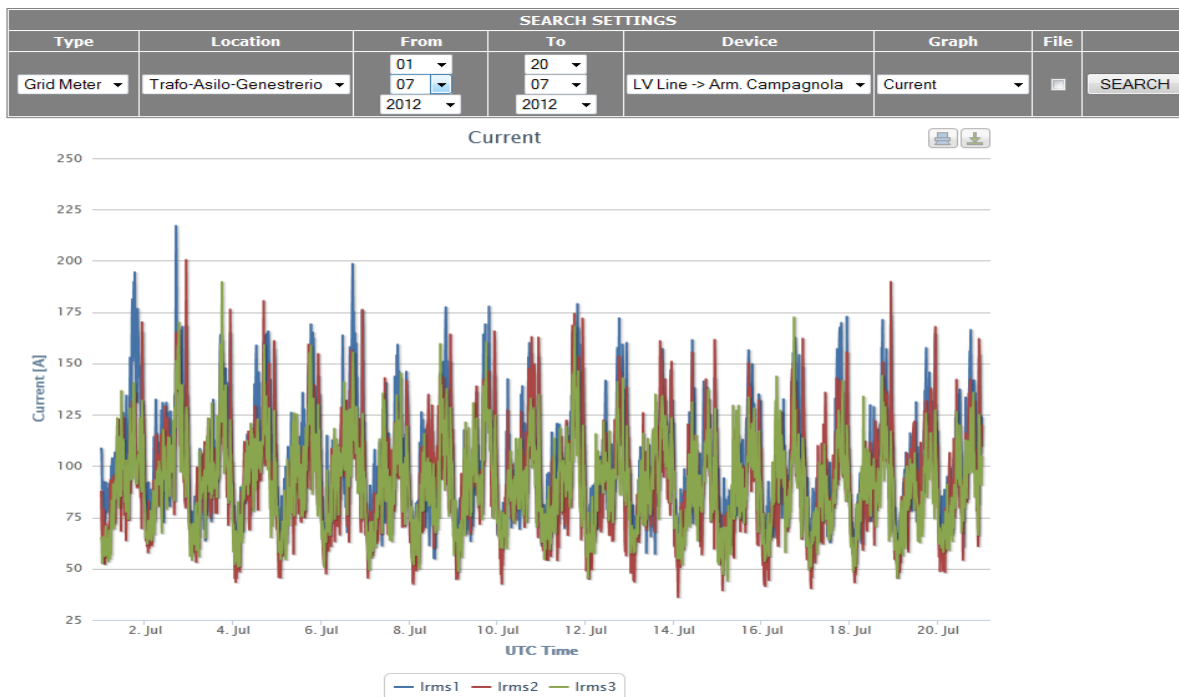


Figure 6 – Example of current measurements at a transformer branch

The following picture shows – for one of the household marked as blue circle – the generated active power of a PV-panel, again for the same period as chosen above.

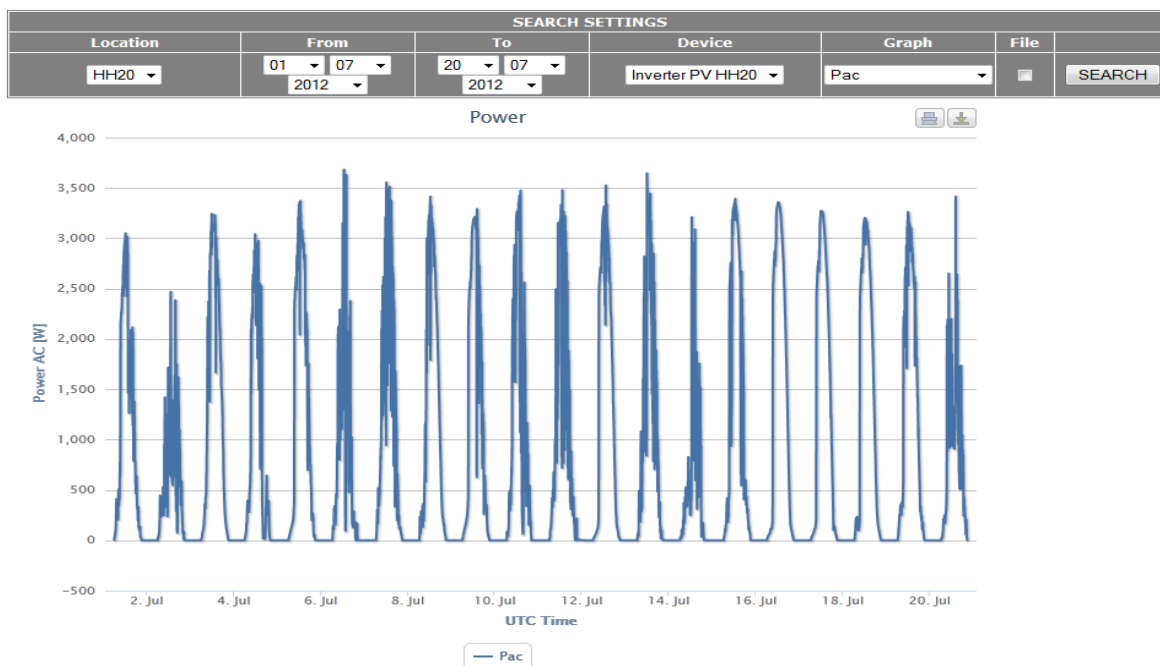


Figure 7 – Example of a household measurement (PV system)

The web interface development has been an essential feature enabling to easily detect firmware glitches during the initial rollout. Moreover the team has implemented an automated daily data quality verification alerting by email the researcher about missing or incorrect data. This allows a reliable and effective support of the device operation.

Currently and going into 2013, data collection from the four Arbiter and HACs is continuing. After making all data ready to be used, the collected data will be analyzed and transferred to

be used as input for the grid model based computations and algorithm development by Swiss2G partner BFH.

## Development of visualization and interaction panel user interface (ISIN)

The development on this work package is currently ongoing. A preliminary user interface will be released at the beginning of 2013 and initially tested internally by the team member. The possibility to give an additional tablet (iPad mini) to each household is being evaluated.

## B2G and S2G smart home (ISAAC)

The design of a **Battery-to-Grid (B2G) system** has been completed. Batteries will be installed in several households in Mendrisio. They will be charged and discharged from and to the grid in order to achieve smart energy management. This system will also permit to simulate the functionality of future V2G electric vehicles.

The S2G team has realized a test facility on the SUPSI campus in Canobbio. The rationale behind this test facility is to allow preliminary testing on the hardware components and on the algorithm scenarios prepared by IDSIA.

The test facility has been named “S2G-home” and has the following components:

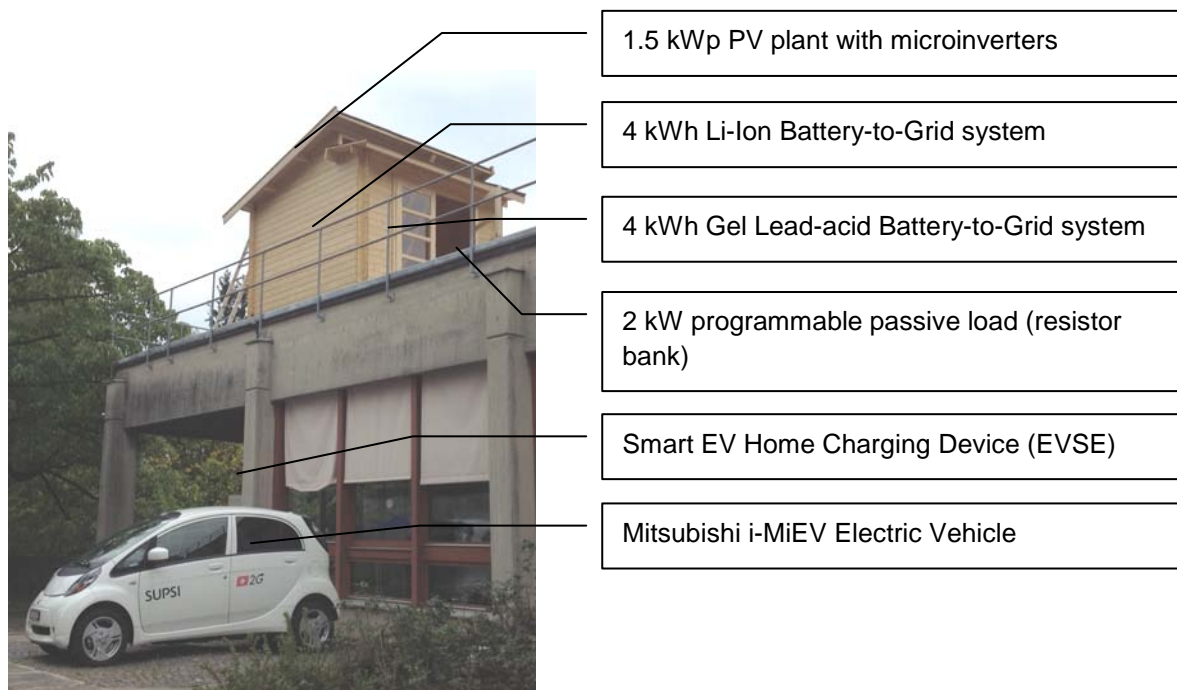


Figure 8 – S2G-Home components and features

The battery technology has been selected to ensure a safe behavior in a domestic environment. This was especially critical for the Li-Ion battery pack. In this case LiFePO<sub>4</sub> chemistry, which is one of the safer options, was chosen. Moreover the battery pack embeds an industrial grade battery monitoring system (BMS) with an electronic safety switch.



*Figure 9 – S2G-Home, detail of the battery systems*

The installation of the facility is almost accomplished and full operation will begin the next months. After verification of the proper working of the system four batteries will be installed in Mendrisio.

## **Collaboration nationale**

The project is actively seeking for opportunities for collaboration outside the consortium or in a different form between the partners.

Recently a CTI-project was granted. "HCD 2.0 is an innovative and smart EV home charging system equipped with self-learning algorithms that optimizes energy consumption patterns and electrical network stability." (CTI no. 14982.1 PFIW-IW). During this CTI the S2G algorithm will be implemented in an EV charging equipment.

The project plans to seek other collaborations with manufacturers of appliances, heat pumps, and photovoltaic inverters. A recent contact with a local battery manufacturer opens up promising perspectives for collaboration. Currently we are evaluating the possibility to install their battery in one of our households.

## **Collaboration internationale**

International collaboration with similar projects is being developed. SUPSI recently acquired an EU project (FP7-ENERGY-2012-1-2Stage / ENERGY.2012.2.1.1 Reliable, cost-effective, highly performing PV systems). This project focus on PV systems but it includes energy management and storage control. This will allow a benchmark between S2G algorithm and the EU project control approaches.

One member of the project team is also strongly involved in the topic of grid management on the international level, serving as a potential door opener for additional international projects.

In this context the DACH initiative has to be seriously take into account. In a meeting in January with all project teams we will define a common strategy in this regard.

## Évaluation de l'année 2012 et perspectives pour 2013

At the beginning of 2012 the project has been streamlined in the process of the elaboration of the second proposal for Swiss Electric Research by separating the Mendrisio and Meiringen parts. The updated project structure is described in annex 1. After this reorganization and the approval of phase B the activities on the work packages started again in June 2012. The end had to be postponed with respect to this new project schedule.

During the following months, the HACs and the grid measurements devices (Arbiters) have been installed. Work on the algorithm and tariff/price scenarios continued without problem starting to use the preliminary data acquired during the installation and testing phase. A complete B2G system has been designed and it has been assembled.

The only delay in this project regards the HAC installations. WP1 was expected to finish at the end of November 2012 but at this time only 40% of households are actually equipped with HAC devices. This was basically due to the necessity of a thorough verification of HAC hardware and software components under real field conditions. This delay will be caught up in the next months. Apart this delay the project is in line with the schedule.

Activities planned for 2013 are:

- the full implementation of all smart grid components, including energy buffers, with HACs fully equipped with S2G algorithms;
- the monitoring of the grid and households, data acquisition and data elaboration;
- the final development of the algorithm with forecasting capacities and its hosting in HACs;
- the evaluation of the impact of intermittent energy generation and algorithms on the grid stability under different tariff and diffusion rate scenarios.

## Références

[1] M. Salani, A. Giusti, G. Di Caro, A. Rizzoli, L. Gambardella. "Lexicographic Multi-objective Optimization for the Unit Commitment Problem and Economic Dispatch in a Microgrid". Proc. of IEEE-PES International Conference on Smart Grid Technology (ISGT), 2011.

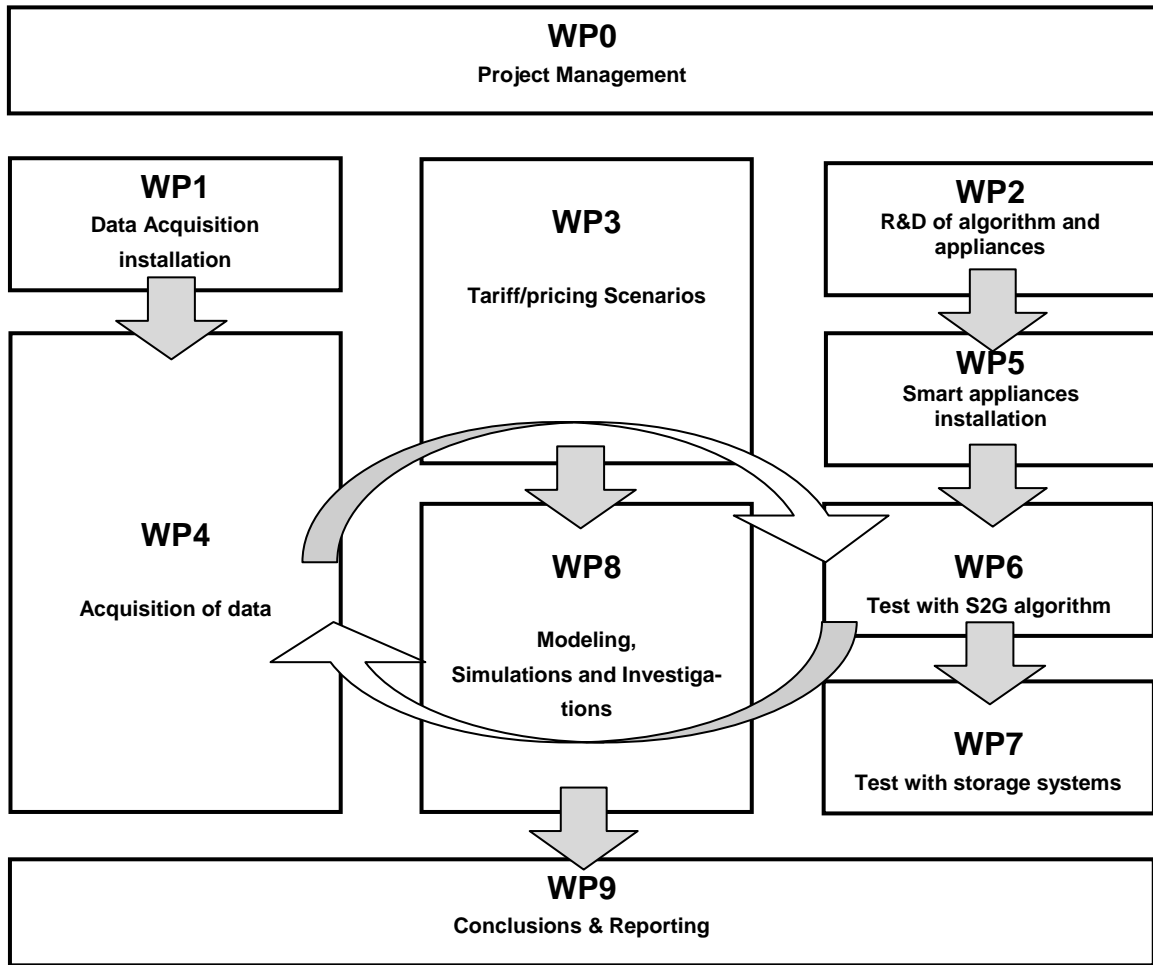
[2] A. Giusti, M. Salani, G. Di Caro, A. Rizzoli, L. Gambardella. "Mendrisio Data Analysis - Preliminary Report". Working paper, available upon request (alessandro@idsia.ch).

[3] A. Giusti, M. Salani, G. Di Caro, A. Rizzoli, L. Gambardella. "Restricted neighborhood communication improves decentralized demand-side load management". Technical Report, IDSIA-07-12, 2012

[4] M. Höckel, T. Häni, S. Eberhart. "Elektromobilität in Verteilnetzen", Messung, Modellierung und Simulation von Netzen mit dezentralen Erzeugungsanlagen, Speichern und Elektroautos, VSE Bulletin, 9/2012

# Annexe 1 – Phase B Project Planning

The phase B of the project is structured with the following work packages:



Short description of the tasks:

Task	Title	Lead
<b>WP0 Project Management</b>		
T0.0	Project Management	ISAAC
<b>WP1 Installation of data acquisition system</b>		
T1.1	Installation of HAC & household data gateway	ISEA
T1.2	Installation of grid data acquisition system	BE
T1.3	Test of data acquisition	ISAAC
<b>WP2 R&amp;D of algorithm and smart appliances</b>		
T2.1	Development of algorithm scenarios with varying levels of communication	IDSIA
T2.2	Development of algorithm for grid constraints forecasting	IDSIA
T2.3	Integration of algorithm into the household appliance controller	ISIN
T2.4	Design of B2G (Battery to Grid) system (bidirectional)	ISAAC
T2.5	Development of visualization and interaction panel user interface	ISIN
<b>WP3 Tariff/pricing Scenarios</b>		
T3.1	Development of tariff/pricing scenarios	DSAS
T3.2	Evaluation of impact of tariff/pricing scenarios	DSAS
<b>WP4 Acquisition of data</b>		

T4.1	Acquisition of household data	ISAAC
T4.2	Acquisition of grid data	BE
<b>WP5 Installation of smart appliances</b>		
T5.1	Installation of B2G (Battery to Grid) systems	ISAAC
T5.2	Integration of energy thermal buffers	ISAAC
T5.3	Installation of dispatchable loads	ISAAC
<b>WP6 Test with S2G algorithm</b>		
T6.1	Test with S2G algorithm	ISAAC
T6.2	Evaluation and analysis of acquired data	BE
T6.3	Review of S2G results and update of algorithm	IDSIA
T6.4	Implementation of the S2G algorithm into the HACs	ISEA
<b>WP7 Test with storage systems</b>		
T7.1	Test with storage systems	ISAAC
T7.2	Evaluation and analysis of acquired data	BE
T7.3	Review of S2G results and update of algorithm	IDSIA
<b>WP8 Modeling, Simulations and Investigations</b>		
T8.1	Maintenance and update grid model Mendrisio with measurements phase B	BFH
T8.2	Development of aggregate model for smart households	IDSIA
T8.3	Investigation of the effect of the S2G algorithm to higher grid levels	BFH
T8.4	Complementary simulations with other grid models	BFH
T8.5	Investigation of S2G algorithm effects on present grid control processes and strategies	IDSIA
<b>WP9 Conclusions &amp; reporting</b>		
T9.1	Final evaluation	ISAAC
T9.2	Reporting	ISAAC
T9.3	Dissemination	ISAAC