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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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Abstract

The diffusion of decentralized and small scale renewable energy sources arises completely new questions for the present centralized control and management of the grid. The diffusion of decentralized renewables leads to a more fluctuating energy supply and poses an unprecedented challenge to balance the energy supply and demand, requiring new forms of load shifting and storage. The general answers to this challenge are smart-grids, applying information technology for a central control and energy management.

The goal of the project is to demonstrate in a pilot project the technical feasibility of decentralized energy production, storage and consumption by combining available and new technologies in an intelligent and locally self-organizing system. The project analyses the practical use of **decentralized** energy production units in 20 smart private households, plug-ins for storage and environmentally friendly mobility and their impact on the local grid.

The key concept of the project is a self-organizing and decentralized load management by an algorithm integrated in the household appliances with the major potential for load shifting and energy generation and storage. The algorithm is designed to control the grid based local and limited information from the grid, such as voltage and frequency, improving the grid performance, the grid stability, and reducing the costs by peak shaving without limiting the consumers.

So far the concept of this algorithm has been tested successfully in a simulated environment. The results of the first measurement campaign on the grid have already been used as local information source for the decision process of the algorithm. In the next phase of the project the algorithm will be hosted on the developed household appliance controllers and installed in the 20 houses fully equipped with PV systems for real world testing. The simulation environment for households and the simulation tool for electrical grids are already successfully interacting and will be capable to show to which extend additional information can increase the performance of the algorithm and what will be the effects of an up-scaling of the configuration realized in the pilot project.

Goal of the project

The diffusion of a small and decentralized energy generation units poses a considerable challenge to the utilities, as grown over the last century, in not more than the next 10 to 20 years. The need to drastically reduce the CO_2 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 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 and therefore complementary to projects like VEiN. 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 limited 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 tremendous 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 in real conditions in about 20 households and the use of advanced optimization and simulation tools. The project is be carried out by an interdisciplinary team of the SUPSI – Ticino, Bacher Energy, 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. The identification of 20 households willing to participate in the pilot and demonstration project is 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. Moreover we plan, that the participants can benefit from a equipment for decentralized, renewable energy production.

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.

Work performed and results achieved

Introduction

The principle aim of the project is to demonstrate the concept of decentralized load management and shifting with 20 households. **ISAAC-SUPSI** was in charge together with Protoscar and AIM (Aziende Industrial Mendrisio, the local electrical distributor) to find and select these households. Protoscar supported ISAAC with the communication strategy bringing a long experience in working in Mendrisio (project VEL1) and strong multi-media skills. AIM provided the project with technical information and support about Mendrisio electrical grid.

Application criteria and announcement

The goal of ISAAC, to find 20 suitable households inside the relative small territory of Mendrisio municipality, was not trivial. The inhabitants of this region had already been exposed to the electric mobility during the previous VEL1 project, but it was not very clear how they would react to the topic of smart grids. The issues tackled by the project were challenging to explain to non-technical persons. In order to overcome these difficulties, it was decided to offer to the participants a photovoltaic system with an installed power of 1.5 kWp. The values of this offer, both from economic and sustainability point of view were very easy to understand. Once convinced the people to participate it would be easier to explain them all aspects of the project in a personal meeting.

ISAAC, in collaboration with Protoscar, organized a media strategy to promote the project and maximize participations results. The project public announcement was made in Mendrisio, the 20th of September 2010, in a public press conference with the most important representatives of Ticino media. Simultaneously a web portal (www.s2g.ch) has been launched with all the information required to understand the focus and the objectives of the project and the participation formulary.

A major article was also published in a special edition of “L’Informatore”, a local newspaper from Mendrisio region. This newspaper edition was sent to all households of Mendrisio.

In order to be able to select the best candidates for the project a list of criteria was prepared. Some criteria were mandatory and considered a prerequisite for participation:

- Household must be a private single family household
- Participant must be a house owner
- Household must be connected to AIM's electrical distribution grid
- Participant must accept a constant consumption metering for a period of three years

Other criteria were not mandatory but considered during the selection

- Desire to extend PV plant power
- Willingness to buy an EV
- Willingness to accept a battery system

Additionally the project had to consider the physical location of candidate's household, especially his connection to the neighborhood transformer. In order to maximize pilot houses effect on the grid, larger density of participants were preferred.

Results of the call for participation

Application results were remarkable, **in less than two months** (deadline was 15th of November 2010) **134 application** forms have been submitted. 103 of them were connected to AIM electrical grid and could be considered by the project.

The number of candidates is quite high if we consider that the total amount of energy counters in the AIM territory is 9151 (this number includes all kinds of users: apartments, industries, offices, etc…)

The majority of candidates were relatively young owners with houses of recent construction. Older people showed fewer propensities to a long term investment in such a PV system.

All type and level of instruction, and professional groups were represented; no predominant group has been identified. The following map shows the distribution of the candidates.

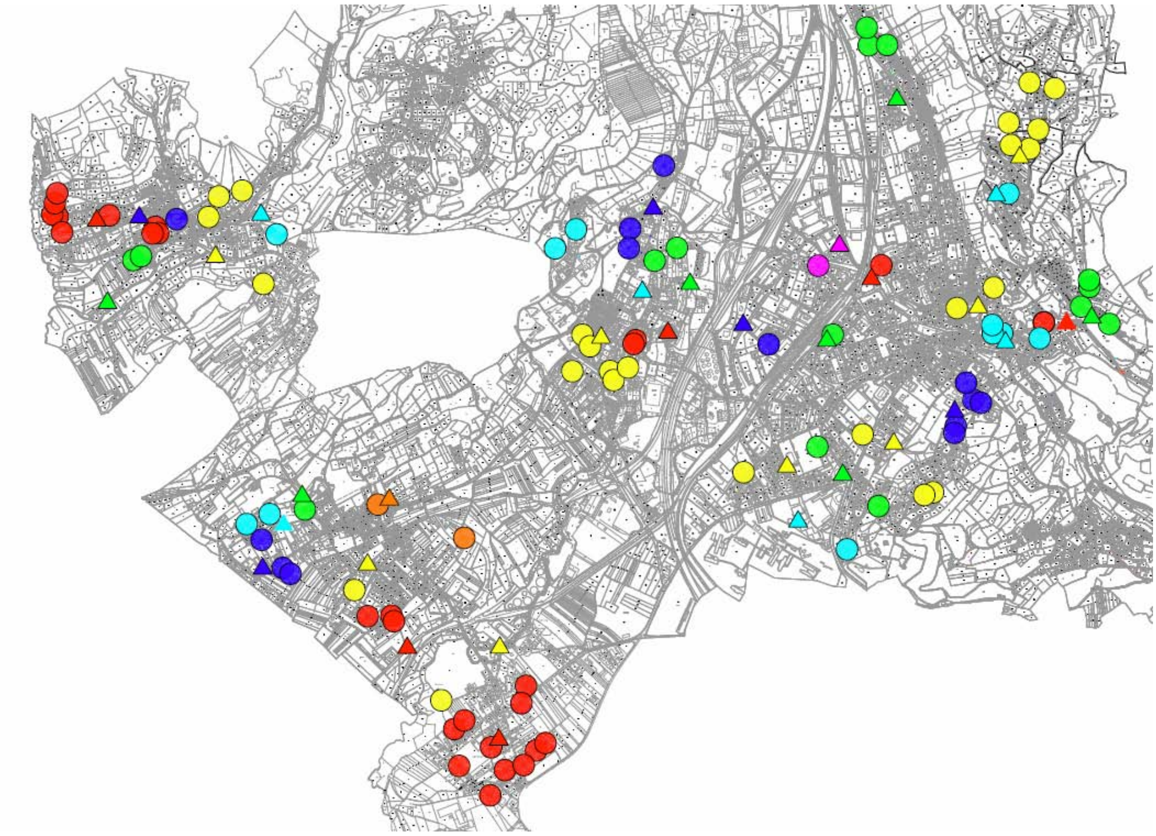


Figure 1: Map of the distribution area of AIM – Mendrisio

The next step was the preliminary interviews of the largest clusters, transformer “Asilo Genestrerio” (11 households) and transformer “Cimitero Arzo (9 households). The purpose of these interviews was:

- Explanation of the project, making sure the candidates understood what it would like to be a participant in S2G.
- Willingness to expand PV plant beyond the offered 1.5 kWp installed power, explanation of KEV incentives, current PV installation costs.
- Willingness to buy or lease an EV, explanation of current state of the art and prices.
- Technical assessment of the house, PV plant suitability and maximum installable power, household appliances inventory, pictures of the situation, etc.

After few days of interviews the following points were very clear:

- PV technology was not well known and easily confused with solar thermal collectors.
- After they were informed about of PV costs and KEV incentives, nearly everybody was eager to extend at least the PV plant to 3 kWp with an estimated personal investment of 10’000 CHF.
- Lot of candidates expressed in the interviews that they didn’t want at all to buy an EV, even if in the participation formulary the opposite was written.
- Confusion about EV technology was noticed too, several candidates expressed the desire to buy hybrid vehicle such as Toyota Prius confusing them with pure electric vehicle. Price expectation was not on pair with current market prices.

At the end a trade-off was chosen. The biggest neighborhood “Asilo Genestrerio” was retained because of his large size. Other two large neighborhoods “Posta Rancate” and “Casa del Bambino Mendrisio” were selected. The EV candidates were given the highest priority and could be part of the project even if they were the only ones connected to the local transformer.

Trafo	**Participants**	**EV**	**PV (kWp)**
Asilo Genestrerio	11	0	41.0
Posta Rancate	4	1	15.0
Casa del Bambino Mendrisio	3	0	13.0
Cimitero Arzo	1	1	4.5
Paolaccio Mendrisio	1	1	3.0

Table 1: The overall installed PV is over the double of the planned power

After the selection process an empirical investigation of customer behaviour, profiles and expectations was also executed. The overall impression of the investigation was satisfactory, in the sense that the sample of participants is really motivated in exploring the possible benefit of SGS, but with quite different expectations, sensitiveness and attitude toward the elements, the functioning and the effect of their specific domestic smart grid. In fact the participants could be easily clustered into three groups according to the motivation and expectations expressed during the interviews. The labels given to these groups are: (1) “Eco-Savers”, (2) “Carpe diem” and (3) “Green is better”. The first group included the 8 households who clearly stated that the financial support made the difference, more than a true ecologic attitude. The second and the third groups are equally represented with 6 observation but, while the “Carpe diem” were interested in being part of the game and experiment directly a new technology, the “Green is better” showed a strong inclination toward ecology.

As far as knowledge is concerned we observed a truly full array of answers, ranging from poor and superficial understanding of changing electricity market to highly documented opinion on photovoltaic technology or nuclear and environmental problems. Surprisingly the "master of the topic" is not directly associated to the "green" intensity of the respondent.

The main problems cited are of course the exit from nuclear technology and the need of having a secure energy provision system. Both topic divides the opinions of the respondents with a large majority against nuclear production and no fear about the way energy will be supplied in the future. It is also important to note that a general confidence on technology improvement is perceived as well as the need of a strong commitment by the public sector as a guide in the energy change process. Many respondents identify responsibility also at micro level, that is to say the way we behave daily as consumers, workers, parents…

As far as renewable sources are concerned, just few respondent did know about: the low actual share in energy production and/or the high cost for producing clean electricity and/or some of the other problems (intermitting production, NIMBY, LCA,…) related to solar and wind power.

Concept and Components of the P&D

This project is designed as a pilot and demonstrator, integrating different hardware components (household's appliances, PV, HAC) with multiple interfaces. Moreover, the project aims to demonstrate with real data the technical feasibility of decentralized load shifting. For this purpose we want to acquire a reasonable amount of data from the real world. As seen in the next figure several elements are measured and monitored. In some cases it will be by mean of participant's interviews or already existing data such technical specifications or grid layouts. In other cases it will be trough direct measurements of house elements. The building block of these measurements is the HAC (Household Appliance Controller), this device, developed by the project, will be installed in every appliance and it will monitor all the relevant values (voltage, current, frequency, etc.).

The data will be used in a simulated environment in order to understand and develop innovative ways of energy management. One of the results of the simulation will be an algorithm. This algorithm will be ported inside the HACs and will control the appliances behaviors.

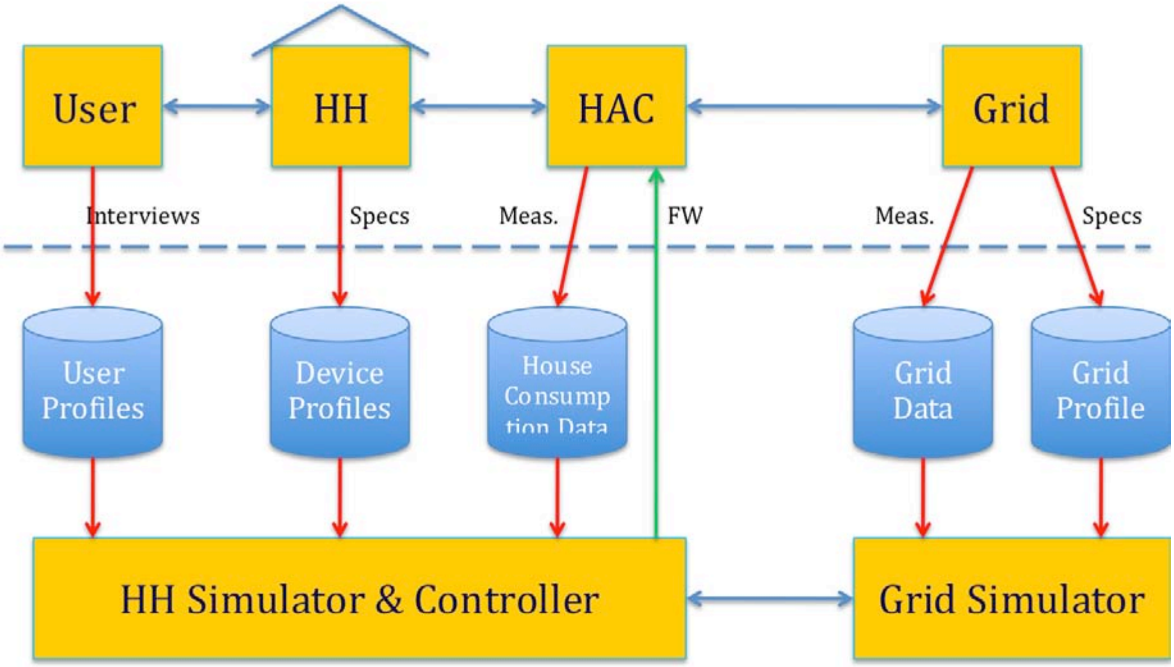


Figure 2: The schematic representation of the components (Hardware and Software)

The project will try to tests several level of autonomy for the house elements, with several degrees of communication between the elements (starting from no communication). The HAC's are equipped with a Powerline communication module; this module uses the normal AC cable inside the house as a communication channel. As we can see in Figure 3, every HAC is connected to the monitored appliance. HAC's data is then collected by a Touch Panel installed in the house. The entire data is then transferred through a regular ADSL connection to the project's web server. The data will then be checked daily in order to ensure the acquisition system is working correctly.

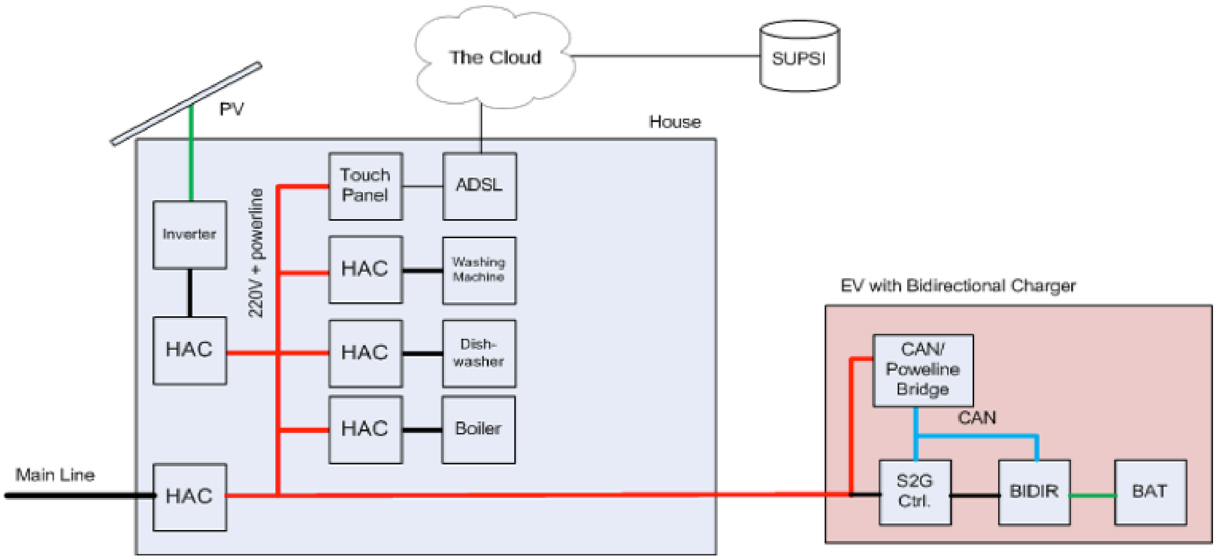


Figure 3: household components

HAC will monitor also PV system (AC side) and the EV. In the EV case, a HAC will be adapted and customized for each EV model. This device will act as a bridge between the CAN bus inside the vehicle, measuring energy consumption and controlling the bidirectional charger (BIDIR). In other cases, for some vehicles, the HACs will be installed inside the external EVSE (Electric Vehicle Supply Equipment), monitoring and controlling charging through mode 3 signals.

PV System

Specifications for the PV system are not very strict. PV applies more to the demonstrator part of the project, therefore the project tried to achieve the most heterogeneity of installations (inverters, modules, annexed or integrated plants, monocrystalline, polycrystalline and thin film modules). Several installer companies had also to be chosen in order to increase the variety of installations. Minimum installed power was chosen at 1.5 kWp. This minimal installation size was offered by the project to the households, as previously described in the application scheme chapter.

HAC – Household Appliance Controller

In residential and small business applications, household appliance controllers, specially developed by **ISEA – SUPSI** for this project, since no commercial devices with the needed technical specifications could be found, are capable to substantially reduce energy usage of water heaters, air conditioning units, refrigerators, washers, dryers, cooking appliances and other devices — even coffeemakers — during peak demand periods by turning them off for some portion of the peak demand time or by reducing the power that they draw.

In the pilot project up to 8 principal appliances will be equipped with a control module. The HACs embed a communication node (based on any protocol), a switch and a power meter and is located between an electrical appliance and its outlet. The communication node ensures the connection to the monitoring system (a panel-PC) and to the home centralized decision maker, if it will be necessary; the power meter analyses the absorbed electric current and generates useful information (functional, statistical, diagnostic and energy consumption) related to the appliance itself and fed in the intelligent agent in the node. The connection to the panel-PC is based on Power Line Modem, but it could be any standard protocol, including ISM band RF wireless communication standard like the IEE 802.15.4 (ZigBee).

Main specifications of the HAC:

- Voltage: 195-265V, 0.1V Resolution, 0.2% Uncertainty
- Current: form 0.1A to 25A, 1% Auflösung, 1% Uncertainty
- Power: consumption in W (active power), 1% Uncertainty
- Stability: 10ppm/°C
- Frequency: 49-51Hz, 1mHz Resolution, 1% Uncertainty
- Cos(phi): 0-360
- Communication with Powerline
- Port for temperature sensors

The functional blocks of the HAC are the following:

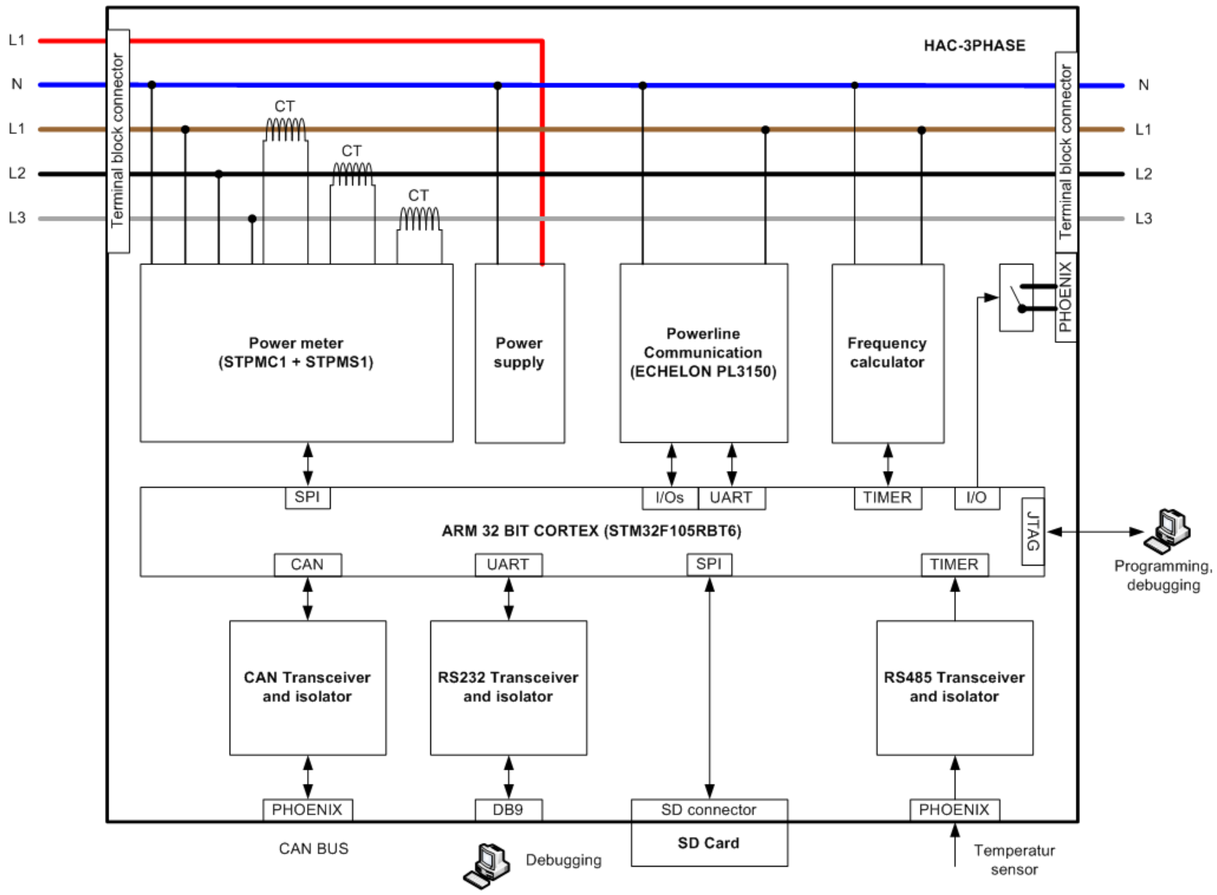


Figure 4: HAC functional blocks

Touch Panel

This device is a gateway unit based on fanless panel PC used as interface to monitor the powerline HACs network and is develop by **ISIN - SUPSI**. The device includes a powerline LON interface PL-22 and the standard Home automation SW application developed for home automation purpose. This software will be modified and adapted according to the S2G requirement. Operating system is an open-source Linux distribution.

During the first phase of the project the purpose will be only the monitoring of appliances, no user interface will be active. In the second phase the user interface will be activated and the participants will be able to see house consumption and actively interact with the intelligent energy management system.

Figure 5: touch panel unit

The chosen unit has the following specifications:

LCD Size	10.2”
Max Resolution	1024 * 600
CPU	Intel® Atom™ 1.6GHz
Dimension (mm)	313.83 x 222.13 x 52.5
Net Weight	1.5 Kg

Stationary and mobile storage

One of the goals of the project was to use EVs as an energy storage system for the houses. These vehicles should be bought or rent by house owners. A list of suitable vehicles has been prepared and submitted to the candidates, however, they were quite reluctant to buy an EV, since no further subsides could be granted. We will not dispose of as many EV's as we planned for the project. Supsi will deliver an electric car for test periods to the willing households, allowing monitoring sufficient data for the mobility part. Data from other experiments with EVs and mobility behaviour patterns help to simulate this part of the project.

However, it is planned to equip several household with a B2G systems according to available budget. This system is similar to the bidirectional charger for EVs but is stationary. Batteries will be installed in the house and they will be charged and discharged from and to the grid in order to achieve smart energy management. Currently this type of product in not on the market, all the battery systems are used to realize an off-grid backup power in case of blackout. Battery inverters are not able to inject power in the grid. It has been decided to realize a system using existing products applying the fewest possible changes. In Figure 6 a block diagram of the system is shown.

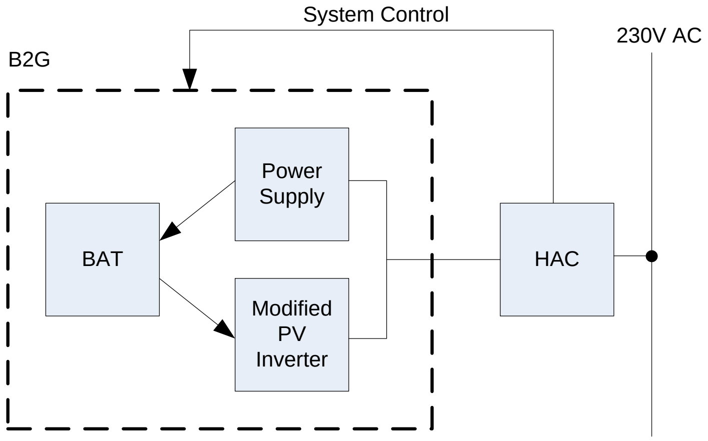


Figure 6: B2G schema of principle

The system is realized with a battery. A DC power supply is used to store energy from the grid in the battery. When required a modified PV inverter is able to reinject this energy to the grid. A household appliance controller, HAC, is used to monitor the energy exchanged and control the elements.

The most important issue with the battery is the installation inside the houses. Safety issues are quite relevant for regular lead-acid batteries because the possibility of gas leaks. This is not ruled out even with sealed models because of the presence of release valves. For this reason a sodium-nickel battery produced by FZ-Sonick has been chosen.

This type of battery is intrinsically safe and the electrochemical reaction can easily be shutdown. The battery includes a battery management system, regulating the charge process and protecting the cells during operation. Moreover the company is located in Ticino, making support operation easier.

The power supply is a regular DC power supply. The charge process is completely managed by battery's BMS.The S2G team plans to use a PV inverter. The firmware will be modified in order to disable built-in MPPT and support battery connection. A Swiss inverter producer, SolarMax, has been contacted for the sake to supply this modified inverter.

Mobile storage capabilities will be realized using the EVs available for the project. Three vehicles are mode3 capable. This means that the charge rate can be controlled externally through the mode3 charge plug without vehicle modifications. HACs will be used to control the external EVSE (Electrical Vehicle Supply Equipment) in order to achieve one-way charge capabilities.

Household simulation environment and algorithm

IDSIA-SUPSI designed and implemented smart decision models (algorithms) to control different classes of household loads, including several appliance classes, and Electric Vehicles (EVs). Full details on the algorithms are provided in reference [1]. According to our basic hypotheses the decision models should act on the basis of local information on the grid. This does not exclude information about weather condition or similar. But the model is not controlled by a central intelligence.

Algorithms operate by shifting loads in time in order to achieve different objectives; in particular, we considered two main objectives:

- stability of the electrical network at the local or global level, and
- cost of the energy for the user.

We evaluated the performance of our algorithms on such objectives, and also studied the tradeoff between the two under a multi-objective optimization paradigm, when considering different energy pricing profiles.

Planning

The role and specifications for S2G algorithms were defined early on; we identified four main scenarios, representing different amounts of communication available between different appliances and different households.

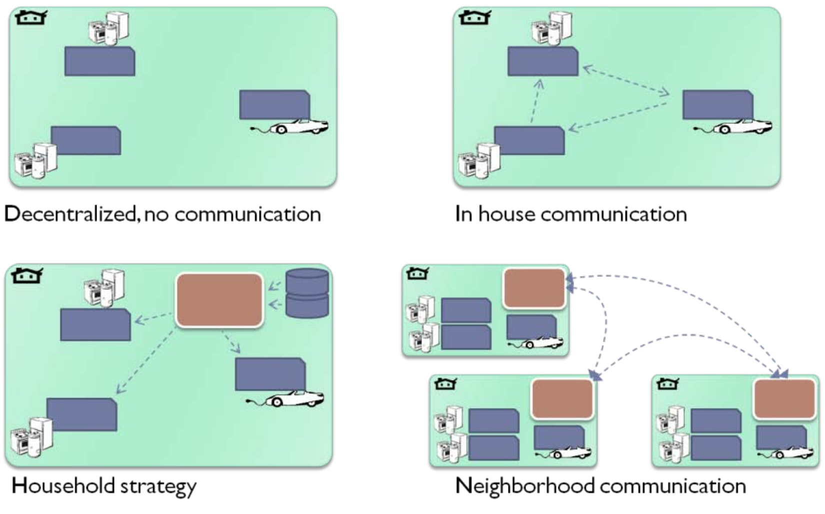


Figure 7: Scenarios with different degree of communication

We first developed algorithms for the “decentralized, no-communication” and “household strategy” scenarios; in a second step the algorithms had to deal with communication between different appliances and communication between different households.

Specifications and interactions with other components

Algorithms have access to a number of data sources:

1. measurements (such as, voltage at the plug, frequency)
2. information from other algorithms (for scenarios allowing for communication) and, possibly, external data providers (such as meteorological information)
3. historical data accumulated previously

Algorithms are designed to optimize energy consumption w.r.t. one or more time-varying penalty function(s); penalty functions must be defined as functions of the data available to the algorithm. The algorithm already incorporates routines for time series prediction, which are used to predict future values of the penalty functions based on their history. Different appliances are controlled by considering their models, ensuring that the appliance's state remains in an operational range while optimizing the energy consumption with respect to the penalty function(s). For example, as illustrated in the figure below, a dish washing program and an EV charging job are requested almost simultaneously. The algorithm decides to start the dish washing program immediately as it foresees an increase in the penalty function until the due date. On the contrary, it postpones the EV job before its deadline in order to take advantage of the foresee local minimum in the penalty function.

Note that penalty functions are signals able to model relevant objectives as stability of the electrical network at the local or global level, and the cost of the energy for the user.

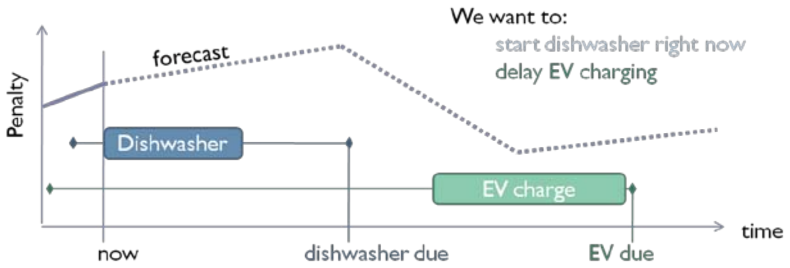


Figure 8: example of appliance smart control

Implementation

S2G algorithms are currently implemented as Java classes, including functionality for prediction of future penalties. The optimization process makes use of GLPK (Gnu Linear Programming Kit). Alternative, pure-Java implementations of simpler, baseline optimization policies are also available for performance comparison.

In the implementation we considered several appliance classes such as energy buffers (water heaters, fridge, freezer, and air conditioning), electric vehicles and programmable appliances (dishwasher, washers, driers) and possibly a battery for energy storage with bidirectional charger.

Current state

S2G algorithms have been implemented and tested in simulation (using both synthetic and real data as inputs) for scenarios not allowing for communication. Their effect has been verified to be beneficial for shaving load peaks and attaining a flatter load profile.

The swarm effect of multiple algorithms on the same grid has been evaluated (with positive results) on a simple grid model. Tests on more realistic grid models are currently underway.

Measurement on the grids (Bacher Energie)

The metering module has been focused to contribute to the general system understanding and to determine key system characteristics which should be measureable at the plog with minimum communication.

1. The entso-e Automatic Generation control system to stabilize absolute time, frequency and inter-area power flows with the goal to keep the frequency at 50.000Hz with minimal deviations and at the same time keeping the active power interchange between power frequency zones at day-ahead determined, market based scheduled values.

2. The primary power system control to stabilize any Europe-wide system frequency change caused by aggregate regional, national and continental changes in electricity consumption or generation.

3. The secondary and tertiary power system control to stabilize the system frequency at nominal value (usually 50Hz) in such a way that only causers of frequency change also correct the frequency.

   It is this complex inter-dependency of AC (alternating current) grid based time, of AC based frequency and whole-sale market-based inter-area power flow schedules which has made (entso-e) Europe-wide, strongly controlled TSO (transmiossion system operator) control centers necessary.

4. The grid inherent based thermal limitations for electricity flows in each grid element such as transformers, transmission and distribution lines, switches:

- o The grid element limitations on the meshed grid voltage layers have been handled in principle by limiting the inter-area power trade from one hour to the next using smart day-ahead market principles combined with smart intra-hour power generation rescheduling with each area. *It is the fact of the meshed grid structure and the complex physical Kirchhoff and Ohms laws leading to "unpredictable" flows in this meshed grid which has made central – or at least regional control – necessary.*
- o The distribution system element flow limits – at least on levels 7 and 5 - so far have been handled by applying a strictly radial (operational) grid structure (an "inverse"[1] tree with a root at the higher voltage levels) and the low-cost monitoring of physical line and transformer capacity reserves: Distribution utilities have to measure the maximum flow in critical elements by a low-cost instrument which is read and reset "manually" once or twice a year; if the distance of maximum measured current to the thermal limit is too small, usually distribution grid capacity has been increased by replacing the cables by "thicker" cables with more transfer capacity. I.e. the thermal limits on the distribution system voltage levels have so far been controlled by the design of the grid realized as "radial inverse tree" and the knowledge that the current flows from root of the tree towards the leafs of the tree: The leafs are the electricity consumers which follow electricity use patterns. Of these patterns, the worst case pattern must be detected meaning those patterns which lead to maximum grid element loading.

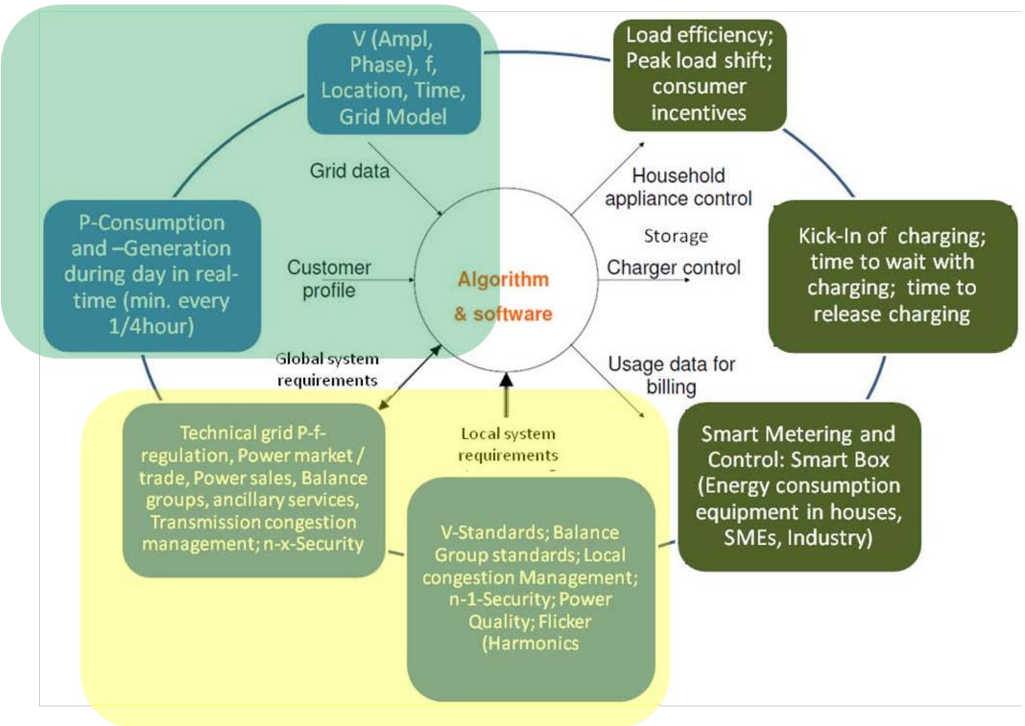
5. The grid inherent voltage magnitude limits ("norms") are usually set to plus or minus 10% of the nominal value (i.e. 230V plus and minus 10% at the lowest voltage level 7). These limits on the distribution system voltage levels have so far been controlled by the right design of the grid realized as "radial inverse tree" and the knowledge that the current

[1] Inverse meaning: The root is the higher voltage level – usually shown higher up than the leafs.

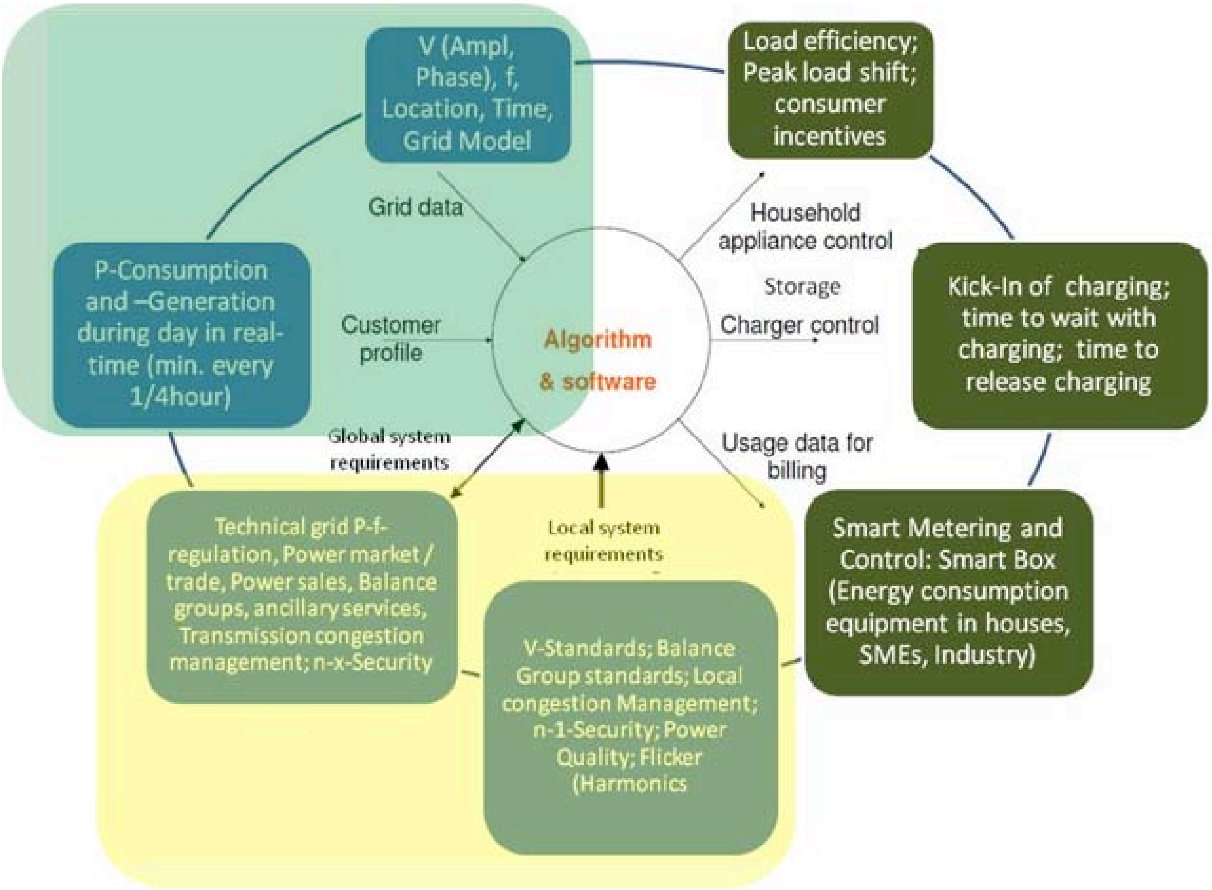
flows from root of the tree towards the leafs of the tree: The leafs are the electricity consumers which follow electricity use patterns. Of these patterns, the worst case pattern must be detected meaning those patterns which lead to maximum and minimum voltages; these voltages must be within the allowed voltage bands. The voltage control on the transmission grid and the upper voltage distribution grid layer 3 is more complex: Large generators themselves can control the voltage at the terminal busses of the generator. But also most transformers are able to change the AC voltage signal magnitude ratio between the voltage layers 1 and 3, 3 and 5, 5 and 7. Some (more expensive) transformers – mainly used from layer 1 to 3, can also change the voltage phase angle between the transformed voltage signals. So – at least until today - the voltage set point and controls at any large generator bus i has a consequence on the voltage of other busses j near-by*. It is also this complex inter-dependency of voltage control by large generators and transformer parameters which has made central – or at least regional control – necessary. Usually, this is performed by the TSO and DSO responsible for the security of supply in the upper voltage layers.*

6. Other critical quantities must be observed at all times such as transient voltage stability and short-circuit currents. They are not dealt with in this project.

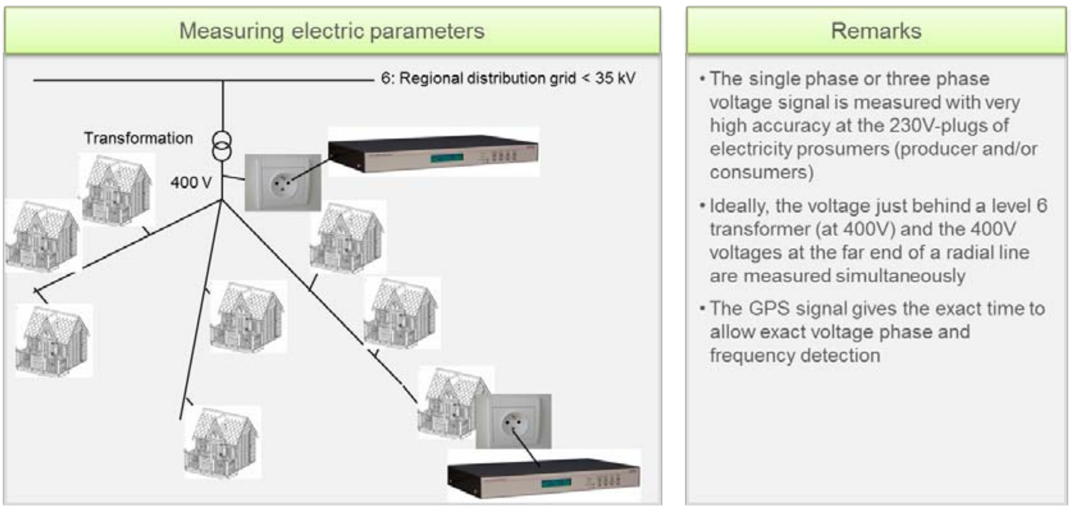
- The Swiss2G concept concentrates on innovative distributed methods and approaches to handle the limits of the distribution system exposed to many new decentral users. I.e. Swiss2G has the goal to consider as first priority at voltage level 7 (230V) the allowed voltage band limitations themselves and as second priority the electricity current limits in the cables used in the voltage level 7. A major goal of Swiss2G is to restrict monitoring and control to the “230V plug”.
- In this Swiss2G Measurement module, we concentrate on the measurement of voltage signal (and all derivable values) at the grid plug and current signals in the grid.



In this Swiss2G Measurement module, we concentrate on the measurement of voltage at the grid plug and current signals in the grid.



The chosen grid measurement location principle is shown in the following figure:



The Swiss2G – team measures only on the 230V (Single phase) and 400V (three-phase) levels of the distribution system. The measurement just behind the transformer (the root of the tree) is used as input for BFH to fine tune the – finally – fully distributed algorithm acting on the voltage at the plug (see lower right Arbiter equipment in above figure).

Meiringen: Measurements were started in December 2010 until ran until March 2011. Measurement intervals and quality was also partially influenced by the limited available time of the local grid operator whose support was urgently needed in any measurement phases of the project. However, in general, the grid operator was VERY supportive in this phase of the project. The following table shows the inherent challenges and measurement configurations done during this very first measurement period following ordering the measurement equipment in the US. The columns in the table indicate the availability, challenges and measured quantities at the various locations in Meirigen during the measurement period. Dark green indicates fully available data sets; yellow and light green indicates partially available data (lost due to inability to see sattelite GPS signal; Low winter temperature and snow problems; GSM communication problems alpine region; Arbiter recording software problems); white indicates no measurement (due to no access to rooms or cabins for resetting measurement and communication equipment).

Mendrisio: One full month (June 2011) was successfully recorded with all measurement equipment. Overall – already using a sub-selection of Arbiter-measured quantities – approx. 12 GB of data has been saved. The Arbiter equipment has been set up to record 1-second quantities including harmonic frequencies. All recorded data – sampled in 5 minute intervals in order to have a manageable data set – have been sent to the project managers. In addition, overview plots of recorded main data (Voltage AC signal, Current AC signal, GPS time) have been sent to project managers for storage on the project server. The project partner BFH has received an ordered and quality checked Excel csv- file containing these quantities and the associated locations to derive a grid model and the simulation of computed grid states to simulate on one side the effect of control actions of the Swiss2G algorithm on the grid itself and on the other side to simulate (later) the massive introduction of distributed generation and storage and many flexible consumer equipment. In addition to this, project partner SUPSI has received the original set of data in 1 second intervals to research possible data correlation on a very fine-grained level.

Grid simulation (BFH)

Da im Verlauf des Projektes die Erkenntnis gewonnen wurde, dass doch erhebliche Unterschiede in Bezug auf Topologie, Betrieb und Nutzung von Verteilnetzen bestehen, wurden die Modellierungsarbeiten wurden in Erweiterung des Antrages auf 2 Verteilnetze, nämlich AlpenEnergie und AI Mendrisio. Das Netz der AlpenEnergie, welche einen grossen Teil des Ortes Meiringen versorgt, besteht aus mehreren Strängen mit relativ kurzen Leitungslängen. Die Leistungsfähigkeit des Netzes (Kurzschlussleistung) ist an allen Netzknoten relativ gering und wird durch die relativ schwache Anbindung an das Verbundnetz bestimmt. Das Netz weisst erhebliche Eigenproduktion auf und kann zeitweise im Inselbetrieb gefahren werden.

Im Gegensatz dazu besteht das Verteilnetz von AI Mendrisio aus langen Strängen, wodurch die Leistungsfähigkeit der Netzknoten sehr unterschiedlich ist. Von besonderem Interesse werden die Auswirkungen der dezentralen Einspeisungen auf die Netzgrössen sein.

Beide Netze wurden mit vorhandenen Messungen validert. Die Validierung des Netzes AlpenEnergie basiert im Wesentlichen auf den sehr detaillierten Messaufzeichungen während des Ladeversuches einer grösseren Anzahl von EV im Januar 2011. Bedingt durch seine grosse Ausdehnung und der relativ geringen Anzahl an Messreihen konnte das Netz von AIM bisher nicht validiert werden. Aus den vorhandenen Datenreihen konnten geeignete Tageslastprofile für die einzelnen Liegenschaften berechnet werden. Dennoch ist aufgrund der Erfahrung der BFH davon auszugehen, dass die Modellierung für die anstehenden Simulationen ausreichend genau ist. Die für Phase 2 geplanten Messungen sollten für die Netzvalidierung wichtige Informationen bieten, welche dann ebenfalls in das Netzmodell einfliessen.

Neben den Modellierungsarbeiten wurden im Rahmen des Teilprojektes Simulation folgende Simulationen und Auswertungen durchgeführt:

- PQ-Messungen am EV-Ladetag Januar 2011: Eine Auswertung der PQ-Geräte an den wichtigsten Netzknoten während dem gleichzeitigen Laden der EV zeigte keine Verletzung der Grenzwerte für die Spannungsqualität gemäss eN50160.
- Simulationen zur Korrelation von Spannungsschwankungen und Leistungsüberlastungen: Mittel Simulationsrechnungen wurde dargestellt, dass die Spanungsschwankungen, welche durch die Last am Ende eines Leitungsstranges hervorgerufen werden, wesentlich kleiner sind, als die Spanungsschwankungen, welche durch andere Effekte (z.B. Transformatorstufenschalter) hervorgerufen werden. Folglich eignet sich die Spannung am Anschlusspunkt allein nicht zur Verhinderung von Leitungsüberlastungen.
- Ermittlung der Lastprofile von Niederspannungskunden aus dem Transformatorlastgang: Zur Modellierung des Tagesgangs der Belastung im Niederspannungsnetz wurde ein Tool auf Basis von Matlab entwickelt mit welchem auf Basis des gemessenen Lastganges am Verteilnetztransformators über Standardlastprofile die Lastprofile an den einzelnen Verknüpfungspunkten im Niederspannungsnetz berechnet werden.

Zum Abschluss der Modellierungungsarbeiten im Phase 1 des Projektes wurde eine Simulation mit einem einfachen Laststeuerungsalgorithmus im Niederspanungsnetz der AIM durchgeführt. Hierzu wurde das bestehende Verteilnetz um zusätzliche Last- und Einspeiseelementen sowie einem stationären bidirektionalem Speicher erweitert. Letzterer wurde ausschliesslich über die Spannung am Verknüpfungspunkt zum Verteilnetz gesteuert.

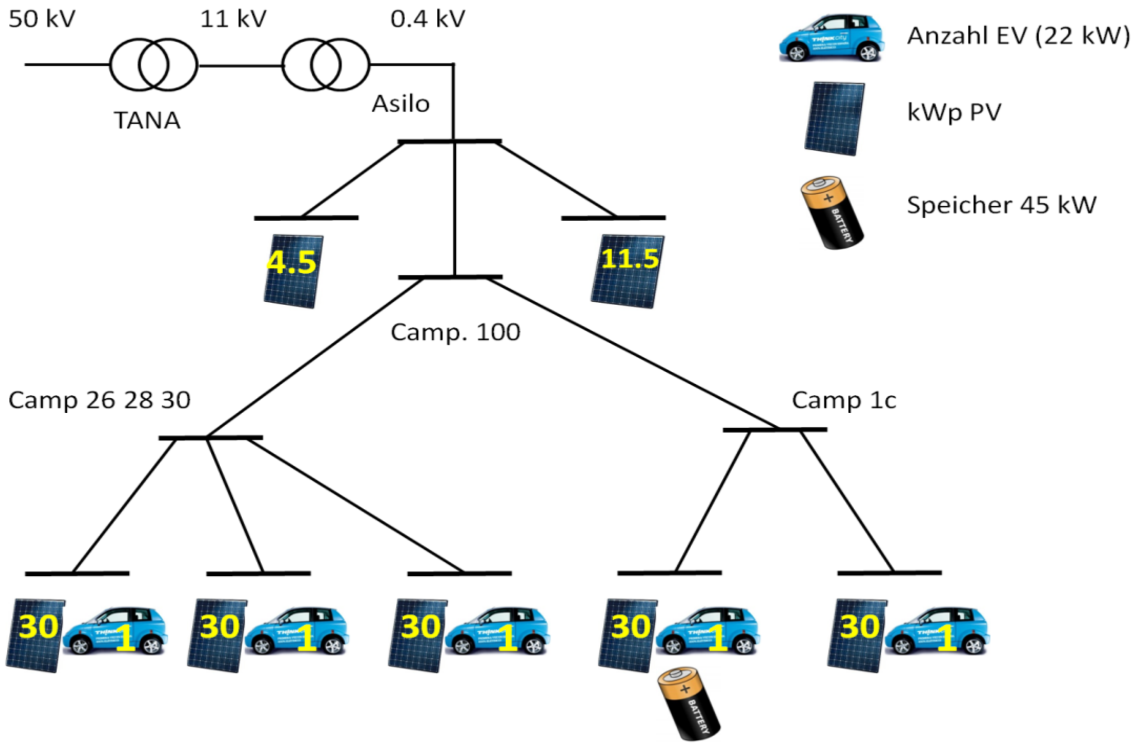


Figure 9: Platzierung der dezentralen Elemente in einem NS-Strang von AIM

Bei den Lastelementen handelte es sich um 5 schnellladefähige Elektrofahrzeuge. Die dezentrale Einspeisung bestand aus 7 PV-Anlagen mit einer Gesamtleistung von 165 kW. Die Simulationen haben aufgezeigt, dass der Aufbau der Netzmodelle hervorragend geeignet ist, um Variantenstudien durchzuführen. Es wurden automatisierte Schnittstellen geschaffen um Messdaten einzulesen und synthetische Daten zu generieren.

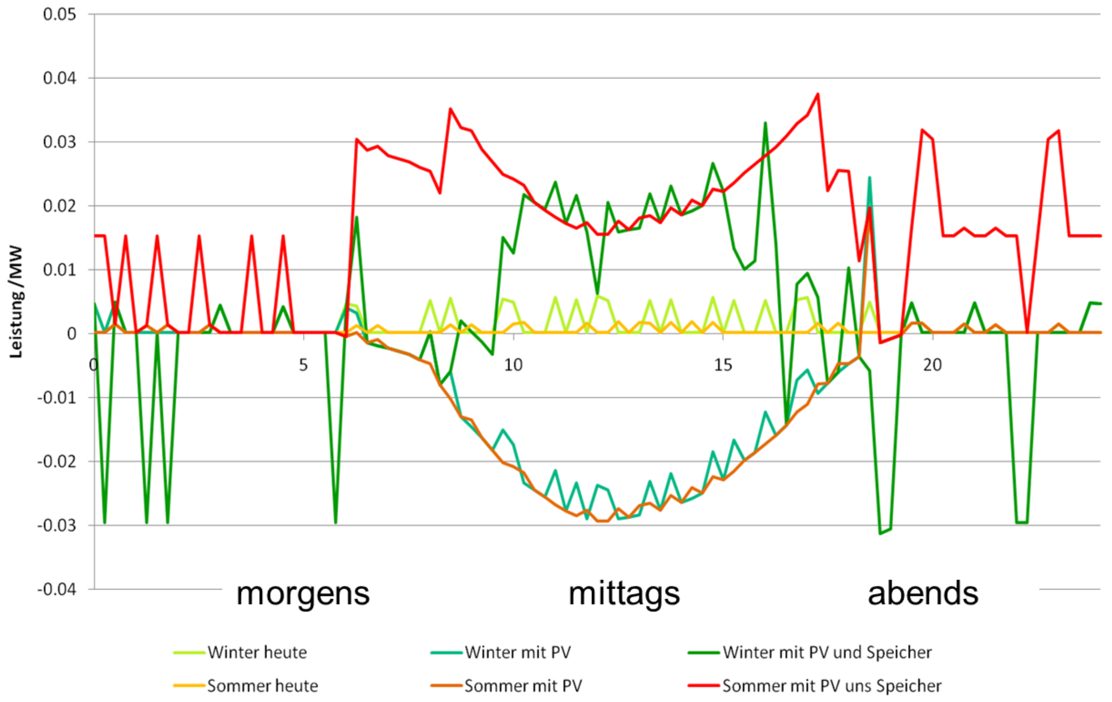


Figure 10: Leistungsbilanz (Aufnahme ist positiv) eines Hauses in 3 Szenarien (nur Haushaltsverbrauch / mit 1 EV und 1 PV / mit 1 EV + 1 PV sowie spannungsgesteuerten Speicher) für einen typischen Sommertag und einem Wintertag. Der Speicher ist in der Lage (rote Kurve) den die Produktion der eigenen und von nahegelegenen PV-Anlage aufzunehmen.

Die Ergebnisse der Simulationen haben gezeigt, dass bereits ein einfacher Algorithmus in einem Netzelemente erhebliche Auswirkungen auf den Betrieb und folglich auf die Belastung der Netzelemente und der resultierenden Spannungsprofile haben kann. Besonders wirkungsvoll scheint der Algorithmus in Zusammenhang mit dezentraler Einspeisung zu sein. Hier ist durch die Spannungsanhebung von Erzeugungsanlagen die Spannung am Verknüpfungspunkt ein hervorragender Indikator für eine lokale Leistungsoptimierung.

Die Modellierung und Validierung der Netze sowie die Simulationen von ersten Cases sind in den ausführlichen Arbeitsberichten der BFH beschrieben.

National collaboration

In the first phase of the project the basic components of the project have been developed and implemented. After this phase of elaboration of the project the different project partners will investigate forms and ways to collaborate with other research teams in the area of smart-grids. The Supsi project team is also involved in setting up a CTI –project with a private partner with his own home charging device for electrical vehicles.

International collaboration

International collaboration has not been developed so far. One member of the project team, however, is deeply involved in the topic of grid management on the international level, serving as a potential door opener in the second phase of the project, when first results can be shown.

Supsi has been involved in a German call for electrical vehicle test regions. However the partner was not successful with his project proposal.

Review 2011

Ticino P&D

As already indicated 20 households could be identified and outfitted with PV. Moreover we reached the clustering of this household and the house-owners a generally very well disposed to participate in the demonstration phase. They also doubled the granted PV power by buying their own PV – panels, indicating certain sensitivity to energy and environmental issues. This relation will be further investigated in phase B.

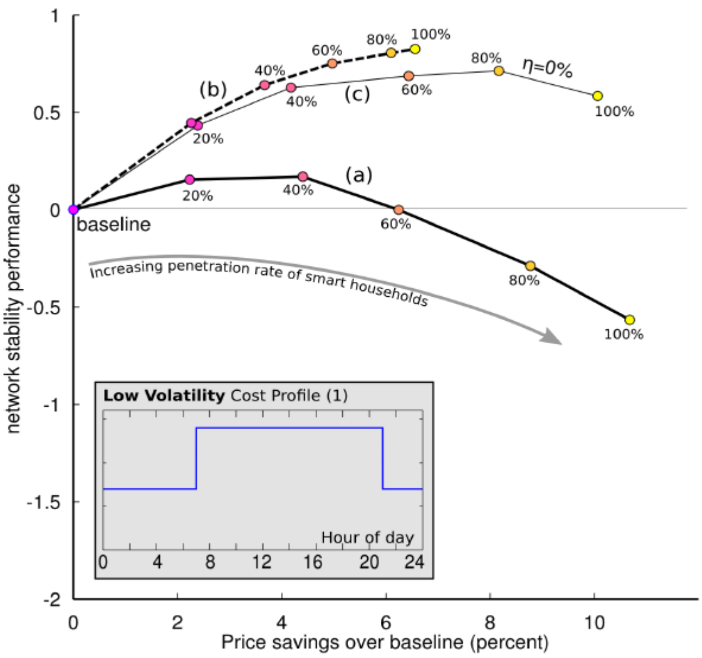
The HAC was successfully developed and the first 5 prototypes have been tested. According to the project plan, they will be implemented at the beginning of the next project phase in the 20 households.

Figure 11: HAC prototype unit

The presentation of the energy consumption on the Touch panel has been implemented and the touch panel correctly works as the gateway for the households.

Simulated experiments have been performed on 50 households connected to the same LV transformer, and are reported in the figure on the right.

Each simulated household has up to 5 energy buffer appliances, 1 electric vehicle, up to 4 programmable appliances and possibly 1 stationary battery. Moreover, each household has a number of non-controllable appliances (cooking, lighting, entertainment). Each household has 1 to 3 residents,



following reasonable routines, which vary every day according to given probability distributions.

As base reference we use a simple scenario in which no control is made (labeled baseline). In our simulations, a household can be either smart (all controllable appliances make use of optimization algorithms) or ordinary (optimization algorithms are not used at all). Tests are run for 10 simulated days.

We tested different settings for our algorithms under the two-level Swiss pricing pricing profile:

- 5 different portions of smart households 0% (baseline), 20%, 40%, 60%, 80%, 100%
- 3 algorithm settings:
    a) optimization of end user energy cost only;
    b) optimization of network stability only;
    c) optimization of network stability after ensuring that energy cost is equal to that obtained by setting (a) (the best possible energy costs for end user);

Each of the 15 simulations (plus the baseline case) is summarized to a single point. The point is positioned as follows: on the x axis we report the percentage price savings due to smart-algorithms; on the y axis we report the network stability measure w.r.t. the baseline – positive values representing better stability.

Optimization setting (a – energy price only), whose simulations for increasing portions of smart households are connected with a thick line, improves both energy price for the users (and, as a side effect, network stability) while the portion of smart households is below 40%. With full penetration of smart households average price savings reach 11% but comes at a cost of larger network instabilities w.r.t the baseline case.

When optimizing network stability alone (setting b), whose simulations are connected with a dashed line, network stability improves steadily; interestingly, energy prices for users also decrease as a side-effect of algorithms shifting loads off peak-times (i.e. to low-price periods), but such improvement is not very marked.

Optimizing both energy price for users and, as a secondary objective, network stability (setting c) leads to almost optimal results for network stability, with energy prices being as low as in setting (a), representing a win-win situation for both stakeholders.

It's very interesting to note how this scenario varies when pricing profiles change, e.g., when the dynamic Swedish pricing is considered instead of the simple bi-level Swiss profile. It turns out that very dynamic pricing profiles allow setting (a) to provide very significant price savings, at the expense of dramatic degradation of network stability due to artificial peaks created by algorithms simultaneously charging energy buffers in short low-price periods. For the same reason, setting (c) is prevented to work correctly, as minimization of energy price for users only admits a single solution, which is adopted by all algorithms. Allowing a margin on optimal energy price for algorithms to improve network stability is possible in the current framework and leads to good improvements. This is not reported in this document, but can be found in full detail in the paper referenced below:

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". Proceedings of IEEE-PES International Conference on Smart Grid Technology (ISGT), 2011.

Grid Measurement (Bacher Energie)

The measurement experience of this Swiss2G phase A has shown the following:

- The installation of 400V plug measurements is relatively easy in private houses, but quite difficult in outside-home locations such as cabins. Also, measurement of three phase voltages in transformer stations is relatively easy. On the other side, not all three phases are available at regular plugs in homes: There usually only single-phase plugs are available. The phase available at such a single phase plug is arbitrary. It can, however, be detected globally with an exact absolute (GPS) voltage phasor measurement because all voltage phasor measurements of the same phase behind a transformer only show a difference between plus / minus 1 degree to the transformer voltage phase. The difference between the individual phases is approx. plus/minus 120 degrees at as single location. The same does not hold for voltage magnitudes which cannot be used to “order” arbitrary measurements.

- The measurement of currents “in the grid” (i.e. in the underground cables) is problematic in all cases: In transformer stations, often the cable wiring is too thick to use the available current measurement transformers at the 400V side. Also, often the available physical space is simply not large enough for current measurements instrumentation using current-current transformers (such as used by the Arbiter). In cabins (Verteilkabinen), often the physical space is also very limited and the “environment” is not ideal for high-sensitivity measurement equipment. In homes (e.g. basements, garages), only the measurement of voltage signals is easily possible; the access to the home meter – metering the total current into the home - is not possible without the help of a certified electrician. In addition, often the place for a current transformer measurement equipment is not available in the box (Haus-Schaltkasten).
- Already simple plots show how complex the electric grid and system behaviour is: In the 400V grid, voltage and currents vary widely even within short time periods due to the low net consumer and generator aggregation effects on this voltage level. This relatively low degree of aggregation – leading to a relatively low degree of “same patterns” during short intervals of a day will even be worse when a higher amount of distributed power infeed at about the same order of magnitude as electricity consumption today will be available.
- In contrast to common sense, the current of a household section 11kV-400V transformer at the 400V side is often maximal at around 22h, i.e. neither at 7h in the morning, nor at 11:30 nor at 18h. It is the ripple control system (Rundsteuerung) which leads to same-time-switching in of many electric water heaters at this late evening time and thus to large currents at this time, decreasing towards 2am in the morning when all electric boiler water is heated up. One can conclude that the Swiss2G algorithm applied in Switzerland with many installed ripple control systems for hot water boilers (and in the winter electric heating systems) will need to include logic to handle this already existing controlled, “non-natural” use of electricity. It seems to be equivalent to the advent of control of batteries of electric cars: It’s about smart shift of stored energy to reduce peaks and fill the gaps.
- The infeed of a few PV modules at HH06 (Mendrisio) shows already very interesting and challenging results. The fact that the voltage at the infeed-phase is lifted could be expected, but perhaps not with this intensity (higher than transformer voltage at a few time instants). Also, simulation based explanations will be needed for the voltage phasor effects caused by PV cells feeding – as in this real-world example - into a single phase.

Overall, the measurement module of Swiss2G – Phase A - shows that the full and detailed complexity of consumer, generator and later storage processes at the 400V level can today only be captured with fully analysed real-world measurement sets at different distribution grid locations throughout Switzerland. The project member responsible for the measurements described in this paper is convinced based on the experience gained with this first set of measurements in Meiringen and Mendrisio, enhanced by findings of the SUPSI and BFH partners and enhanced by own knowledge related to the complex control of highly reliable power systems up to the transmission level that at least decentralized local voltage magnitude control at the 400V level caused by controlled, smart switching of electricity consuming equipment “behind the plug” through the “plug-measurement only” Swiss2G algorithm has a high chance of success. It is, however, not yet proven, that voltage magnitude only measurements without any communication of near-by measurements can achieve the job. Measurements and simulations indicate also a sensitivity of both the voltage magnitude (difference) and of the phase angle difference between 400-V plugs for securely controlling flows in the grid. More months during summer and winter must be measured to determine patterns and correlations between plug-only quantities and their differences towards critical current flow in the 400V grid. An early switch to voltage magnitude only measurements is not yet recommended from the point of view of this project partner: Assuming that voltage magnitude measurements only is pre-mature and needs to be verified through high-accuracy measurement and grid modelling before applying this principle to the “plug-only measurement” algorithm.

To conclude: Corresponding concepts for local, decentralized voltage control using “plug-only measurements” without any communication of other measurement are now, at the end of phase A of the project Swiss2G, look promising, but they are still in their infancy. The issue is very complex. This is also due to a still untested and non-yet-measured effect of an increased number of decentralized PV cells feeding – both symmetric 3-phase and unsymmetric single phase - into in the demonstration grids and also due to the missing number of electric (car) batteries consuming electricity from and potentially feeding into the grid.

In order to advance the state of the art in this very complex issue of decentralized monitoring and control of the 400V grid of the future, this should be implemented, be measured and be simulated in phase B of Swiss2G together with the embedded behaviour of already existing ripple control (Rundsteuerung) of mainly electric boilers and electric heaters (where locally applicable today). The goal of phase B should be to get deeper insights into the real-world, real-time electric grid state changes and the necessary distributed Swiss2G algorithm to guarantee continued security of supply without the need of a costly expansion of the grid at the lowest voltage levels and expensive balancing power for the variability caused by PV-cell feed in the 400V grid

Grid Simulation (BFH)

Dem Projektteam stehen mit den Netzen Alpenenergie und AI Mendrisio zwei recht gute Referenznetze für weitere Untersuchungen zur Verfügung. Durch die Implementation der Feldmessungen in die Netzmodelle konnten diverse Case Studies durchgeführt und wertvolle Erkenntnisse für die Ausgestaltung des Algorithmus gewonnen werden.

Es hat sich herausgestellt, dass die reale Netzbelastung heute und damit die Spannungsabfälle an den Netzknoten relativ gering sind, die lastbedingten Spannungsabfälle allerdings auch im Bereich der maximalen Belastung der Betriebsmittel im Vergleich zu andere Einflüssen (Transformatorregelung) weniger stark sind als erwartet. Die Spannung am Anschlusspunkt der Kunden eignet sich jedoch bei der aktuellen Strategie des Netzbetriebes vor allem als Kriterium um Lasten auf lokale Einspeisungen abzustimmen. Es wurde gezeigt, dass im Zusammenhang mit einer dezentralen Einspeisung durch Photovoltaikanlagen bereits ein einfacher Algorithmus kann erhebliche Auswirkungen auf Auslastungen und Spannungen im Verteilnetz haben kann.

Die Grenzwerte für die Spannungsqualität gemäss der Norm EN50160 oder den Technischen Regeln DACHCZ werden auch bei starker Zusatzbelastung des Netzes im Allgemeinen nicht tangiert. In Phase 2 sind vor allem die Effekte der Spannungsanhebung durch Einspeisung nach DACH und dem Flicker noch genauer zu untersuchen.

Die Wirkung eines Algorithmus könnte erhöht werden, wenn zusätzliche Netzinformationen einbezogen und/oder Regelprinzipien für Spannung durch den Verteilnetzbetreiber oder Frequenz durch die Übertragungsnetzbetreiber angepasst werden.

In Abhängigkeit des gewünschten Effektes (target object/function), könnte es zudem sinnvoll sein, gewisse Einstellungen «vorort» in Abhängigkeit von den lokalen Netzgegebenheiten (Auslegung, Belastung, Einspeisung) zu ermöglichen. Diese Einstellungen können die Definition von Grenzwerten, die Auswahl von Inputgrössen oder die Ausgestaltung des Algorithmus betreffen.

Summary of results

- **20 households are equipped with 88kWp of PV – panels, earlier than project plan**
- **The simulation tool and algorithm are fully functioning in the artificial environment. First tests with real data, measured on the local grid (see Bacher Energy) show a reasonable reaction to the voltage changes in the grid, with respect to cost optimization for households as well as for load shaving for local utilities. The real meaning of the results has to given in the next phase (in advance with respect to project schedule)**
- **Prototype of HAC with Touch screen has been constructed and successfully tested (in time with respect to project schedule)**
- **The investigation of the user profiles is ongoing (slighted behind project schedule)**
- **High precise grid measurement campagne has been carried out in Meiringen und Mendrisio and the data were subsequently analyzed, giving new insights in voltage patterns in distribution grid).**

“Proof” of Concept” is given with fully functioning and versatile algorithm.

Outlook 2012

Ticino P&D (SUPSI and Bacher Energie)

The next steps are essentially determined by the previous work, successfully carried in time during the first phase. The major challenge is to demonstrate the effects of the simulations and the working of the algorithm in the real “pilot” world and to interpret the obtained results.

- **Equipping the 20 households with HAC and touch panels and with mobile and stationary batteries, starting the real-time monitoring of the appliances and the PV systems.**
- **Equipping the households with control of thermal buffers (electrical water heaters) by overriding thermostat functions with HACs**
- **Equipping two households with smart appliances (washing and laundry drying machine modified for HAC control).**
- **Equipping two households and the SUPSI EV with smart EV chargers (mode3 one-way charge controlled by HAC).**
- **Further measurement campaigns analyzing real effects of PV, batteries and load shifting by algorithms.**
- **Analyses of grid data and identifying effects on the grid.**
- **Up-scaling of with grid simulation tool and understanding effects and impacts on higher voltage grid and benchmark with business as usual.**

- **Exploring scenarios with communication between appliances and households. Measuring marginal effects of communication (Neighborhood communication).**
- **Understanding the effects of the functioning of the algorithm for household members and utilities. Evaluating advantages and disadvantages of smart grid in terms of cost savings as well as and changes on behavioral patterns.**

Grid Simulation (BFH)

In Phase 1, many measurements had been carried out to get the information about the use of the grid. A first verification had been of the grid AlpenEnergie had been successful. The measurements in Mendrisio do not allow the verification at the same level, a further combination of grid information, actual measurement results and future measurement results will be used for a verification of the Medium and Low Voltage grid of Mendrisio. The main interest is the change of the grid behavior due to the PV- Installations and the use of the EV.

Related to the special situation of the grid AlpenEnergie, which allow the islanding operation, this grid model will be enlarged to full dynamic model for RootMeanSquare simulation. The results will show how a local grid without connection to the UCTE will react on the swarm intelligence.

Using the verified grid simulation tool an extrapolation of the project results to large numbers of PV, EV and HAC will be tried. One main question, which should be answered, is whether the algorithm will destabilize the grid, if it will be used in more and larger areas. This will also include to option to influence the users which are equipped with the swarm intelligence by moderate and controlled variations of the frequency and/or the transformer adjustments within the tolerance of the standards. This option could be regarded as an indirect communication and could be introduced without delay and without any investment. This approach would allow the smooth and continuous introduction of grid usage optimization.

Additionally it should be proved at the beginning of Phase 2, it is helpful to use other distribution grids for some case studies and if other partners are interested to support this project with information.