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Swiss2G – Pilot- and Demonstration Project

An innovative concept for the decentralized management of distributed energy generation, storage and consumption and measurement modules

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Abstract (max. 300 words)

The growing concern over climate change, the end of low cost fossil fuel and the development of renewable energy technologies are profoundly reshaping the energy sector and fostering electric mobility. The diffusion and connection of small and decentralized energy generation units connected to the grid leads to completely new questions concerning traditional centralized control of the grid and load management. The role of the consumer will be redefined and poses a challenge to the utility companies.

The overall goal of the pilot and demonstration project is to equip 20 houses in Mendrisio with photovoltaic modules, smart-metering devices for households and fixed or mobile storage units (electric cars) for understanding the potential functioning and limits of smart grids in real-world environment. The project investigates in this pilot project (phase A of two phases) the technical feasibility of as much as possible distributed power system control for decentralized energy production, storage and consumption by combining available and new technologies in an intelligent and self-organizing system.

A fundamental element of the projects concerns the acquisition of real-time data at the 400V distribution grid level in order to a) derive a robust grid network model, b) to support robust algorithms to control and to switch several electricity consuming and producing devices in the households including c) the battery of electric cars and its states of loading, feeding-in power and not doing anything and finally d) a robust system control behaviour. The tasks to achieve these goals are mainly done by the other project partners (BFH, KWO, Battery Consult).

The underlying innovative idea of this project phase A regards the attempt to optimize the load management, to reduce peak loads by the development of the prototype Swiss2G algorithm based on distributed decision making and self-organizational capacities. The project aims at investigating and understanding to which extend it is possible to reduce the communication between the distributed production, consumption and storage units in comparison with concepts based on central decision making.

1. Goal of the Project

1.2 Overall Swiss2G aim and concept

The future integration of a large number of renewable energy sources and Electric Vehicles (EVs) into the electricity supply grid is expected to cause important changes for and challenges to the present grid structure. The ability to influence via incentives the user load profiles without sacrificing consumer satisfaction has important influence on this change process. Smart grid concepts represent the dominant approach in industry requiring large upfront investments for bi-directional communication and central management systems.

The Swiss2G project investigates an alternative bottom-up approach without upfront investment. The grid frequency as information about the generator status and the local voltage signal in the local distribution branch are both available at every socket. An algorithm shall be developed which combines these local grid data values with individual customer requirements and habits as well as with local grid characteristics, local distributed generation like PV and utility parameters. This algorithm will be applied to each EV with bi-directional chargers and to each suitable main household appliance. The statistical overlay of all these “intelligent” single consumers is expected to act like “swarm intelligence” for the reduction of regulation power demand.

The first phase of the Swiss2G project covers the grid measurements for typical grid situations, the development of Swiss2G algoritms, the simulation of the grid behaviour relative to the Swiss2G parameters, and the prototype development of key hardware components that will be required for field trials in the second project phase B. In phase A, the aim is to demonstrate the feasibility of the Swiss2G concept on a theoretical basis.

1.2 Structure of the Swiss2G project

The Swiss2G project consists of sub-projects for specific tasks and technical or methodological challenges. These are the ABLIM, BIDIR, PV2EV and MESSMODUL subprojects. The build-up is illustrated in the figure below.

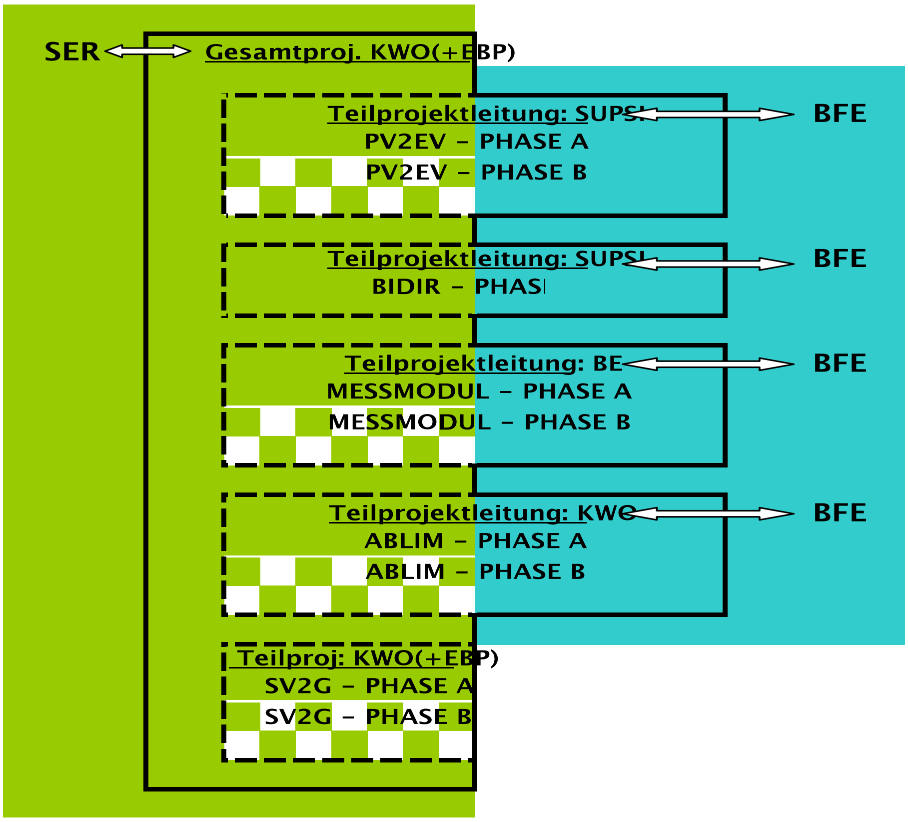


Figure 1. Illustration of the Swiss2G build-up. The umbrella project Swiss2G consists of four sub-projects with separate BFE contracting each; funding from Swisselectric research, as well as third-party and in kind contributions, form the co-funding. Project coordination tasks on the umbrella level are grouped into the SV2G module.

The Swiss2G project, and therefore each of the sub-projects therein, are split into a conceptual and proof-of-concept (by simulation) phase (phase A), and a demonstration (proof of concept by measurement) and grow-up phase (phase B). All sub-projects are interlinked, they are dependent on inputs from other sub-projects and/or provide important outcomes to other sub-projects.

1.3 Goal of the sub-project PV2EV

In the framework of this project the goal is to set up and implement the equipment for decentralized electric energy generation in 20 households, the measurement devices (household appliance controller), to and to develop a Swiss2G algorithm for the integration of a large number of decentrally organized electricity producing and consuming electrical devices connected to the lowest voltage level of today’s electricity grids. I.e. this type of equipment and electric vehicles, equipped with a bidirectional charger, will be enhanced with the "Swiss2G"-Algorithm to maximize the use for the electricity grid stakeholders. The following goals a envisioned:

- General reduction of load peaks during connection times (e.g. in the evening when coming home)
- Grid loading relieve for congestion management
- Reduced peak grid loading at lunch time.
- Less load variation during the day and as a consequence, better average loading of distribution grids.
- Reduced amount of traditional regulating power

The project swiss2G has the following indirect goals:

- Create sustainable environmental effects (CO_2-Reduction) through substitution of gasoline by electricity
- Use water in the alpine hydro dams at increased economic value and not mainly as flexible regulating power.
- Reduce grid losses.
- Reduce additional investments in peak generation and peak grid capacities.

The project intends to analyze a configuration with minimal additional communication and information exchange infrastructure, in order to avoid additional expensive communication infrastructure for these decentralized grid users. This has the consequence that controls and/or incentives to change the use of the grid will come from measurements and givens to be captured and metered as near as possible to the decentral user of the grid.

Initially, the project team intends to use accurate voltage signals at the 230V or 400V plugs combined with the power consumption and generation of decentralized grid users. A key goal is the research towards a concept which does not need a single central energy management control station; instead, the goal is as much distributed, decentralization and minimal communication between the decentral users combined with possibly some form of hierarchical, regional or local area information concentration and communication.

The intelligent algorithm will be directly attached to the electricity consuming, storing and generating devices, including electric cars. The collective effect of this algorithm attached to these decentral devices shall satisfy the above mentioned goals.

2. Project organization

The project is part of a larger project called Swiss2G. The decentral behavior and optimization of the grid connected device is researched by SUPSI. The grid simulation part of the project is handled by BFH. The "Measurement concept" (By BACHER ENERGIE AG) is – together with the works done at SUPSI - integrated part of the Swiss2G project.
The organization of this highly interdisciplinary project is a major challenge. In particular in the beginning of the project a considerable effort was dedicated to get the project partners on a common track and to elaborate the manifold interfaces. The project ranges at SUPSI over three departments and six institutes, which had to be coordinated internally as well as with the external partners.
Moreover the first phase of the overall project has to comply with a tight time schedule, obliging the research teams to dispose of sufficient work force and resources. A strict project organization has been agreed upon and a regular reporting process en-

ables the project manager to clearly understand the progress of the project. The following chapters shortly report on the ongoing work process.

The focus of the first period of the project was on the elaboration of the state of the art on Smart Grid and the household selection process. Moreover the project team of IDSIA at SUPSI produced substantial progress on the algorithm for the decentralized control, taking considerable advantage on the time schedule. See appendix 2. The project, thanks to a tight management and to commonly agreed rules is progressing according to the project plan.

3. State of the Art

The state of the Art report elaborated by SUPSI substantially covers the differ devices and components analysed in this project and represents the first chapter of the overall project. The State of the art report is divided into the following sections:

- Decentralized energy generation
- Electrical storage systems (fixed and mobile)
- Smart Grid Typologies and associated pilot studies
- Optimization models
- Domotics (Home automation) and Energy monitoring
- Electric power system standards
- Business models and consumer behaviour
- Swiss2G concept in the present the Smart Grid debate

The State of the art report gives an overview of the most significant pilot and demonstration projects. It documents the choice in the different areas of the project in Mendrisio and helps to orient the reader in the fast growing literature on the smart grids. The desk research on the different topics was integrated by the material which was presented during different international conferences.

The State of the art report will be fully integrated in the project report of phase 1.

4. Household selection and grid description

4.1. Household selection process

A very critical part of the pilot and demonstration project is to find at least 20 households willing to participate in the project scheme and to comply with the different criteria. Therefore the ISAAC, in charge of this task, gave high priority to this task,
This process included the following tasks:

- the design of the communication process, mainly carried out by Protoscar, in order to find the candidates to participate in the project by:
    - designing a documentation to be published in the newspaper
    - by preparing a press conference with printed and electronic mass media coverage
    - preparing a dedicated webpage

- the definition of the selection criteria,

- the preparation of a model contract between the household owners and the responsible party of the project,

- the negotiation with the municipality for accelerated permission for PV-module installation,
- the preparation of the form to fill-in by the candidates,
- the registration of the candidates,
- the selection of the households.

The communication process with the local population resulted in a very positive answer. The deadline for participating in the project was November 15th, 2010. In a little more than one month the project team received the following answers to the tender:

- 134 announced candidates
- 96 candidates in the area served by the local utility AIM (Aziende Industriali Mendrisio)
- 43 potential households, complying with the defined criteria set

The distribution of the candidates is represented on the map in annex 1. The candidates are highly clustered around transformation stations, being a very promising condition for the project and helping to concentrate the selected households on a few distribution grid branches. The selection is planned during the month of December 2010 and January 2011. Immediately after the selection process the equipment will be put in place and the grid will be modelled in the simulation tool (Digilent) interfacing with the decentralized Swiss2G algorithm.

4.2. Grid description at the 50kV and 400 V level (AET and AIM)

The project team has met with the grid operator at 50kV and 400V. The grid configuration and characteristics have been discussed and been illustrated in separate, but very extensive meetings. The first has taken place immediately after the project start, the second after the launch of the project participation call in the local newspaper. Both utility operators are very interested in the pilot project and substantially back the research project, given their genuine interest in the outcome of the result.

5. Measurement concept

For a full description of the measurement concept and the interfaces to the work of the partners, see appendix 3 of this report. The key elements of the measurement concept are shown in the following figures:

Hypothesis: Support of security of supply by the distributed algorithm

S2G

Hypothesis: Security of supply can be increased by use of decentral measurements of voltage amplitude and voltage phase difference as input to the decentral algorithm

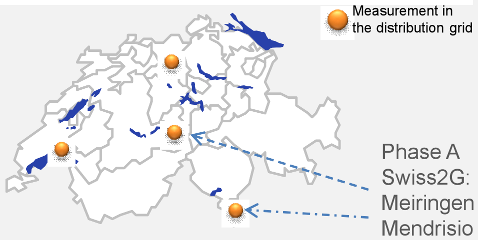
Functional behaviour

- Each voltage in the electricity grid has a main frequency phase angle and amplitude; the maximum amplitude of the measured sinusoidal voltage signals occurs at a slightly different time (time measured via GPS-time signal) at each node.
- The difference of phase angles und–amplitudes of voltages at any two nodes change depending on the line flow
- The difference of voltage signals at regional, supe-regional at the level of the frequency control zone indicates the degree of grid loading.

New questions

- How large is the change of phase angle and amplitude in the distribution grid depending on grid loads and infeeds?
  - Indication of grid use at the plug
- How large is the phase angle differnece between high, medium and low voltage distribution grids?
  - Indication for large area flows and grid loading sensitivity by PV, EV and other electricity consumers

Places of measurements (Phase A and B)



The flows in the grid

$$P_{km} = U_k^2 g_{km} - U_k U_m g_{km} \cos\phi_{km} - U_k U_m b_{km} \sin\phi_{km}$$

$$Q_{km} = -U_k^2 \left(b_{km} + b_{km}^{sh}\right) + U_k U_m b_{km} \cos\phi_{km} - U_k U_m g_{km} \sin\phi_{km}$$

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In phase A, the project tean will make measurement in the 400V distribution grids in Mendrisio and Meiringen.

The formulas for the "flows in the grid" use the following parameters and variables, all at main frequency:

P_{km}:	Active power flow from node k to node m
Q_{km}:	Reactive power flow from node k to node m
U_k, U_m:	Voltage magnitudes at nodes k and m.
Φ_{km}:	Voltage phase angle difference Φ_k - Φ_k of nodes k and m
g_{km}, b_{km}, b_{km}^{sh}	Parameters of (distribution grid) line between nodes k and m

The project team will measure U_k and Φ_k and P_k and Q_k at various nodes k in the grids to fine tune the power flow simulation parameters and results. I.e. with given grid parameters g_{km}, b_{km}, b_{km}^{sh}, given measured active P_k and reactive Q_k power loads at each grid node, the grid simulation can compute accurate voltage variables U_k and Φ_k for each simulated node. In the simulation, non-measured active and reactive loads at the simulated distribution grid nodes must be tuned in such a way that measured and computed voltage variables are identical.

Measuring & algorithm concept

Measurement Concept

The work of BACHER ENERGY Ltd (measuring), University of Applied Science Bern (Simulation) and SUPSI (distributed algorithm) can be divided into four parts.

Measuring electric parameters

- Measuring of the following electric parameters (single or three phase):
  - Voltage
  - Frequency
  - Phase angle
  - Harmonics (voltage and current)
  - Flicker
  - Current
  - Power
  - ...

Data transfer (Bacher Energy Ltd)

- The metered values are transferred via a direct Ethernet connection to a local PC and from there via GSM IP connection to the information control center at BACHER ENERGY Ltd in Baden
- Data will be transferred to partners in csv-format.

Data mining & simulation (Univ of Appl Science Bern)

- The csv data is filtered and transferred from the information control center to the grid simulation tool (Digsilent) to tune the grid model

Distributed algorithm (SUPSI)

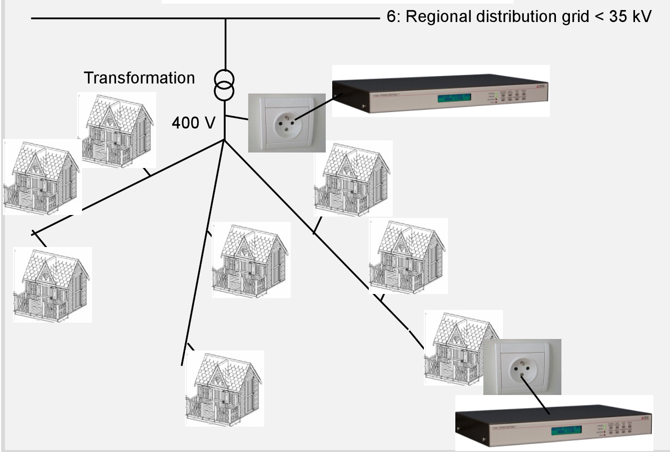
- The output of the simulation tool is used by the distributed algorithm as simulated input of the real-world behavior

Measuring electric grid states and parameters

Measurement Concept

The measuring device uses a GPS signal in order to get a highly accurate time stamp

Measuring electric parameters



Remarks

- The single phase or three phase voltage signal is measured with very high accuracy at the 230V-plugs of electricity prosumers (producer and/or consumers)
- Ideally, the voltage just behind a level 6 transformer (at 400V) and the 400V voltages at the far end of a radial line are measured simultaneously
- The GPS signal gives the exact time to allow exact voltage phase and frequency detection

Measurement and data transfer

Measurement Concept

Data transfer from measurement equipment to PC and from PC to internet occurs in parallel

Raw measurement data transfer	Remarks
	• The metered voltage data is transferred via a direct Ethernet connection to a local PC and from there via GSM IP connection to the information control center at BACHER ENERGY Ltd in Baden • The PC records all values in raw format • The information centre converts all raw data into csv data format

Measurement Concept – connections grid – metering equipment, GSM-Modem, notebook-PC, antenna-head

Measurement Concept

The measurement equipment needs an exact time stampt obtained by GPS-Signal via an antenna whose head is outside of the measurement room (Connection with Coax-cable to the measurement equipment)

	Grid-measurement	GSM-Modem	Notebook PC
Connecte with	• Power cable (1-phase) with plug 230 V for voltage supply • By power cable (1- or 3-phase) to plug 230 V or 400 V to monitor voltage at plug • By 15m RG-6 Antenna cable with with GPS antenna head • By Ethernet-cable with GSM-Modem • Optional connection by powerline cable between measuremtn equipment and GSM modem	• By Ethernet-cable with notebook-PC • By GSM-wireless grid with office BACHER ENERGIE AG in Baden (measurement collection)	• By power cable with plug 230V to supply notebook PC (has battery for power outage survival)

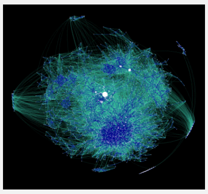
Data mining & simulation

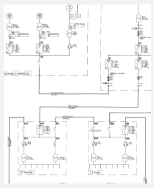
Measurement Concept

In order to model the distribution grid, data is necessary of the local electricity distribution grid and for all connected electricity consumers and generators.

Data mining & simulation

Data mining





Grid model

Remarks

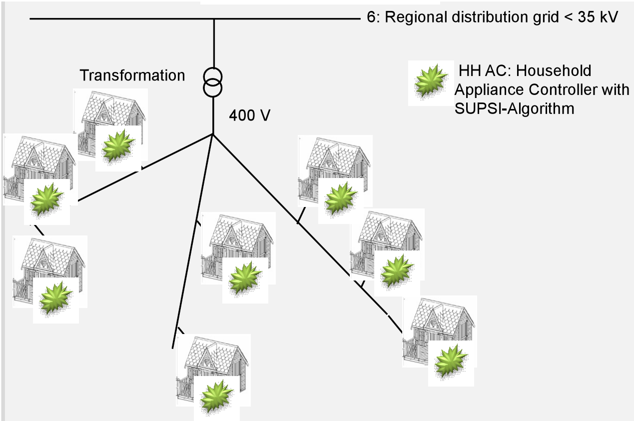
- The csv data is filtered and transferred from the information control centre to the grid simulation tool (Digsilent) to tune the grid model
- The simulation tool needs as further input the grid system data of Meiringen and Mendrisio (possibly also higher voltage data from AET and BKW)

Distributed algorithm

Measurement Concept

The output of the simulation tool (Digsilent) is used by the distributed algorithm (SUPSI) as simulated input of the real world behavior

Distributed algorithm



Remarks

- The output of the simulation tool is used by the distributed algorithm (SUPSI) as simulated input of the real-world behaviour
- *The distributed algorithm (HH AC: Household Appliance Controller) is applied to real-world intelligent electricity consuming equipment, EV and PV generators*
- *The HH AC monitors and controls the individual consumption and production of electricity using*
  - *Historical data of the equipment*
  - *Real-time metered data at the plug and the local environment*
  - *Minimal system state information communicated from the outside*

Phase B Swiss2G

6. Next steps

The next steps:

- Definitive household selection and planning of the equipment, interview with member of the households – in order to define the consumer profile before installation of PV plant or household appliance controller
- First measurement campaign on the relevant branch of the local grid
- Installation of PV- modules and HAC
- Implementation of grid topology in the simulation tool
- First attempts to simultaneously simulate the Swiss2G algorithm and grid simulation tool.
- Acquire real data from the measurement campaign to be delivered to the simulation group.

7. Appendix

1: Map of Mendrisio with households participating in the tender process

2: Detailed presentation of the concept of the algorithm

3: Measurement concept