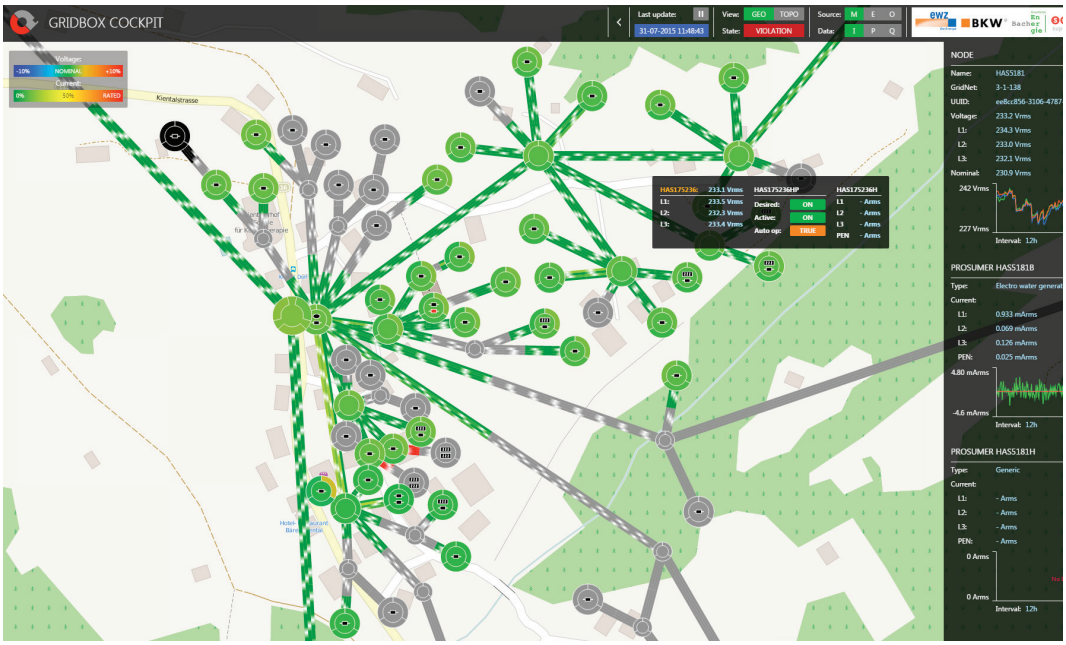
Distribution Grids with an Outlook

Electricity monitoring and management systems are becoming increasingly sophisticated everywhere—whether in road and rail traffic, in wireless networks or in production facilities in industry. In the electricity industry, systems for monitoring and controlling electricity flows are in vogue. A pilot project involving the distribution system operators BKW (Bern) and ewz (Zurich) investigated the technical feasibility of such a system at mid- and low-voltage levels. The Gridbox technology creates the basis for innovative applications.



The distribution grid equipped with Gridboxes with its current flow shown on a web interface in real-time. The green and gray connections schematically show the conductor cables from the substations and distribution cabinets to households. Each connection shows three phases and the neutral conductor. By clicking on a household (circle symbol), the system displays how much total electricity the household currently consumes. The Gridbox makes it possible to switch loads on and off such as electric boilers, heat pumps, batteries and photovoltaic systems and to regulate them gradually. Illustration: SCS

Dr. Benedikt Vogel, commissioned by the Swiss Federal Office of Energy (SFOE)

Electricity is invisible to the eye. Nevertheless Swissgrid, the operator of the national electricity transmission grid, knows at every moment the condition of the extra-high voltage transmission system. The 6700 km long transmission grid has 140 switching stations across Switzerland with approximately 8,000 measuring points. At switching stations, current and voltage data are collected at power lines and transformers and transmitted each second to the Swissgrid grid control center in Laufenburg. Thanks to these measurements, the national grid company knows the real load on the system and can ensure its stability through appropriate intervention at

A technical report about the results of a pilot and demonstration project in the field of grids, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine ET Elektrotechnik (issue January 2016).

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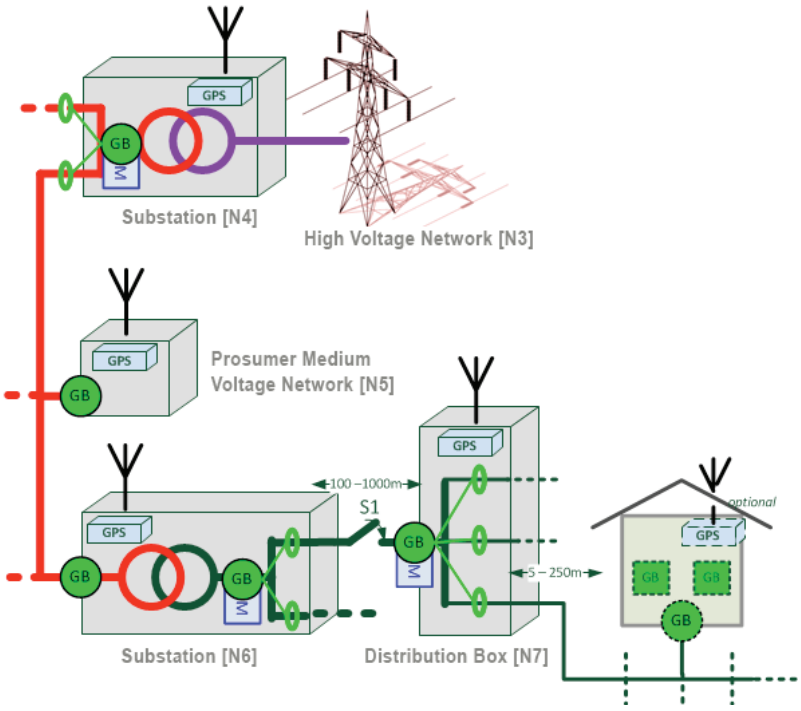
any time. The extra-high voltage transmission grid has been equipped with the appropriate monitoring infrastructure for decades. This has not been the case with medium and low voltage grids, which bring electricity to customers: "The distribution grid at levels 5 and 7 is still largely blind and passive. Here hardly anything is measured and nothing can be actively controlled," says Stephan Moser, electrical engineer and Head of Energy Systems at Supercomputing Systems AG (SCS). That should change now. This is the basis of the current project Gridbox, which SCS together with BKW, ewz and Bacher Energy is supporting and Stephan Moser is heading.

The Gridbox, installed here in a distribution cabinet. Photo: SCS

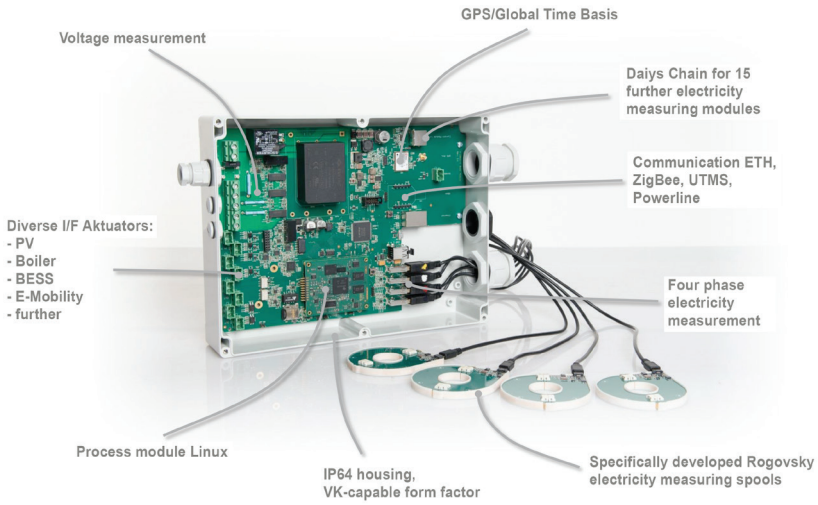
Platform for New Business Models

The basic idea of the project is to equip the distribution grid with a measurement infrastructure (Gridboxes). This should at all times enable an assessment of the system status. Knowledge of the grid status opens up a range of applications, especially for distribution system operators (DSO). DSO can check whether the voltage is within prescribed tolerances for every measured point in the network, for example. Or thanks to monitoring data, they can steer the loads (electric water heater, battery storage) such that fluctuations incurred by solar and wind power in the grid do not cause capacity overload. A fault in the grid (e.g., a short circuit caused by a fallen tree) can be quickly localized and its nature determined. If an energy provider knows the condition of its grid in detail, he can operate it with less reserve capacity; this saves costs for grid expansions and facilitates planning. Furthermore, distribution system operators can reduce maintenance cycles thanks to detailed information about the state of their infrastructure elements (e.g. transformer plants).



Gridboxes are installed at various points in the medium and low voltage grid, enabling system monitoring and also control of flexible loads and generators. Photo: SCS

Nationwide monitoring of electricity distribution grids also opens up promising future applications for energy suppliers or other service providers in cooperation with private customers and companies: Monitoring systems can detect the power consumption of each customer and have the data available to regulate in real-time heat pumps, water heaters, battery storage or decentralized PV installations. Electricity consumers with an in-house PV system ('prosumer') can optimize their own consumption. On this basis, new pricing and business models are conceivable. Thus, electricity consumers and power generation facilities can be aggregated and controlled so that they become 'virtual power plants' (similar what the Swisscom subsidiary SES does with their product 'tiko'; see article "tiko belebt den Regelenergie-Markt" at www.bfe.admin.ch/CT/strom). End users could specify in a liberalized electricity market with dynamic prices, when and from which provider they wish to purchase their electricity. Conceivable are also new business models through evaluation of grid data.



The Gridbox base module and four Rogowski coils for contact-less electricity measurement (front right). Photo: SCS

Pilot project in the Berner Oberland and in Zurich

One possible path towards this brave new world of distribution grids used in many different ways is Gridbox technology. The Gridbox is a measurement, communication and control system that is installed at key points in the power system: the house of electricity customers, in distribution cabinets (each supplying roughly one street block with power) or in transformer stations (each supplying parts of a neighborhood or a small village). From each Gridbox the measured data is transferred via mobile communication, powerline (PLC) or fiber-optic network, to a central location where the data is processed and stored. The data is then further processed into the appropriate control signals—depending on the application. The control commands then travel the same route back to the individual Gridboxes to transfer the desired information and control tasks.

Under the current project, the Gridbox will be tested in two pilot grids in the Berner Oberland and in the city of Zurich: In the area of Frutigen and Kiental, a good 60 households were equipped with a Gridbox in June 2015 with 21 more Gridboxes in distribution cabinets on low voltage levels and also in transformer stations on mid-voltage. In this way, a good 50 km of BKW medium and low voltage grid is available to the measurement infrastructure. The second pilot region is located in an urban environment: In Zurich-Affoltern, a low-voltage grid area, 40 houses and about 700 customers were equipped with a total of nearly 50 Gridboxes in June 2015. "The pilot

project Gridbox for ewz is a first major milestone on the way to the distribution grid of the future," says Benedict Loepfe, Director of Distribution Grids at ewz. "Together with the largest battery storage unit in Switzerland, which we have also installed in Zurich-Affoltern, we have probably the most unique practice laboratory in the world. Here we want to continuously learn what contributions we can make as distribution system operators to implement the energy transition."

Description of the Overall System

The Gridbox project started in 2011 with two concept studies that were financed by the SFOE Research program "Grids," followed by the development of Gridbox devices and their installation in the two pilot grids. Since June 2015, the one-year demonstration and testing phase has been running. A central question of the field tests is whether a Gridbox measuring system is able to calculate the state (currents, voltages) of an entire grid region even though Gridboxes are installed only at selected points. This actually appears to suffice, since applying mathematical modeling (algorithms) to the measured values of the individual Gridboxes can extrapolate the entire grid state. Thanks to this so-called 'State Estimation' currents and voltages are estimated each second for any node in the grid regions. In the words of Dr. Oliver Krone, Head of Smart Grid Engineering at BKW Energy AG: "We have demonstrated that State Estimation using phase-synchronous and high-precision measurement is technically possible in the low-voltage grid." The next step is to find out by how much the number of grid boxes can be reduced and still obtain a reasonably accurate estimate of the overall grid state in order to reduce overall system costs.

Another result of the two test grids: The data transfer from the Gridboxes to the central location and back is sucessfully carried out quickly and reliably. The communication protocol specially developed for the pilot ('GridNet') proved to be very tolerant of packet loss and short connection interruptions. Although the mobile data network has a limited capacity for data transmission, it can reliably handle the volume of data from the Gridboxes. However, a prerequisite is that the volume of data - 2 MB per Gridbox per second - in the Gridbox must be reduced by a factor of 1000. Successfully tested during the project were technologies with regard to plug-and-play functionality of the Gridboxes. This means that a Gridbox at any point in the grid can be switched on and then identify at which place it is located and its data used in the sequence to correctly describe the entire grid.

Innovative Partnership

In collaboration with BKW and ewz, two of the largest distribution grid operators along with specialists from the information and communications technology (ICT) worked together on the Gridbox Project. This cooperation is the trend for the further development of Swiss grid infrastructure. Thus, a key finding of ewz Manager Benedict Loepfe: "To build the distribution grid of the future on your own is impossible. It requires a mix of expertise from grid planning and operation, as well as ICT and data management. In the Gridbox project we are ideally positioned with our project partners to achieve this."

- For the two final reports of the design phase, please visit: https://www.aramis.admin.ch/Texte/?ProjectID=31232
- For further information on the project, please contact Dr. Michael Moser (michael.moser [at] bfe.admin.ch), head of the SFOE-research program "Grids."
- For more technical papers on research, pilot, demonstration and flagship projects in the field of "Grids," see www.bfe.admin.ch/CT/strom.

How the Gridbox System Works

To make power grids 'intelligent,' there are different approaches: The grid can be equipped with decentralized, non-coordinated measurement and control units that can exchange data. This is how the GridSense system of Alpiq works (see article "Schwarmintelligenz für das Stromnetz" at www.bfe.admin.ch/CT/strom). Unlike the Gridbox system, locally collected data are transferred to regional headquarters where they are evaluated and processed into control signals, allowing for coordination of all devices and further functionalities.

Gridboxes are installed at key grid nodes: in homes, distribution cabinets and substations. Gridboxes capture each second the phasor information (time synchronous amplitude of current and voltage, and thus the phase angle between the two curves) and power quality measurements such as distortion factor and harmonics. By comparing phasor information, different Gridboxes are able to convey important information about the status of the entire grid. To facilitate the data comparison, each measurement value is related to a globally synchronous GPS time stamp. The Gridbox is a control and measuring device that combines the most important features of a Phasor Measurement Unit (PMU), a power quality measuring device and a disturbance recorder in one unit.

A single Gridbox can currently measure the current in up to 40 conductors (10 cables), which is important in distribution cabinets and substations. Here (specially developed for the project) Rogowski coils are used, which are placed around the circuit and measure current via a contactless inductive technique. For the voltage measurement, the Gridbox is directly connected to the conductor. The two pilot grids in the Berner Oberland and in the city of Zurich are equipped so that conclusions about the power consumption of connected households are not possible.

Technologies for monitoring, control and management of distribution grids are being tested and are already used by different electricity suppliers. New systems include the above-mentioned GridSense of Alpiq, the company DEPSys with its system GridEye or - to name a foreign example - the system iNES of the German energy infrastructure service provider SAG. BV

SFOE Supported Pilot, Demonstration and Flagship Projects

The current project of SCS, Bacher Energie, BKW and ewz is one of the pilot and demonstration projects with which the Swiss Federal Office of Energy (SFOE) promotes the economical and rational use of energy and is driving the use of renewable energy. In addition, the SFOE has referred to a number of flagship projects, which are also geared to the objectives of the Energy Strategy 2050. The SFOE promotes pilot, demonstration and flagship projects by providing 40% of non-amortisable costs compared with the cost of conventional technology. Requests can be submitted any time.

www.bfe.admin.ch/pilotdemonstration, www.bfe.admin.ch/leuchtturmprogramm

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02/2016