SMART OPERATOR, THE PROJECT FOR THE EFFICIENT CONTROL AND MONITORING OF THE LOW-VOLTAGE GRID

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ABSTRACT

The increasing amount of decentralized and fluctuating power generation poses major challenges to distribution system operators. Instead of reinforcing grid assets the conventional way, the supply of consumers may be better achieved by exploiting the flexibility of appropriate innovative grid components controlled by ICT. This approach is the objective of the Smart Operator (SmOp) project [1]. In the meantime, the project entered into its validation phase.

After the development, adoption and implementation of the components and the hard- and software into the distribution grids and connected households, the communication system has been established and the laboratory test has been carried out. Today three German low-voltage grids are under operation and control of the SmOp delivering measurement data. This database will be analysed and evaluated, allowing to transfer results to future grid situations and to assess the components´ contribution for grid improvement.

INTRODUCTION

The transition from fossil to renewable power generation in Germany requires a transformation of distribution grids as well. More than 90% of renewable energy generation (REG) is connected to distribution grids especially in rural areas, there is a pressing need for major extension of the distribution grids [2].

Besides the growth of feed-in of fluctuating REG, such as photovoltaic (PV) and wind, there will be also a change in consumption profiles of households. This will be caused by the increased usage of electric heat pumps and the expected growth in e-mobility and adjustable appliances which are able to respond to external signals (Demand Side Response).

The growth of decentralized generation is still going on. It is essential that grid operators maintain the capability to deal with voltage fluctuations and increasing stress on power lines and grid components. Nowadays, this issue is being addressed using grid extensions and upgrading of transformers. Modern ICT offers new possibilities through active management of flexible demand in the grid. The SmOp monitors the entire low voltage grid and triggers steering signals to avoid impermissible voltage values. An additional goal of the grid operation is to prevent overload of grid assets. To achieve this there are several possibilities, such as operating a storage asset, exploiting the flexibility of local consumption and/or generation of electricity in households.

Project goals and organisation

The Smart Operator project already entered into its validation phase pursuing the overall project goals:

- Increase grid efficiency through intelligent monitoring and steering of producers, storage and consumers as well as improved load management by innovative grid components
- Proof of technical functionality and the applicability of the developed technology is based on three field tests
- Recommendation on the regulatory framework for the grid operators based on the results of this pilot project
- Assessment of the effects on the grid of storage operation and usage of consumer flexibility.

The project consortium of RWE Deutschland AG (project manager), PSI AG, Horlemann Elektrobau GmbH, Hoppecke GmbH & Co. KG, Maschinenfabrik Reinhausen GmbH, Stiebel Eltron GmbH & Co. KG, the Institute for High Voltage Technology (IFHT) of RWTH Aachen University and the University of Twente works since 2012.

Three German low-voltage grids were selected to host the grid tests. The grids are located in rural areas and have been chosen according to strong feed-in from renewables. In one of these grids, integrated households are optimized by a home energy controller (HEC).

Project plan

The project was initiated in June 2012 by RWE. It started with the concept phase, followed by the development of the required hard- and software and the laboratory testing phase. The field test set up phase started in the second half of 2013 and the first of three test grids has delivered data since July 2014. The validation phase and the project will be terminated by the end of 2015.

FUNCTION OF THE SMART OPERATOR

The SmOp controls the low voltage grid in real-time and constantly improves its efficiency by learning from historical data (see [3] for details). The control algorithm has been developed by the Institute for High Voltage Technology (IFHT) of the RWTH Aachen University. It has been implemented on the basis of an application programming interface (API) provided by PSI. The API offers easy and flexible access to communication, data management and network application functions on the SmOp and thus serves as a versatile framework for the development and enhancement of control and optimisation functions.
As basis for its commands the SmOp uses a matrix in which all possible switching options are saved. On the basis of evaluation of the switching options it selects an option from this matrix and checks the new grid situation with a power-flow calculation. If neither overloading nor voltage overshoot are detected the grid situation will be set accordingly. Figure 1 shows the basic function of the SmOp, collecting the data, deriving grid conditions, controlling the grid and creating forecasts.
When the SmOp first goes into operation (in a new grid), all switching options are of equal weighting. If a switching option is successful, for instance, keeping the voltage within the allowed limits by charging a battery, then this switch option gets a higher weighting and the next time it will be the more likely option. In this way the algorithm constantly learns how to optimally control the LV grid. Before the Smart Operator gets rolled out in the grid there is an intensive learning phase with real measured data.

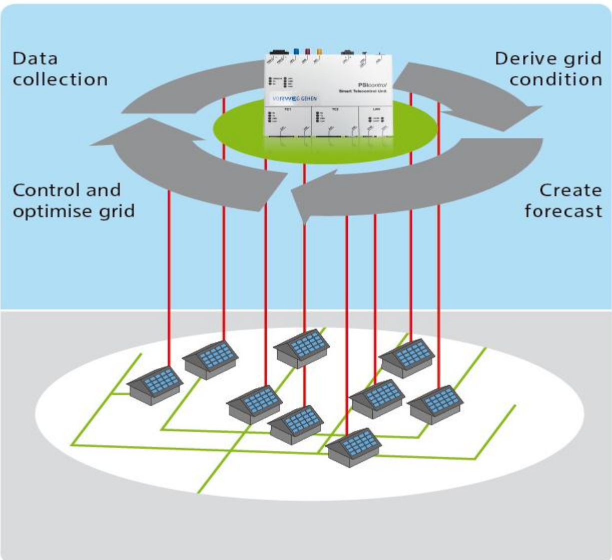


Figure 1 The basic function of the SmOp

Besides the intelligent grid components further devices are used in the households to control local demand and generation. These are connected to the SmOp via a Home Energy Controller (HEC). The algorithm for the intelligent household control has been developed by the University of Twente.

The SmOp can be connected to a network control centre (SCADA/DMS) using its remote telecontrol unit (RTU) properties. In addition, a management and monitoring tool, the SOManager (SOM), has been developed by PSI. An example screenshot of the SOM user interface is shown in figure 2. The SOM transfers weather forecasts to the SmOp and allows for the activation and passivation of the control algorithm. It provides various tools to visualize the operation of the SmOp and the state of the low voltage network: Overviews and summaries, lists, network diagrams, protocols and logs. If a problem is reported by the SmOp, the SOM sends a notification message to the operation staff.

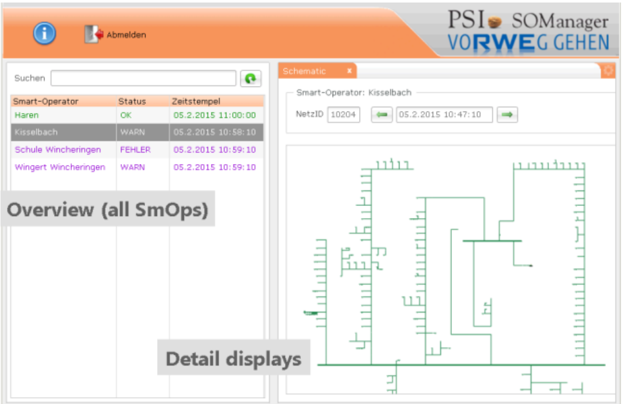
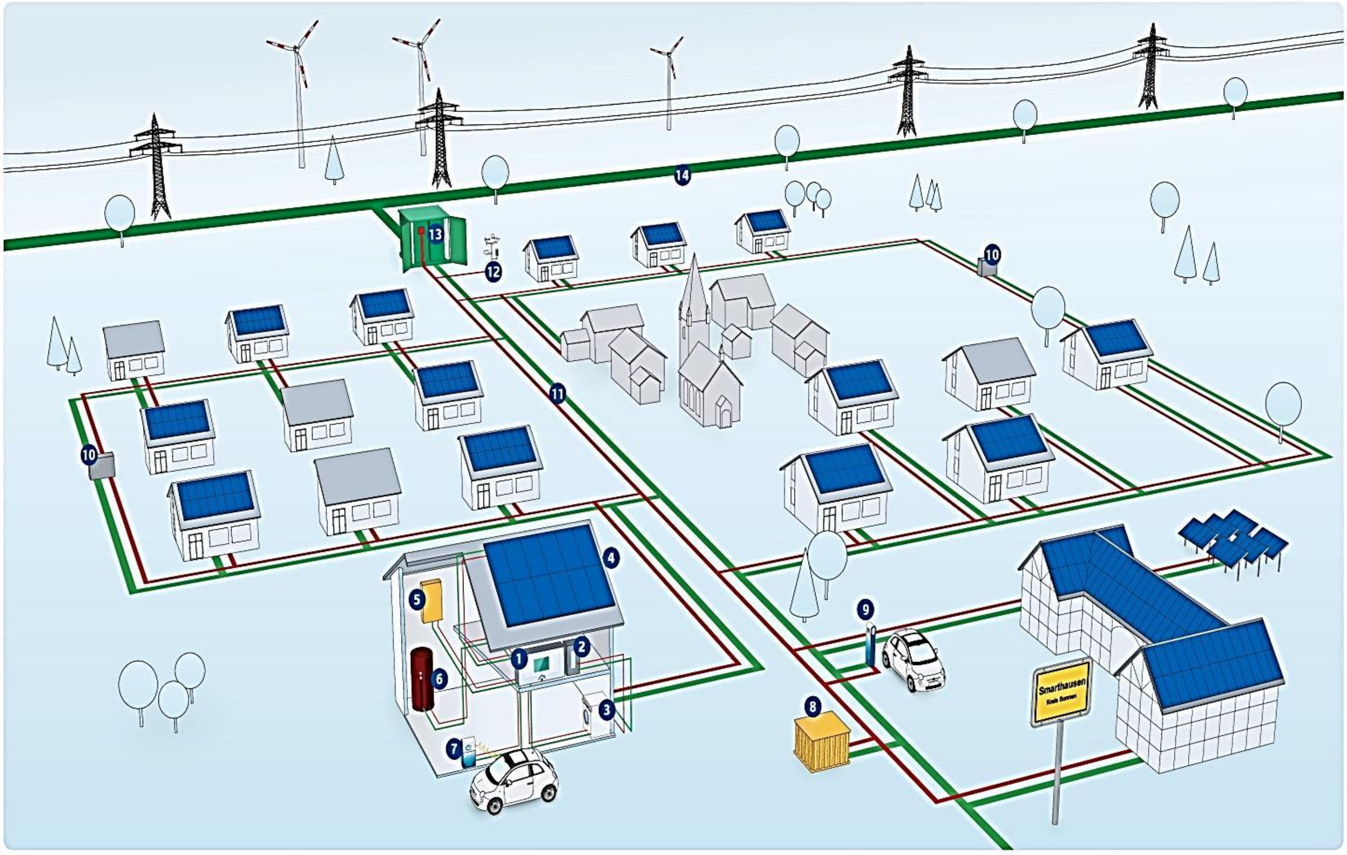


Figure 2 Browser-based user interface of SOManager

TEST SCENARIO

The test procedure started with an integrated laboratory test on the first level and was followed by field tests.
The isolated HEC function was first real tested as an integrated project in a newly built kindergarten.
Three German low voltage grids were selected to host the grid field tests. These grids are located in rural areas and have been chosen according to strong feed-in from renewables.
The behaviour and the eligibility of the employed grid components and communication technology are being checked and a possible demand for further development will be identified. In one of the test grids, the generation and consumption in private households will be controlled by a HEC.
The SmOp controls the grid while communicating with the electricity generators, the consumers, storages and grid components.



1 Home Energy Controller
2 Smart Meter
3 Intelligent home appliances
4 Photovoltaic
5 Household battery storage
6 Heating/Heat storage
7 Cargo box
8 Grid battery storage
9 Charging station
10 Low voltage switch
11 Low voltage and communication grid
12 Weather station
13 Smart Operator in transformer station
14 Medium voltage grid

Figure 3 The structure of the demonstration grid

To test the effects induced by e-mobility, electric vehicles (EV) charging stations and boxes will be allocated into the demonstration grids.

One focus of the project is to find out the appropriate communication infrastructure, under performance and efficiency aspects.

In two grids, optical-fibre networks have been installed for communication. They are reliable, fast, provide a comfortable data capacity (bandwidth and latency) and can be used for additional purposes. In one grid the project employs powerline communication technology using the existing LV grid for data transmission. In order to maintain the necessary range, repeaters had to be installed.

Additionally to the employed broadband technology (B-PLC) narrowband technology (G3-PLC) was tested. Inside the buildings Inhouse-Powerline is used for communication.

Figure 3 shows the structure of the demonstration grid with intelligent grid components and households.

The field tests allow the evaluation of all previous simulations of grid operations. The operability of the complex system as real grid operation is being tested.

Laboratory test

The laboratory test took place in the premises of the IFHT of RWTH Aachen with the focus on checking the complete system based on the interconnection of all components with the communication and control via the SmOp and the HEC algorithm. The test preparation was the simulation of the feed in of decentralised generated electricity, load and storage inside a LV grid behind a local grid transformer [4].

For this reason, real components were connected to a test scenario. All important electrical values have been recorded (current, load and voltage). The functionality was successfully tested on the basis of scenarios of different grid conditions.

The SmOp ascertains a priority control signal, based on its algorithm taking into account the actual grid condition (e.g. switching condition, data of specific grid components), about HEC load and weather data.

A local objective function determines the behaviour of the SmOp to reach an overall optimum in the grid segment. The data- and signal processing is based on state of the art ICT by PSI.

The HEC's algorithm produces on the level of a household's feed-in, load and flexibilities, optional load profiles which can be chosen by the SmOp to optimise the grid.

Real test of the HEC in Haren

The real test of the Home Energy Controller and the communication inside a building was carried out in a newly constructed kindergarten in Haren in Lower Saxony. The HEC adopts the local energy management and provides available flexibility via the SmOp to the grid. The HEC constantly records ongoing feed-in data of the PV system, the consumption and flexibility of the combined heat pump/hot water storage, the battery storage and other intelligent household appliances (washing machine, dryer and dishwasher) and an EV charging box. This is put into optional demand profiles locally and autonomously via the TRIANA algorithm inside the HEC [5].
The interface to the intelligent home appliances is the SmartHome Controller (based on the standard technology developed by RWE Effizienz GmbH). The SmOp gets the options via the HEC and the demand profiles to optimise the building's energy balance. Figure 4 shows the HEC and the device controller in the centre of the communication and control process between SmOp and the smart household devices.

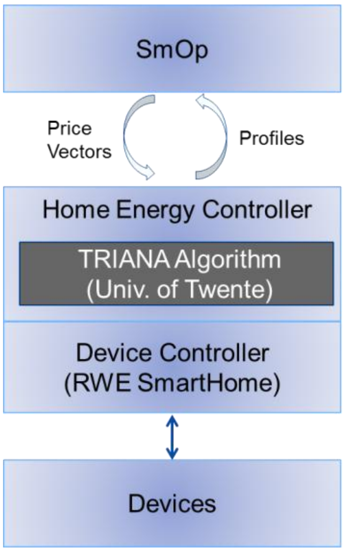


Figure 4 Communication between SmOp, HEC and intelligent household appliances

The field test in Haren was successful and the precondition for the further roll-out and operation in the Wertachau field test.

Field test Wertachau

The local grid Wertachau in the municipality of Schwabmünchen in Bavaria is being observed and optimised by intelligent grid components and smart interior engineering.

The grid consists of 150 households, thereof 25 with intelligent domestic appliances, 23 photovoltaic installations with 160 kWp generation capacity, 10 night-storage heating systems, 8 electric hot-water storage tanks and an optical-fibre communication network.
Installed Smart Grid components (besides SmOp, HECs, Smart Meters und weather station) in the Wertachau grid are: a Voltage Controlled Distribution Transformer, three low-voltage switchgears, two EV-charging stations and a 150 kWh lead-gel battery storage.
Smart Meters for 25 HECs with connected intelligent household appliances. In these cases the customers have declared their willingness to cooperate with the Smart Operator project and to contribute to a successful field test.

Field test Kisselbach

In the Kisselbach grid (Rhineland-Palatinate), the focus lies on the observation of a local grid, optimised by battery storage and low-voltage switchgear with an optical-fibre communication network. The grid covers 200 households, 12 PV installations with 170 kWp of generation capacity, 21 night-storage heating systems, one electric hot-water storage tank and 6 heat pumps.
Installations in the grid are: The SmOp, Smart Meters in nearly every household, a weather station, two EV-charging stations, low-voltage switchgear and a lead-gel battery-storage (150 kWh).

Field test Wincheringen

In two local grids in Wincheringen (Rhineland-Palatinate) the focus is on the grid optimisation by Smart Grid components and grid storages in a broadband powerline communication environment. 220 households, 13 photovoltaic installations with 210 kWp of generation capacity, 2 night-storage heating systems and 37 heat pumps are available.
The installed Smart Grid components (besides SmOp, Smart Meters and weather station) in Wincheringen are: in the first grid a voltage controlled distribution Transformer, two low-voltage switchgears and an EV-charging station and in the second one a low-voltage switchgear and two medium battery-storages (30 kWh lead-gel and 30 kWh lithium-ion storages).

IT security standard

The SmOp, the connected grid components and the intersystem communication have to fulfil the ISMS-standards.
The project follows the BDEW White Paper "Requirements for Secure Control and Telecommunication Systems". The requirements of this White Paper are obligatory for all control and telecommunication systems, which will be newly procured or installed and which will be operated in the process environment of a utility in Germany. The protection level determination was accomplished by an

external service provider and implemented successfully in the system.

GRID ANALYSES AND DATA VALIDATION

The functional capability of the system and its sub-systems is being checked to gain further experience for grid planning and grid operation.

The measured data from the selected grids is stored centrally and continuously and it is analysed in a SQL database belonging to RWE Deutschland AG. The measurement data will be analysed and evaluated, allowing to transfer these results to future grid situations. Already conducted or planned analyses are e.g. the availability of data per grid component, diurnal variations, creation of reference groups, profile accounts and statistical evaluations.

Experiences from the ongoing field trials will be described highlighting opportunities as well as remaining challenges on the way to future smart grid roll-outs. Another part of the analyses will be the results of the operation of the SmOp algorithm. The actions taken by the SmOp, such as switching options and their time and frequency of use, will be analysed in detail.

REGULATORY FRAMEWORK, BUSINESS CASES

Assessing financial prospects and risks when introducing the SmOp is another object of the project. Evaluating the respective costs and benefits will prove that the SmOp is a valid alternative to conventional reinforcements in future grids. Key goal within the evaluation process will be to quantify the cost of the utilization of flexibility based upon the field tests mentioned above. This will be mirrored by assessing the benefits of available flexibility for reducing grid extension. Results of this analysis will be the basis for an overall welfare assessment.

FIRST FINDINGS AND OUTLOOK

As a first result from the test operation it can be stated, that the interaction between the SmOp and the intelligent grid components in the test grids is running stable and reliably. The SmOp controls the load flow and straightens the voltage band. First analyses of the database show, that optimisations were carried out by the SmOp and the algorithm is improving over time.

Figure 5 shows an example for an action triggered by the SmOp based on real data. The SmOp controls the charging of an electric vehicle in order to prevent a voltage drop of 2% (see upper graph in figure 5). The intervention into the charging process is presented in the lower right chart. Between 8 pm and 8.40 pm the SmOp reduces twice the loading of the EV from 22 kW to 7 kW. This implicates that even the control of a single EV could have an recognizable improvement of the voltage.

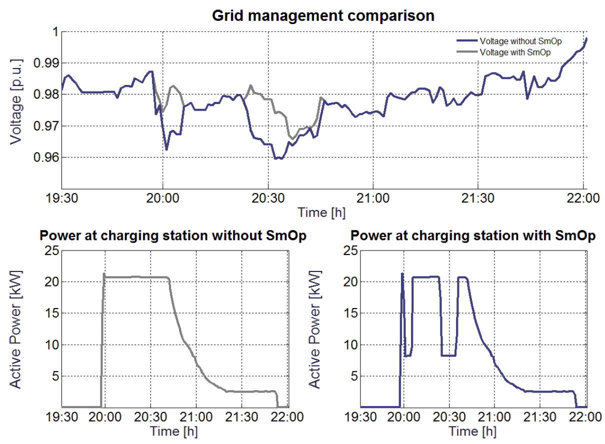


Figure 5 Active Grid management by the SmOp

The project will deliver valuable input for an improved grid planning in the future. The different grid components will be available to smart grid planners in the form of a catalogue, with their characteristics, behaviour and sensitivities.

Another task will be to extract from the complete measurement data base, simplified reference profiles, able to characterize a grid, to reach high quality simulation results. They will reproduce realistic behaviour and define which data and frequency rate is necessary to get valid prognoses.

The SmOp algorithm will be reviewed in detail, the self-learning function checked, the effectiveness and the number of the eligible strategies and the adjustment settings in the interaction with the grid components optimised.

The intelligent grid components and their behaviour will be revised and optimised accordingly e.g. set of voltage limits, the degree of utilisation, the response behaviour and the efficiency.

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