IMPROVING QUALITY OF SUPPLY AND USAGE OF ASSETS IN DISTRIBUTION GRIDS BY INTRODUCING A "SMART OPERATOR"

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ABSTRACT

The increasing amount of decentralized and fluctuating power generation and an increasing number of electric vehicles, heat pumps and other new consumption appliances pose major challenges to distribution system operators. However, this also offers new opportunities for improved usage of distribution grid assets. Instead of extending grid assets in the conventional way (e.g. with additional and/or higher capacity of cables and transformers), the supply to consumers may be better achieved by exploiting the flexibility of appropriate devices using ICT. This approach is the objective of a "Smart Operator", which is conceptually presented in this paper.

INTRODUCTION

The transition from fossil to renewable power generation requires a transformation of distribution grids as well. Since 97% of renewable energy generation (REG) in Germany is connected to distribution grids [1], there is currently a pressing need for major extension of the distribution grids and this is expected to continue to grow as the level of REG rises in the coming years [2]-[3]. Besides the growth of feed-in of fluctuating REG, such as photovoltaic (PV) and wind, there will also be a change in consumption profiles, especially in households. This will be caused by the increased usage of electric heat pumps and the expected growth in e-mobility and adjustable devices which are able to respond to external signals, such as white goods.

With the expected growth of decentralized generation it is essential that grid operators maintain the capability to deal with voltage fluctuations and increasing stress on power lines with particular attention to the change in the direction of the power flow. Nowadays, this issue is being addressed using grid extensions and upgrading of transformers. Besides the classic methods of extending the grid, modern ICT also offers new possibilities through active management of flexible demand in the grid, such as electrochemical energy storage, heat storage and electrical household devices. In this paper the development and introduction of a centralized and 'smart' steering device, the Smart Operator, is presented. This device makes it possible to monitor the entire low voltage grid and – if required – to trigger steering signals to prevent potential grid instability and 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 and on-load-switching of the tap changer at the substation. These solutions are presented in this paper.

The following objectives are to be reached:

- Increased grid efficiency through intelligent monitoring and steering of producers, storage and consumers as well as improved load management and innovative grid components
- Proof of technical functionality (at first under laboratory conditions), as well as of the applicability of the developed technology in the grid based on three field tests
- Recommendations 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.

A consortium of RWE Deutschland AG (project manager), PSI AG, PSI Nentec GmbH, Horlemann Elektrobau GmbH, Hoppecke GmbH & Co. KG, Maschinenfabrik Reinhausen GmbH and Stiebel Eltron GmbH & Co. KG is working from 2012 to 2014 on innovative ideas for sustainable distribution grids. The required Smart Operator control algorithm is developed and will be tested in a smart grid laboratory by the Institute for High Voltage Technology (IFHT) of the RWTH Aachen University. Upon approval by all project partners it will be field tested in three German rural areas. The algorithm for the intelligent household control will be developed by the University of Twente.

FUNCTION OF THE SMART OPERATOR

The basic concept behind the Smart Operator is the autonomous operation and monitoring of the grid. A detailed description of the algorithm is given in [4].
Various innovative and intelligent components are used in the grid, such as

- regulated local grid transformers,
- various types of electrochemical storage,
- remotely controlled low voltage switches,
- charging stations for electric vehicles.

Besides the intelligent grid components further devices are used in the households to control local demand and generation. These are connected to the Smart Operator via a home energy controller (HEC).
The basic idea is shown in Figure 1. At first, the Smart Operator receives various measurements from the grid. These measurements are taken at various points in the grid as well as in smart meter of the households.
Next to the consumption data these meters can also transmit voltage data. At selected points in the grid additional measuring instruments are installed.
Measuring instruments are also installed in the transformer substation and in the low voltage switch and the storage facility. The grid conditions which cannot be measured are estimated as described in [5].
The expected grid conditions for the next 24 hours are calculated. The basis for this calculation is a combination of grid data from the past and expected weather conditions. With this data it is possible to make a prognosis of supply and demand. With this prognosis an uncritical grid operation can be set up. In this way it is possible to prevent potential overloading or exceeding voltage limits.

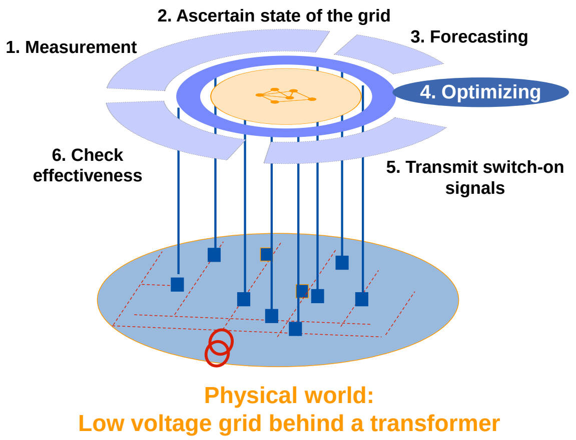

Figure 1: Basic concept of the Smart Operator

Every command determined by the Smart Operator is checked by a load flow calculation before being sent.
Through the continuous monitoring of the grid by means of the measurement data the forecasts are constantly checked. If differences from the forecast are identified a re-optimization of the grid is carried out and, if required, new switch commands are sent. This approach ensures the safe operation of the grid at all times (see [4]). In the event of a fault in the Smart Operator an alarm is sent to a superordinate system and all the components switch from the regulated grid operation to operate independently. In this way the regulated local grid transformer, e.g. can be controlled by the Smart Operator but it can also independently keep the voltage at the busbar within allowed limits.

WORK PACKAGES

The project is being coordinated centrally by RWE Deutschland AG and is divided into a number of work packages. The overview is depicted in Figure 2. A detailed description of this process follows later on.

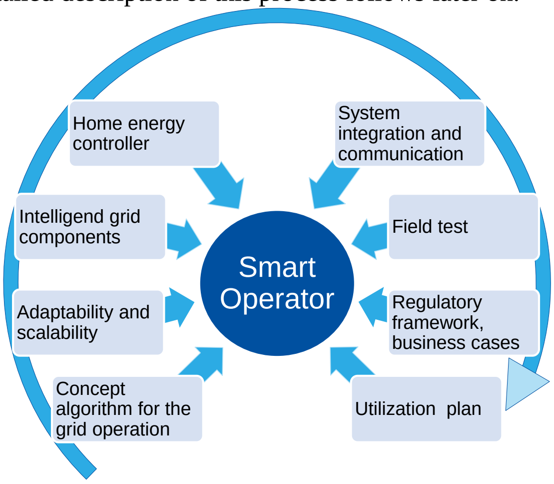

Figure 2: Overview of work packages

The individual steps in the process are carried out by or with project partners. Following successful simulations and laboratory testing of the autonomous controlling of the low voltage grid a field test will be conducted. In evaluating the project equal attention will be paid to economic viability and technical feasibility.
At first, the Smart Operator will be tested in grids in rural areas, because in these grids the decentralized power production through wind and sun is particularly high while the grids have limited capacity. These low voltage grids are located in Wertachau, Kisselbach and Wincheringen in Western and Southern areas of Germany.

Control algorithm for the grid operation

As already mentioned, it should be possible to manage a low voltage grid independently by the Smart Operator. For this it is necessary to develop a suitable control algorithm for the operation of the grid, which would stipulate how the Smart Operator reacts in certain situations. The Smart Operator controls the low voltage grid in real-time and constantly improves its efficiency by learning from historical data. The algorithm is being developed by the IFHT of the RWTH Aachen University.
As a basis for its commands the Smart Operator uses a matrix in which all possible switching options are saved.

It randomly selects an option from this matrix and checks the new grid situation with a load-flow calculation. If no overloading or voltage outside the allowed limits is detected the grid situation will be set accordingly.
When the Smart Operator first goes into operation 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.

Adaptability and scalability

The theoretical research of grid operations with a Smart Operator and practical field tests will be adapted for other low voltage grids. The effects of multiple use of a Smart Operator on medium voltage grid levels will also be investigated. Using the Smart Operator should enable an improved operation of the low voltage grid with positive effects for upstream grid levels to avoid over-loaded grid assets, e.g. in the medium voltage level. At the same time it will be examined whether the Smart Operator can also be used all over the country or only in selected regions.
When the effects of its use at other grid levels have been established it will be possible to analyze the benefit of a central “master” Smart Operator in the medium voltage grid which communicates with the Smart Operators in the low voltage grids. This would make the uncritical operation of the grid both in the low voltage grids and in the medium voltage grids possible.

Intelligent grid components

In the project various innovative grid components are tested. These are to be used intelligently by the Smart Operator to guarantee stable and safe grid operation.
The local grid transformer will be replaced by a Voltage Controlled Distribution Transformers (VCDT) using an integrated on-load tap changer (OLTC), which can regulate the voltage in 9 steps of 2.5% each to provide a broad range of the possible voltage bandwidth supply.
The GRIDCON Transformer is delivered by Maschinenfabrik Reinhausen (MR) and enables the Smart Operator to activate the step by step voltage regulation.
Furthermore, four different kinds of battery storage systems are introduced.

1) Large grid storage systems with a capacity of 150 kWh are used for peak shaving. The size of the reduction in power and further storage behavior will be examined. For the relation of capacity to power (*E2P*-ratio), theoretical values are derived in literature [6]. Based on these elaborations, a reduction of a PV peak, e.g. from 60 kW nominal power to 30 kW leveled feed-in (and hence, an *E2P*-ratio of 150kWh/30kW=5 hours) should be possible. This storage is intended to reduce the burden on the transformer in the event of large PV-feed-in peaks.
2) A further possible application for the grid storage of 150 kWh is to maintain the voltage at the end of the line. Here, depending on the grid conditions active and/ or reactive power can be consumed or supplied.
3) In addition to the large battery systems, smaller units with capacities of 30 kWh are used as decentralized assets in order to contribute to (balanced) voltage levels. For this, these assets are positioned next to selected PV generators.
4) Furthermore, battery systems are installed in households to increase the flexibility of the consumption/generation, which is enabled by the local battery in the operation of the HEC (see details below).

Grid separation switches are to be used to control the grid topology, so that, if necessary, two branches can be joined together to form a closed ring structure.
These technologies will be selected according to the grid area and will be used either in combination or separately. The central controlling function will be carried out by the Smart Operator.

Home energy controller

The communication with controllable loads in households takes place via intelligence (Home energy controller (HEC)) installed in the households. The HEC controls the loads and producers in the households including among others PV generators, heat pumps, white goods and battery storages.
For the household appliances the HEC works out the optimal timetable. For this, different optimization objectives are applicable, e.g. maximize the self-consumption of locally generated electricity. Furthermore, the HEC may adapt the local energy profile to react on incentives and steering signals provided by the ‘Smart Operator’ (e.g. in cases of grid problems).
The HEC uses information from weather forecasts and combines this with consumer behaviour patterns to produce a forecast of the consumption/generation profile. Thus, it seeks to optimize usage, so that e.g. a heat pump is preferably switched on at midday and the temperature in the refrigerator is reduced if sufficient PV feed-in is given. If the Smart Operator chooses a load profile for the next few hours the HEC tries to realize it and the schedule is passed on to the components.
The customer can intervene at any time and still has complete freedom to do as he or she pleases, so that the HEC and the Smart Operator have to react on unforeseen customer behavior. In case the temperature in the refrigerator rises above the permitted level, the refrigerator will start anyway even if this is not foreseen in the HEC’s prognosis.
A detailed description of the approach to steering the HEC and offering flexibility is given in [7].

System integration and communication

Communication between the intelligent grid components, the HEC and the Smart Operator as the central communications point takes place via various media and protocols. As the IT requirements in grids will be even

more demanding in the future it is very important that communication is not confined to one medium. In the project the use of fiber optics and power line for communication will be tested. Each technology will be considered separately and subjected to field tests later. Apart from the purely technical issues it is also very important to construct secure lines of communication.
It is imperative that the communication cannot be accessed by unauthorized parties both in terms of pure communication between the devices involved in transferring measurements and the control commands from the Smart Operator.
The energy measurements taken in the households are forwarded by the Smart Operator to the data center. The only difference between the Smart Operator and other uses of smart meters in billing customers is the forwarding of the information.

Field test

The proof of the Smart Operator's value in practise will be provided by demonstration grids, which will be set up in 2013. In these grids the various communications media will be installed or retro-fitted. In these grids new substation transformers with on-load tap changers as well as grid storage and all other intelligent grid components will be retro-fitted.

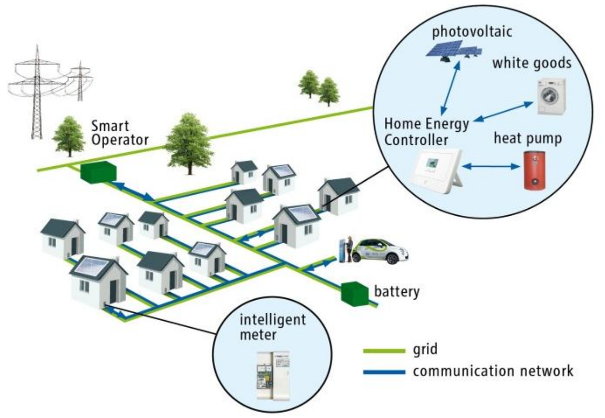

Figure 3: Structure of the demonstration grid

In selected demonstration grids the production and consumption in private households will be regulated by a HEC with the cooperation of the customer. In these cases the customers have declared the willingness to cooperate with the Smart Operator project and to contribute to a successful field test. Figure 3 shows the structure of the demonstration grid. The graph shows an example of the structure with the possible components in the grid and the households. Communication will be conducted between all the components and centrally coordinated by the Smart Operator.
To test also the effects induced by e-mobility some electric vehicles and charging stations will be allocated in the demonstration grids. These field tests enable the evaluation of previous simulations of grid operations.

Regulatory framework, business cases

Revealing prospects and risks for the introduction of the Smart Operator is another object of the project. The business cases will show if and how the Smart Operator could be an economic and 'smart' alternative to conventional reinforcements in future grids. For this, it will also be necessary to develop an appropriate regulatory framework. Adjustments will be suggested after considering the results based on the experiences in the field test.

Utilization plan

The measurement data base from the field test will be analyzed and evaluated after the field tests. One part of the analyses will be the evaluation of the grid with the measured data to scale these results to future grid situations, e.g., higher PV-installation in the grids.
Another part of the analyses will be the operation of the Smart Operator algorithm. The actions taken by the Smart Operator, such as switching options and their time and frequency of use, will be analyzed in detail.

OUTLOOK

Until mid of 2013, the algorithms will be implemented in the Smart Operator to enable the communication with all intelligent components. First, this is realized inside a simulation process controlling a low voltage grid in allowed ranges. All these theoretically determined findings will be checked in the field test. Before the installation and the start of grid operation by means of the Smart Operator all communication processes will be bench tested.
Final results and consolidated findings will be available by the end of 2014.

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