INNOVATIVE CONCEPTS FOR EFFICIENT ELECTRICAL DISTRIBUTION GRIDS

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ABSTRACT

This paper presents the results of the project "Grids for Future Electricity Supply", which is supported by the German Federal Ministry of Economics and Technology. A consortium of RWE Deutschland as project manager, ABB, Consentec and TU Dortmund has worked from July 2009 to June 2011 on economic solutions for sustainable distribution grids. Innovative approaches are identified, evaluated and auspicious ones have been demonstrated in a German rural area.

With consideration of trendsetting equipment an outline of distribution grids, which are sufficient for the energy supply-tasks in 2030, are given. All of the presented solutions have been customised to utilities' specifications and it will be a commercial solution for an alternative distribution grid realisation.

INTRODUCTION

To use renewable energy it must be exploited where and when it is available. Therefore a huge number of dispersed generation units is necessary. Because of their nominal power, they are usually connected to the distribution level of electricity supply. This forces a redesign of distribution grids with respect to economic and efficient power supply, because they are not optimised for powerful feed-in.

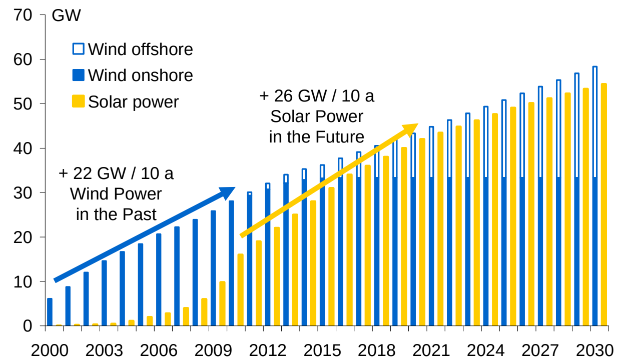

Figure 1: Renewable Generation in Germany

In Germany the onshore exploitation of wind power has increased rapidly over the last 10 years but there will be less growth in the future (figure 1). The main growth of wind power is predicted to be offshore, but this does not affect existing distribution grids. However, there is a growth which is affecting distribution grids and it is caused by solar power. The main expansion in this type of energy will occur in the next 10 years [1, 2].

In order to cover rising demands, the extension of the distribution grid is always a suitable solution, but is it an efficient one? Distribution System Operators (DSO) in Germany are forced by incentive regulation [3] to realise efficient grid structures. Therefore the demands must be exactly predicted on the one hand to adjust the minimum amount of needed equipment. On the other hand, technological developments must be taken into account because they can allow easier and cost-saving solutions. For example, the developments in power electronic devices have increased in functionality and decreased in price during the last decades. This expands possibilities for mass-market usage in the supply of energy. Therefore grid concepts must be reviewed periodically.

FUTURE GRID PROJECT

Electricity supply has to provide two main functionalities.

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First, electricity generation and load must be balanced every time. Many projects work already on widespread solutions for this task [4]. Secondly, the customer forced power flows must be achieved economically without restrictions. This is the focus of the project "Grids for Future Electricity Supply" which is supported by the German Federal Ministry of Economics and Technology. It combines the know how of RWE Deutschland as a distribution grid operator, ABB as a manufacturer of power system equipment, Consentec as a specialist in economic evaluation of power grids and the TU Dortmund University as a research institute in electrical engineering.

The project considered the energy supply-task development up to 2030 because of the long depreciation times of power supply systems. Thus, the asset management must set the course today that the new challenges like renewable power connection lead to an efficient distribution grid in the future.

The aims of the project are to identify, evaluate and demonstrate economic solutions for sustainable distribution grids. Especially the real-life demonstration of innovative concepts for efficient electrical distribution grids is an important part of the project. During the project-time from July 2009 to June 2011 about 3 million Euros have been invested in the demonstration distribution grid, which give an outline of a smart grid design.

TRENDSETTING EQUIPMENT

Future distribution grids will still mainly use current technologies to provide an efficient power supply. Nevertheless, new equipment have to be identified based on current trends and innovative technical approaches respectively to ensure the realisation and efficiency of the future grid concepts. Especially in rural grids, new or adapted equipment can be more efficient compared to conventional grid expansion, because voltage constraints are more relevant than the rated loading of the equipment. Therefore, various voltage regulators for distribution grids based on different technologies are analysed and developed.

Direct Voltage Regulator

The on-load tap changer and the PCS 100 active voltage conditioner (AVC) by ABB are technically and economically evaluated as direct voltage control units. Instead of changing the transformation ratio with a tap changer, the AVC feeds-in or absorbs an additional voltage via power electronics to gain a constant outgoing operating voltage [5].

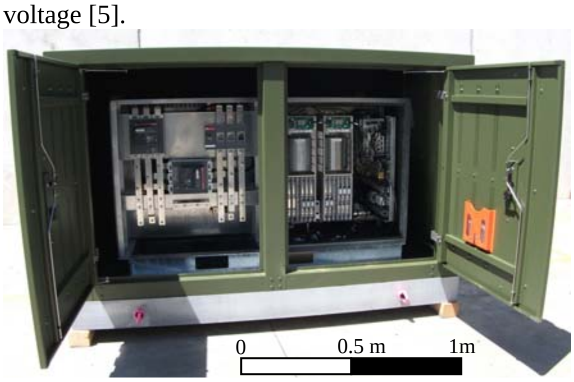

Figure 2: Active Low Voltage Conditioner

Although the AVC has been designed for voltage sag protection in industrial applications, several benefits of the AVC are also usable for utilities, e. g. its modular construction, the independency of any transformer and the continuous, fast and stepless voltage control. Multiple AVCs with different power ratings have been further developed for utilities' demands and tested for the first time outdoors within the demonstration distribution grid. Figure 2 illustrates the first prototype of a LV AVC for outdoor use.

Wide-area Controller

Generally, voltage controllers set the voltage on the secondary side of the equipment to a fixed value. In contrast, a wide-area controller monitors several critical nodes in the supplied grid via telecontrol (figure 3). The objective of the wide-area controller is not to regulate the operating voltage of a single node to a constant value, but to lead the operating voltage of all critical nodes within a determined band width.

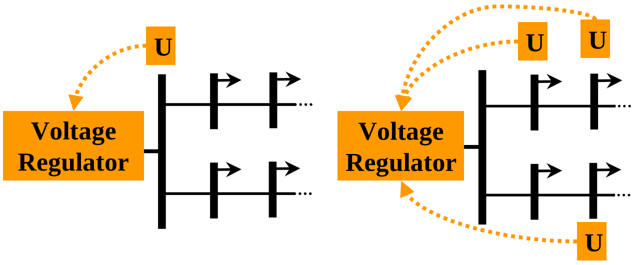

Figure 3: Conventional versus Wide-area Voltage Regulation

Analyses with NEPLAN® have shown that the wide-area controller can be a useful module for voltage regulation, but several aspects, e. g. switching in the grid or changes of the load/feed-in characteristics regarding critical, and here from observable nodes, have to be kept in mind.

Electronic Sectionalizer

The electronic sectionalizer by ABB can be interpreted by its functionality as a "low-end" circuit breaker to divide supply layers inside mainline supply concept. Together with longer branch circuits it helps to keep reliability constant on a reference level. The sectionalizer differs between permanent and temporary faults and opens at a permanent fault during automatic re-closing of the upstream circuit breaker in the transforming substation (figure 4).

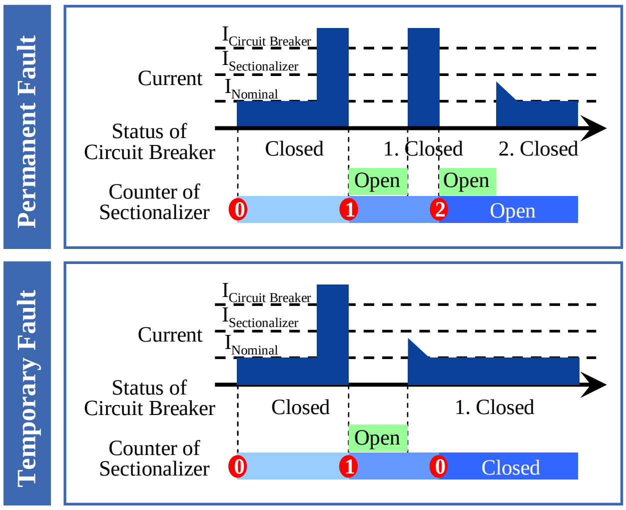

Figure 4: Tripping Scheme of a Sectionalizer

Until now, the sectionalizer has been mostly implemented in very rural grids outside of Europe. Therefore, the sectionalizer has to be enhanced to fulfil all technical constraints, e. g. short circuit rating, for the comprehensive utilization in European grids.

INNOVATIVE GRID CONCEPTS

An innovative grid concept can be the combination of new and conventional equipment but also a new arrangement strategy of conventional ones. Thus, a grid concept describes a solution of the energy supply-task. The economic benchmark for each innovative approach is the conventional grid expansion. All identified and analysed concepts can be sorted into four groups, which are explained by the realised concepts in the demonstration grid.

Information and Communication Technology

The use of information and communication technology (ICT) is often adjudicated as the main component of a future smart grid but it is only one part of it.

ICT helps to reconstitute grid observability under high renewable feed-in. Therefore it is sufficient to measure the voltage, active and reactive power and the direction of the load flow at some known hot spots in the grid. As an alternative these values can be collected from main renewable generators. The processing of both sources in the control system is sufficient and does not affect customer privacy.

Another subgroup of ICT-concepts is the active grid optimisation at load limits. The optimised tap-changing by wide-area controllers belongs to this group. It allows more connection of renewable generation at existing grids.

Disposition of Storage Devices

A storage device can be operated with regard to grid aspects if it is controlled by local load flow and/or voltage level. In combination with fluctuating renewable generators the power flow can be homogenised and the used voltage range is smaller. The last point is especially relevant in extensive rural distribution grids. Reactive power control helps to broaden voltage limits already, but active power control is more powerful and can be used to reach the limits of voltage and transportation capacity simultaneously.

Battery storage units can be used for this purpose, but they are still expensive and their cycles are limited. Natural gas is easy to store with high energy density, but in rural regions it depends on existing biogas generation-plants. The avoidance of biogas generation in times of e. g. solar power feed-in works as a virtual electricity storage device and is an innovative concept.

Local Voltage Control to exploit Grid Transportation Capacity

Another concept for local voltage control by use of active and reactive power is to adjust power quality by electronic voltage regulators. The concept is to fix the voltage near to the customer and to allow a major voltage range in the pre-located grid. This enables the connection of many renewable generators to the existing grid, which has been up to now optimised to use the whole voltage range on the load side.

Hierarchical Supply Layers in Medium Voltage Level

Two levels of power supply are realised at medium voltage level, when the corresponding grid parts follow different concepts. One example is the execution of different voltage limits in both grid parts. Another differentiation between the levels can be in the cross-section or type of line equipment. With strong cables on the first level some points in the grid can be provided with high short circuit power. In combination with easy switches between the first and second level (e. g. electronic sectionalizers) a powerful and reliable backbone medium voltage grid can be realised to enhance renewable power feed-in without extensive grid rebuilding. This concept is called mainline supply with dissoluble grid parts by electronic sectionalizers and has also been realized in the real-life demonstration grid.

EVALUATION METHOD

The aim of the evaluations carried out has been to analyse the innovative grid concepts outlined above regarding technical and economical criteria. At the same time, these investigations served to determine the need for further development of the existing evaluation methods and software tools.

The investigations have been carried out by applying (amongst others) the so called "reference network analysis" (RNA). The RNA is a tool that determines cost optimal target grids taking into account a detailed geographical description of the supply-task, technical restrictions (e. g. voltage limits) and guidelines regarding the considered grid concepts. In order to come to practically oriented recommendations the existing grids and the restructuring measures that are necessary to meet the future energy supply-tasks (i.e. mainly increasing decentralized generation) have to be taken into account.

As an exemplary result of these analyses, figure 5 shows the sum of the cost of the restructuring measures between 2010 and 2030 by applying different grid concepts in a rural area.

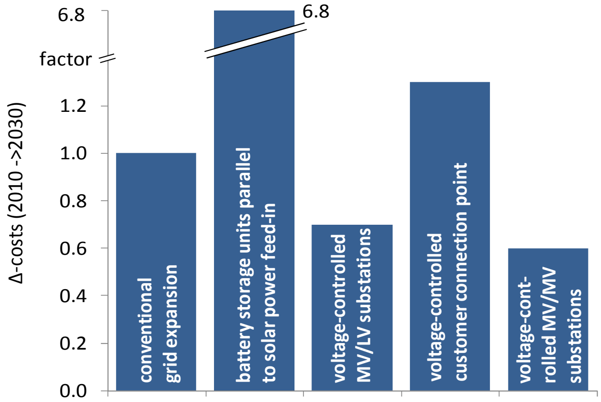

Figure 5: Cost of Different Grid Concepts

The results show that the cost for necessary restructuring measures can be lowered significantly by applying innovative grid concepts instead of the conventional concept. Such analyses have been carried out for different supply-tasks. The main findings are that innovative voltage regulation in rural grids is profitable and the advantage can be realised by using the various concepts and equipment explained above.

Moreover, these simulations have shown that not all characteristics of all innovative grid concepts can be analysed in a comprehensive manner by applying existing evaluation methods and tools. Additional reviews have to be integrated in the optimisation of the RNA software tool which e. g. compare voltage-controlled MV/LV substations and conventional grid reinforcement concerning cost-effectiveness.

TEST GRID INSTALLATION

The demonstration grid is mainly located in the administrative district of Bitburg-Prüm, which is a rural area in the western part of Germany. This area has a low load and is highly pervaded by renewable feed-in in the low and medium voltage level. The following data illustrates the situation in the area where the demonstration grid is located:

- 5,500 inhabitants, 170 km² area
- 10 km cable and 84 km overhead line
- 74 MV/LV-substations
- 4.5 MWp solar power installed
- 6.5 MW wind power installed
- 9.0 MW installed load
- 3.0 MW contemporaneous maximum load

All four above mentioned groups of innovative concepts are covered within the demonstration site.

ICT

The advantages of ICT in low and medium voltage level (LV, MV) are demonstrated by observing voltage and power values at main renewable generators and central points in the grid. A result is that about 30 measuring points are enough for advanced grid operation. Additionally the simultaneity of the renewable generation in LV-level is determined by using ICT transmitted measurements at the connection points of the generators, the MV/LV- and HV/MV-substations.

Disposition of Storage Devices

A biogas generation plant is amended by low-pressure gas storage and it is operated to avoid electricity feed-in during powerful feed-in from solar power. This reduces grid costs and enhances grid capacity for additional generation.

Local Voltage Control

The local voltage control is extensively tested by installation of seven AVC.

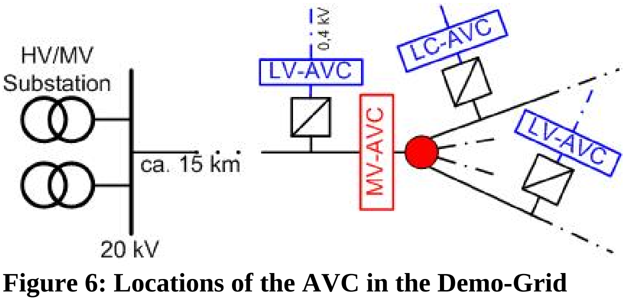

Figure 6: Locations of the AVC in the Demo-Grid

They are integrated at different positions in the distribution system (figure 6) from inside MV- to LV-level at single house connection points.

Hierarchical Supply Layers

To demonstrate hierarchical supply layers within the demonstration grid a strong cable backbone with a length of 8.5 km has been built and the already existing overhead-lines are connected to the cable via three different switching concepts. The functionality of the previously mentioned electronic sectionalizer will be compared with a remote operated load break switch and a simplified circuit breaker. The different operating sequences in case of faults at the overhead lines are shown in figure 7.

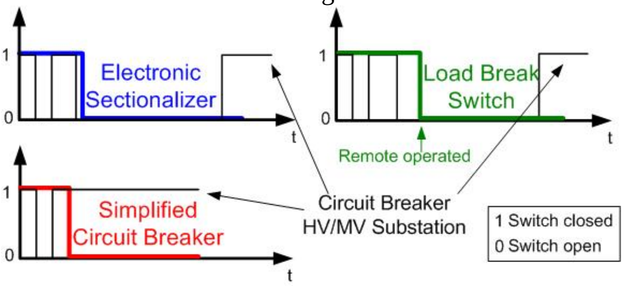

Figure 7: Operating Sequences of the Switches

CONCLUSION

Many innovative approaches for distribution grid design are evaluated and focussed to grid concepts using trendsetting equipment in this project. The auspicious ones like voltage regulation close to the customer, virtual electricity storage, backbone grid parts and ICT are presented in this contribution. They all broaden the use of existing grid capacity under efficiency aspects and are demonstrated in a real-life grid.

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