BEYOND GRID INTEGRATION OF RENEWABLES – VOLTAGE REGULATION DISTRIBUTION TRANSFORMERS (VRDT) IN PUBLIC GRIDS, AT INDUSTRIAL SITES, AND AS PART OF GENERATION UNITS

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ABSTRACT

Since 2012 voltage regulation distribution transformers (VRDT), that is distribution transformers equipped with on-load tap-changers, have become a central means to facilitate the economic integration of renewable energies into public power grids. Interestingly, with the growing popularity of the technology, it becomes apparent that there is a multitude of use cases beyond renewables integration and that the technology is not limited to public grids but can also find application in industrial grids and become part of generation units. The primary driver behind these new found field of application for distribution transformers with on-load tap-changers is a new generation of such tap-changers which is much more compact and much more economic than traditional tap-changers.

INTRODUCTION

Since 2012, voltage regulation distribution transformers (VRDTs) have arrived as a network-capable smart grid asset. A VRDT is a conventional distribution transformer equipped with an on-load tap-changer. The VRDT technology was initially developed for one primary purpose, namely to comply with the voltage band in the case of a high penetration with distributed generation.
Meanwhile the VRDT technology has found worldwide adoption and hence represents an established grid asset for the public network operators facing problems with the integration of distributed renewable.
The key to the success of VRDTs in public power grids is the fact that they transfer proven technology from the high voltage networks into the distribution grids and are highly compatible with the standards and processes of grid operators.
Since nearly a century, power transformers in high voltage grids have been equipped with on-load tap-changers to dynamically adjust the voltage of such transformers. The underlying technology had originally been industrialized by Maschinenfabrik Reinhausen and relies on changing the number of active windings of a transformer with an electro-mechanical system.
Figure 1 shows how this proven concept can generally be applied to the distribution grid through a VRDT.

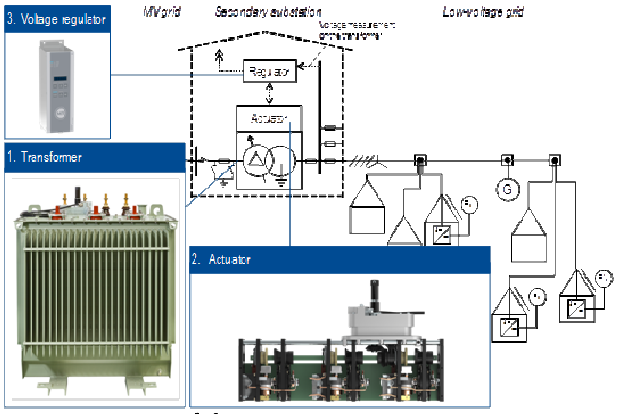

Figure 1: Layout of the System VRDT

A secondary substation, e.g., connecting the 20 kV grid with the 400 V grid, is equipped with a special distribution transformer that comes with an actuator such as an on-load tap-changer that allows changing the voltage of the transformer dynamically under load [8]. The market offers different technological concepts for such actuators. Advanced solutions allow an actuator to be installed without having to change the dimensions of the transformer. This is the only way to ensure that a VRDT can be used in all existing secondary substations. Particularly with regard to the large installed base of compact stations, this requirement is a central point for almost all distribution network operators. In addition, an actuator lifespan that corresponds to that of the transformer with no or only minimum maintenance is usually a primary, economically based requirement [8] This requirement is frequently hard to fulfill for concepts based on power electronics. Moreover, advantageous VRDT concepts facilitate a large regulation bandwidth in that they can significantly alter the voltage of the transformer while at the same time allowing for fine-grained regulation steps in order to avoid network effects such as flicker.
In order for the actuator to facilitate the voltage changes required to stabilize the grid some intelligence needs to determine when which actions are appropriate. This is the role of the voltage regulator which relies on algorithms to determine the right reactions given the current state of the grid. To assess the latter it relies on sensors which in the most simple setup measure values on the low voltage bus bar of the secondary substation. In more complex setups there can also be sensors deployed deeper in the low voltage grid, e.g., at the end of the most critical feeders. For most situations classical bus bar control is sufficient.

In case of remote sensors being deployed they can communicate with the controller via GSM or Broadband Power Line [8].
The challenge in transferring the idea of transformers with on-load tap-changers from the high voltage to the medium voltage context lies in meeting the requirements of this new context with regards to economics, dimensions and weight, and maintenance requirements. Only a few years ago first concepts that matched these demands became available. Meanwhile they have proven their value to the operators of public and industrial distribution grids with the total population of VRDTs estimated at 1.500 units.
In comparison to other conceivable solutions for voltage control in the distribution grid such as distributed energy storage or inverters providing reactive power, VRDTs seem advantageous since the technology they are based on has proven itself over many decades in the high voltage grids. Moreover, they seem highly economical since they facilitate a high degree of compatibility with existing network infrastructures and the processes of network operators. When a network operator selects an appropriate technical concept there is basically no difference between the operation of a conventional distribution transformer or a VRDT. Figure 2 shows a photograph of a VRDT which on the outside is hard to distinguish from a regular distribution transformer.


Figure 2: Voltage Regulation Distribution Transformer

Based on the setup of VRDTs and based on the features they offer, it has been found that, in distribution grids as well as in industrial grids, there are also other applications for the technology than the classical use cases the revolve around the grid integration of renewable. All of the use cases do, however, rely on the grid side effect a VRDT offers by stabilizing the voltage on the low voltage side of a transformer within a predefined threshold.

ECONOMICAL OPTIMIZATION OF DISTRIBUTION GRIDS

An efficient distribution grid has as little equipment as possible. This enables savings of both investment as well as operating expenses. VRDTs help to improve the efficiency of grid sections. Using them can reduce the total number of secondary substations. The number of secondary substations needed for a grid area is determined firstly by the maximum demand to be covered and/or the maximum feed-in to be transported and secondly by the maximum possible distance between the secondary substation and grid connection points from a voltage standpoint. VRDTs dynamically adapt the voltage and permit a larger electrical supply radius around each secondary substation. In this way, even consumers or feed-ins, which are at a great distance from the secondary substation can be connected .
Reducing the number of secondary substations is only possible by expanding the supply radius of some selected substations. This, in turn, means that the output voltage of those substations must be increased. With the VRTD, a grid asset is available to realize this use case. Because a VRDT is able to determine the specified voltage range in the low voltage grid autonomous of the existing voltage range in the medium voltage grid, the following mode of operation is possible:
The limit of these new supply radii can be extended as far as the thermal capacity and/or the permitted voltage drop of the line allows.

We illustrate this mode of operation with a real world example from a small, one-street-village with around 1.500 inhabitants and 12 secondary substations in Germany. 7 stations are in the residential part of the village.
4 substations are more than 40 years old and are due for a complete renovation, the physical structure as well as the electrical equipment.
As a planned course of action to improve the existing power grids, the dismantling of two substations is considered. This is possible by using two VRDTs.

Fig.1 shows the part of the village we examined.
All transformer stations supplying energy to the village are numbered from 1 to 7.

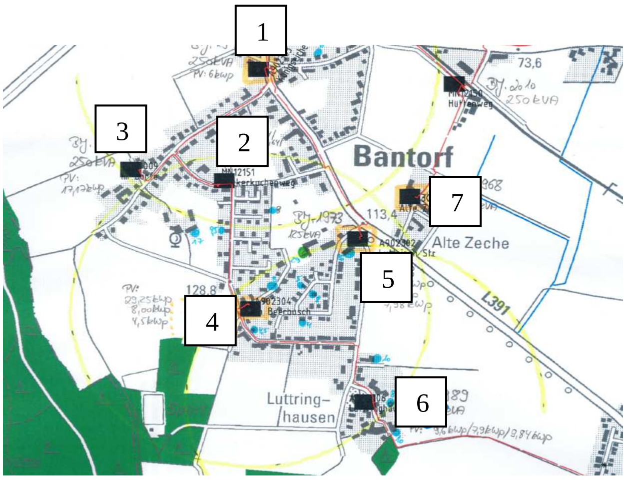

Fig.1

In Fig.2, the electrical supply radius of each transformer station is shown.

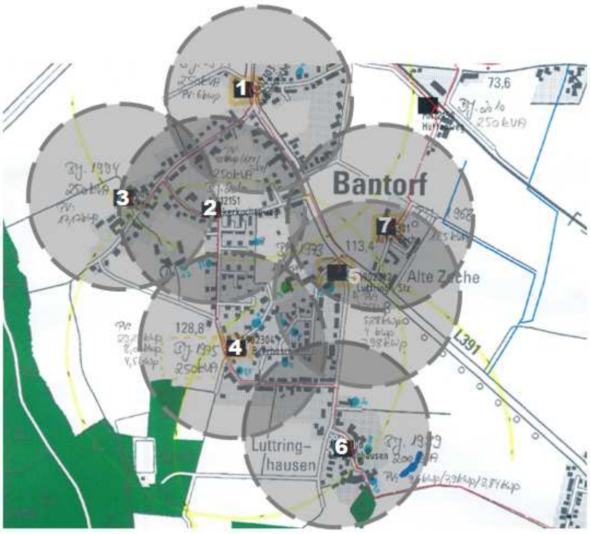

Fig.2

The first step is to substitute the transformers in substation 2 and 7 with voltage regulating distribution transformers.
VRDTs dynamically adapt the voltage and permit a larger electrical supply radius around each secondary substation.
By selecting a verified control range, the new effective electrical supply radius of both transformer stations can be increased, with the result that the grid area is sufficiently supplied (see Figure 3).

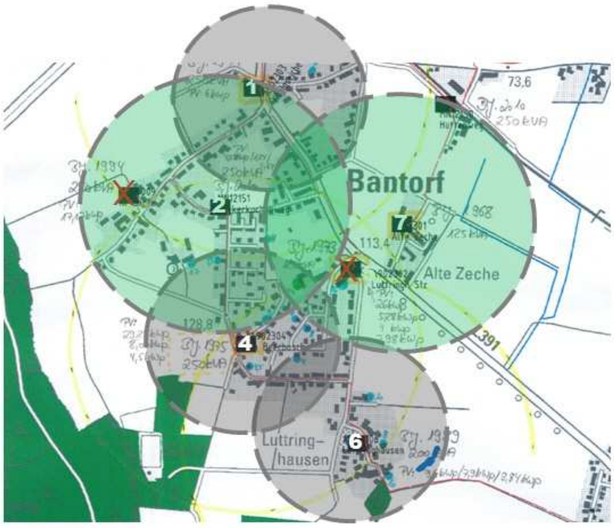

Fig.3

Fig.3 shows the target grid system after replacing the transformers in substations 2 and 7 with VRDTs. The increased supply radii achieved through the adoption of VRDT technology made it possible to eliminate substations 3 and 5.

STABILZING INDUSTRIAL PROZESSES IN VOLATILE GRIDS

For industrial processes to run stably and reliably, they require a stable voltage supply within a narrowly defined band. In grids with limited generator power, long distances, or volatile consumers and producers, the supplying medium voltage may be subjected to large fluctuations in voltage. As a result, production cycles may be interrupted, motors may not start, or control systems may crash. This can cause serious damage, especially in sensitive industrial processes. Hospitals are particularly critical in this respect. In addition to direct impacts on processes, frequent changes in voltage may also have a negative impact on the life of equipment.

A VRDT in the industrial distribution grid ensures that loads have a stable supply of voltage regardless of the volatility of the medium voltage as exemplified in Figure 4. VRDTs with a large regulating range, which are able to reliably regulate even large fluctuations in the medium voltage for many years without any maintenance, are well suited to this application. Compact dimensions help to keep costs down because the VRDT can then be installed in place of the non-regulated one.

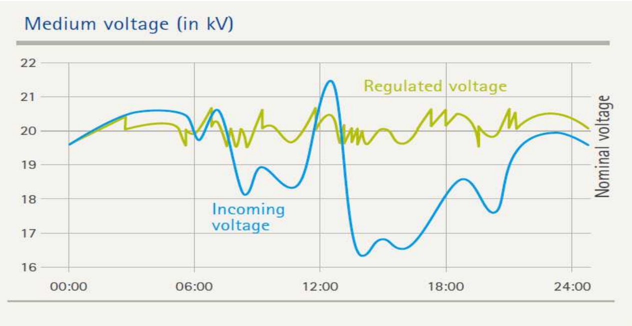

Fig. 4

A VRDT in the industrial distribution grid ensures that consumers have a stable supply of voltage regardless of the volatility of the medium voltage.

COMPLYING WITH GRID CODES ECONOMICALLY

For integration into the grid, dispersed generation units based on renewable energies must meet the respective requirements of the grid operator in the form of grid codes. The provision of reactive power is particularly critical [7]. Especially when underexcited, the ability of the generation plants to provide reactive power is limited in the event of undervoltage. In consequence, grid codes can often only be met either by oversizing the inverters or by requiring the generation plant to operate such that it reduces the amount of active power fed into the grid to suit the situation [3].

VRDTs can avoid oversizing the inverters or reducing the amount of active power fed to the grid and thus ultimately make the generation plant more cost-effective [7].

Due to their ability of keeping the low voltage on an almost constant level, the provision of reactive power does not necessarily lead to restrictions in inverter capacity any more. As an example, a Q-V-Profile of a typical wind energy converter is shown in Figure 5. In particular in terms of underexcited operation (lagging), the capacity shrinks significantly with voltages close to the thresholds of 90 % and 110 % of nominal voltage.

Therefore, an operating voltage close to nominal voltage is desired if technical modifications with respect to oversizing components (e.g., the inverter) are to be avoided. For instance, the transformer accounts for approximately 3 to 4% of the total costs of a wind turbine whereas the share of the inverter accounts for ca. 6 to 7% [5]. Since the costs for a VRDT are only slightly higher compared to conventional transformers, it is worth investing in the modification of the transformer instead of in more expensive power electronics.

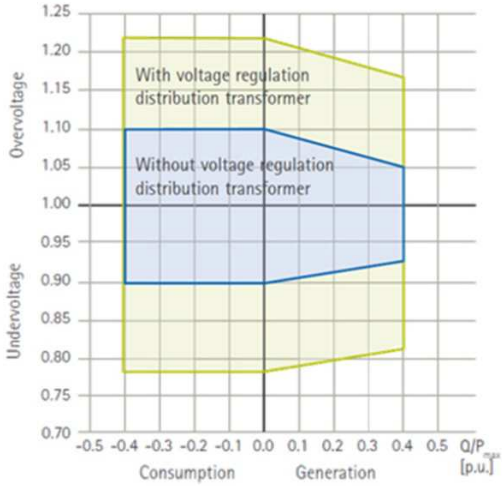

Fig. 5

Additionally, it previously happened that expensive reactive power compensation had to be installed in plants in order to meet the requirements of the code, because of the decreased reactive power potential. In this context, the VRDT can also be a very cost-efficient alternative. As a matter of fact, MV/HV power transformers of the entire plant (in case of HV connection) have the ability to change their tapping as well. However, this function is normally performed too slowly, as every iterative switching step needs about 30 seconds. This is not fast enough if voltage changes occur more rapidly and if the wind power plant has to provide a specific amount of reactive power based on the system operator's request. The set-points of reactive power, according to the Q-V or cosφ-P characteristic of the BDEW medium voltage guideline, must be reached within 10 seconds [4]. VRDTs, however, can change the tapping within ca. 3 seconds, if desired. Consequently, this means that lacking capability due to abnormal operation voltages can be balanced and the full capability of the wind turbine in terms of reactive power provision can be used.

SUMMARY AND CONCLUSIONS

VRDTs are a new grid asset that can be help for both the operators of public and industrial grids.
They help integrate renewable in a efficient way, increase the overall grid efficiency, stabilize industrial processes and allow for more economical dispersed generation units.

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