INCREASE OF THE GRID INTEGRATION OF DECENTRALIZED POWER PLANTS BY THE APPLICATION OF CERTIFIED GRID REGULATION UNITS IN SECONDARY SUBSTATIONS AND POWER GENERATION UNITS

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ABSTRACT

Due to power infeed of mostly volatile energy sources connected to distribution grids, measures are needed to ensure voltage stability in regional grid sections. Thus, grid operators require sophisticated ancillary services to counteract fast changing grid conditions while generation units are obliged to withstand voltage fluctuations in a considerable range for providing ancillary services, e.g. reactive power support over a wide voltage band. So, from a manufacturer point of view technical modifications need to be taken into consideration in order to comply with the requirements from newest grid codes. In this regard a simple and applicable solution can be found in Voltage Regulating Distribution Transformers (VRDT). Initially designed to be used within the power system as a control device to provide flexibility and adjustments between medium and low voltage grids, they can also be applied as generating unit transformers in e.g. wind power plants or as switching element in variable shunt reactors (VSR) providing enhanced capabilities of the generation units with respect to applicable voltage ranges for continuous operations and reactive power supply. The paper describes both applications and a done certification process for VRDT and VSR.

INTRODUCTION

To aim at a successful sustainable energy supply a secured grid integration of generating systems based on renewable energies sources is necessary. Two important key factors are crucial for maintaining the security of supply and grid stability when it has to be dealt with an increasing number of dispersed generators like solar and wind energy converters. On the one hand power generating units and plants should participate in system services in order to contribute to a flexible management and operation. On the other hand an essential key factor can be seen in advanced technologies for the systems that improve the flexibility of the grid in case of regionally fluctuating power flows from generating plants to ensure further integration in accessible grid areas without exceeding the thresholds of capacity. These measures of handling strong dynamic operations must take place in the entire system, more precisely every voltage level. Nowadays grid codes are constantly being revised in order to tackle the challenges as a result of a new generation pattern with massive power infeed in low and medium voltage levels. In this context voltage operation bands in existing grid codes have led to massive discussions between grid operators and manufacturers in the last years. New and forward looking codes include operating voltage ranges that exceed the conventional capability of currently most generating units. In the latest draft of the ENTSO-E Network Code for example, it is required for generators of type D with connection equals or above 110 kV to ensure an operation of the power plant at much wider voltage bands compared to the status quo, temporarily even down to 85% and up to 115% of nominal voltage, respectively (see Figure 1). Whereas the continuous operation may be provided by most of the units employed today these requirements still impose a significant challenge from a manufacturers point of view since – in general – full reactive power supply must be possible within the entire voltage band, too.

Therefore many manufacturers and plant operators will have to modify and improve their technologies to be able to meet these requirements. Potentially a solution can be seen in oversizing power converters but increasing the costs of each generating unit significantly. As well the provision of additional reactive power systems on plant level will lead to considerable higher costs. A different solution can be found in the usage of supplementary equipment which ensures an operation of the plant at stable voltage conditions even if the grid voltage changes considerably. Such device can be found in Voltage Regulating Distribution Transformers (VRDT).

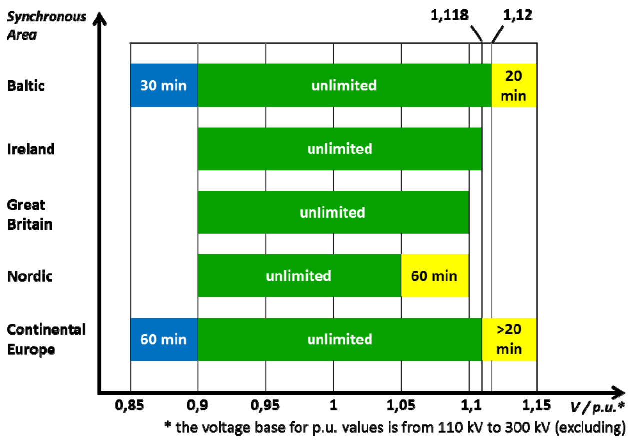

Figure 1: Voltage ranges according to ENTSO-E NC RfG [1]

Equipped with intelligent controllers the internal logic executes a switching operation within a few seconds if the voltage deviates from an individually defined set-point. This fast controllable step-up transformer can be used in configuration with single generating units e.g. wind turbine, but also in application as central farm transformer. Based on its intended utilization the communication device of the VRDT can act either together with the generation unit's control or autonomously in the plant. In both cases the generation units benefit from a harmonized operation voltage since grid fluctuations are balanced and stabilized because of an adapted transmission ratio. As the transformer can vary the secondary low-voltage within a range of +/-10% of nominal voltage, the generating units can be operated easily in larger ranges without changing the layout. Therefore, VRDT can easily decouple the generating unit's operating voltage from the grid voltage conditions within a predefined range.).

VOLTAGE REGULATING DISTRIBUTION TRANSFORMERS (VRDT)

VRDT based on the On-Load-Tap-Changer Technology are new solutions for distribution system operators (DSO) and manufactures of renewable energy systems (RES) to improve the voltage stability in low and medium voltage networks .

A. Technology

With the usage of VRDT the output voltage of the transformer can be controlled dynamically. The VRDT consists of some key components like a conventional distribution transformer, on load tap changer (OLTC), voltage regulator, controller and sensors. The latter ones can be installed at the VRDT or somewhere remote in the feeder which allows external control opportunities and autonomous control of a voltage set-point.

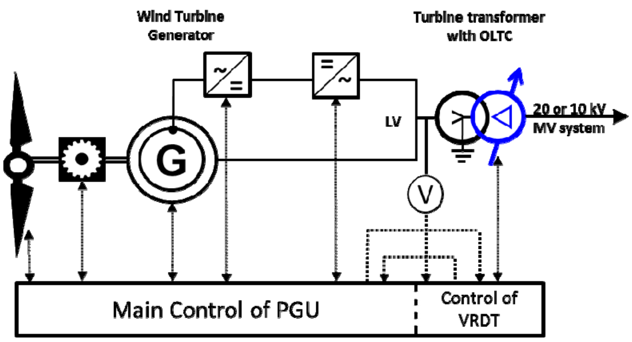

Figure 2: Configuration of a wind turbine with integrated VRDT

By integrating the tap changer at medium voltage side the transmission ratio can be changed stepwise whenever the voltage controller detects a secondary low voltage that deviates from a pre-defined set-point. Normally, a VRDT can control the voltage within a range of +/-10% of the nominal voltage (V_{nom}). This range will be divided into a fixed number of steps of the OLTC. Typically there are 9 steps which enables change the voltage by 2.5% V_{nom} with each step (V_{step}).

B. Application

VRDT were initially designed to regulate the voltage in distribution grids in order to aim at more flexibility in the conventionally quite static medium and low voltage grids. As a direct result their first purpose is to make a further penetration and integration of decentralized power generators feasible. Their application is in particular attractive when due to voltage restrictions in a specific low voltage feeder a connection of additional generating plants is not possible anymore. In these cases investments in rather new technologies like the VRDT are more efficient than in expensive grid expansion measures by erecting new comprehensive connection lines. This issue has been discussed in recent publications several times, e.g. [2].

Additional chances for the enhanced integration of RES evolves when VRDT are integrated in power generating units and plants. In such application it is beneficial for the manufacturer of the PGU to use a simple component with integrated control function which improves operating ranges of the entire PGU and thus stringent grid code requirements can be fulfilled. The control mode of the VRDT when e.g. used as a machine transformer of a wind energy converter can either interact with the main control system of the PGU or act autonomously when the setting of the VRDT control is initialized according to the requirement of the grid code and harmonized with the parameter of the controls of PGU and plant controller (see Figure 2). A basic requirement in this context can be seen in all control functions in terms of voltage control and reactive power supply. Due to the ability of keeping the low voltage on an almost constant level the provision of reactive power does not necessarily lead to restriction in capability anymore. As an example a QV-Profile of a hypothetical wind energy converter is shown (see Figure 3). In particular in terms of underexcited operation (lagging) the capability 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 when technical modifications with respect to oversizing of components like power converters shall be avoided. For instance, the transformer account for approximately 3 to 4% of the total costs of a wind turbine whereas the share of the power converter accounts for ca. 6 to 7% [3]. Since the cost for the adapted transformer are only slightly higher compared to conventional transformers it is worth investing in the modification of the transformer instead of more expensive power electronics.

Additionally, in the past it happened that because of this decreased reactive power potential some expensive reactive power compensation had to be installed in the plants in order to meet the requirements of the code. In this context the VRDT can be a very cost-efficient alternative, too.

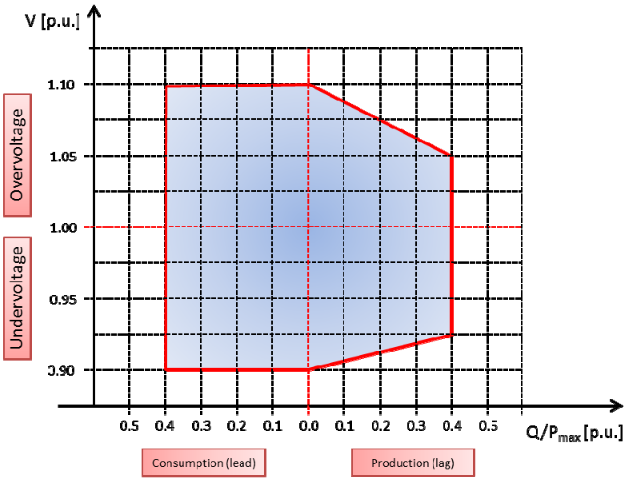

Figure 3: Example of a Q(U)-Profile for PGU

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 performs normally too slow since every iterative switching step needs about 30 seconds. This time is not sufficient if the voltage changes in a shorter period and the wind power plant has to provide a specific amount of reactive power based on the systems operator's request. The set-points of reactive power according to the Q(U) or cosφ(P) characteristic of the BDEW medium voltage directive must be reached within 10 seconds [4]. A VRDT however can change the tapping within 3 seconds if desired. Lacking capability because of abnormal operation voltages can be balanced then, and the full capability of the PGU in terms of reactive power provision can be used.

Apart from this important advantage of decoupling the reactive power capability from grid voltage it also essential that all other requirements of common grid codes are fulfilled and not invalidly influenced by the usage of the component. At least they are subjected to remain untouched or maybe even improved. While certification for generating units and plants is mandatory in Germany the transformer has been tested and certified successfully as a component according to the relevant technical standards. Thus the following chapter describes in particular the firstly designed and applied verification method and the challenge of meeting requirements and certification standards are highlighted including proposals for adaption.

VARIABLE SHUNT REACTOR (VSR)

A. Technology

For the compensation of capacitive charging power, static compensation systems have been normally used so far. To achieve continuous flexible instead of fixed compensation, controllable compensation systems are necessary. The Variable Shunt Reactor regulated by an On-Load-Tap-Changer as an innovative solution for this issue was developed. Table I gives an overview about the basic electrical data of the VSR.

Table I: VSR - Basic Electrical Data

Voltage level	20 kV
Principle	OLTC based on reactor principle
Numbers of OLTC	2
Inductive power range	350 up to 1000 kvar
Max. operating positions	13 (two OLTCs series-connected)

Main components of the VSR are a specified designed three-phase-oil-reactor with variable inductance and an on-load-tap-changer (OLTC). The VSR is directly connected to the 20 kV PV-park busbar. As the standard configuration the maximum inductive power range is set from 350 up to 1000 kvar by installing two OLTCs in series. According to these settings, reactive power differences from 45 up to 65 kvar occur between the operating points.

B. Application

Main application of the grid regulation unit VSR is the integration in large-scale PV parks which are connected to the medium voltage level by extraordinary long cables.

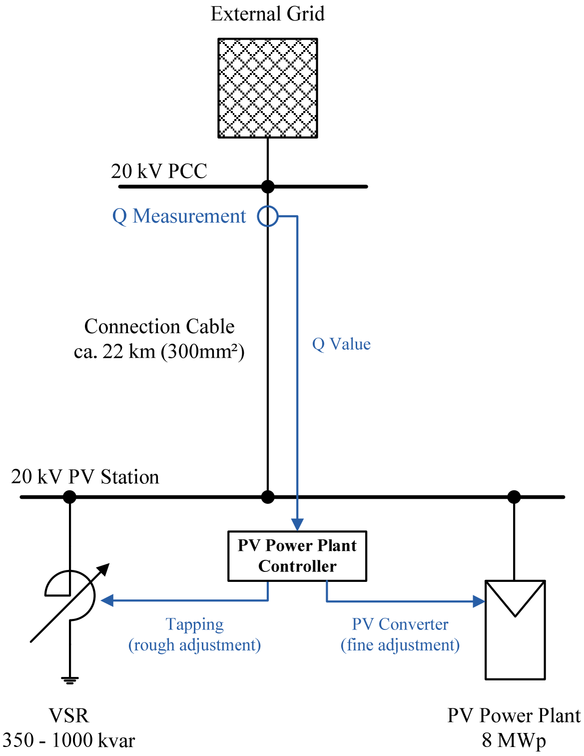

Figure 4: Case of Application – PV Park

The following case of application represents a typical PV park with a rated power of 8 MWp, connected to 20 kV grid in Northern Germany via standard VPE cable with a length of 23 km (see figure 4).
Figure 5 shows the active and reactive power flow in the system for a fluent passage from day to night time and hence from high to low active power infeed. It is obvious that the capacitive load current of the connection cable increases with lower active power infeed of the PV park. When exceeding predefined reactive power limits at PCC, the required compensation steps will be selected by the OLTC. Therefore, especially at night times the reactive power flow into the grid can be completely avoided.

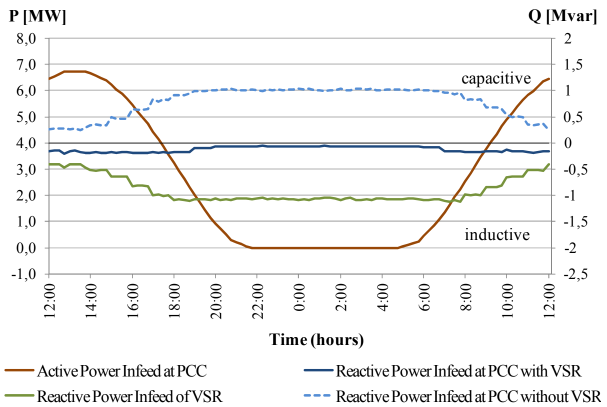

Figure 5: Reactive power compensation (on a typical day in summer)

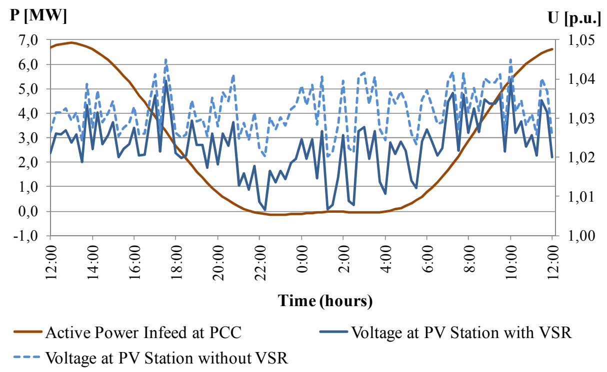

Figure 6: Voltage decrease (typical summerday)

It is noticeable, that by installing a VSR the voltage at the PV station decreases with increasing capacitive power compensation. This behaviour aims at the desired effect of avoiding impermissible overvoltages in low infeed times. In addition to the power waveforms, figure 6 represents the voltage profile at the PV station with and without installation of a VSR.

CERTIFICATION PROCEDURE

For a broad application of new technologies a high level of valuable and reliable functionality is necessary. Therefore the clear definition of operation modes of VRDT and the valid verification of its reliability in constantly changing operation conditions are of primary interest. It is therefore of highest priority that quantitative and qualitatively conformity is verified in order to allow system operators or other users of the VRDT to assess its characteristics based on a proven validity of information. The assessment of the electrical characteristics of the VRDT is based on the well established scheme of product certification as being applied to power generating units in Germany since 2004. The approach according to the newly designed certification guideline Z 417 by FGH certification office consequently contains conformity assessments based on type tests for the operating equipment comprising the existing relevant normative standards as well as some advanced requirements specifically defined for the VRDT's control system, see Fig. 7 [5].

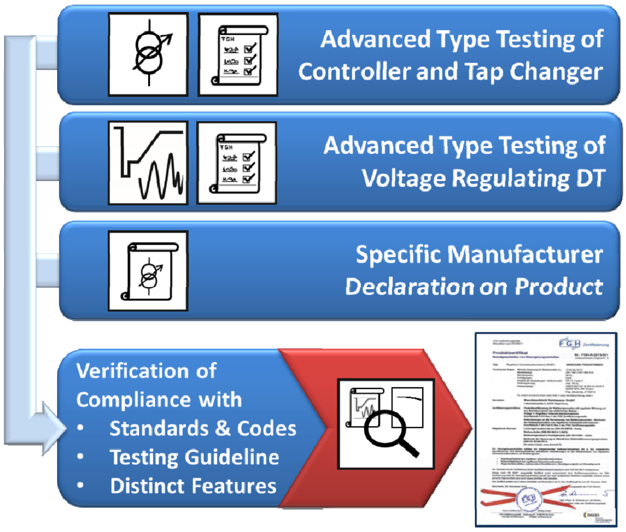

Figure 7: Certification scheme for VRDT according to FGH certification guideline Z 417

The assessment of the advanced requirements includes

1. Evaluation of control accuracy and dynamics for voltage regulation at low voltage terminals;
2. Control characteristics and switching modes;
3. Extensive testing of the component's behavior at critical external electrical influences and its robustness against failures.

in order to consider in particular the performance of the VRDT during disturbances which may occur in terms of frequency or voltage deviations and can be summarized by EMC standards of the EN 61000 for e.g. immunity against voltage fluctuations, harmonics, voltage dips, voltage unbalances and frequency fluctuations.

The evaluation of the general transformer's and tap changer's characteristics relies on existing product standards, such as DIN EN 60076 or DIN EN 60214.

The overall testing procedure has been defined in the FGH guideline Z 501, Part IV, taking into account the given product standards (see above), references to general EMC standards in EN 61000 series as well as own developments of FGH. The tests focus on real normal as well as critical operating conditions during grid operation and identify the capability of the components, see figure 8 [6]. Next to the definition of testing set-ups and testing procedures Z 501 also defines the explicit success criteria for each test.

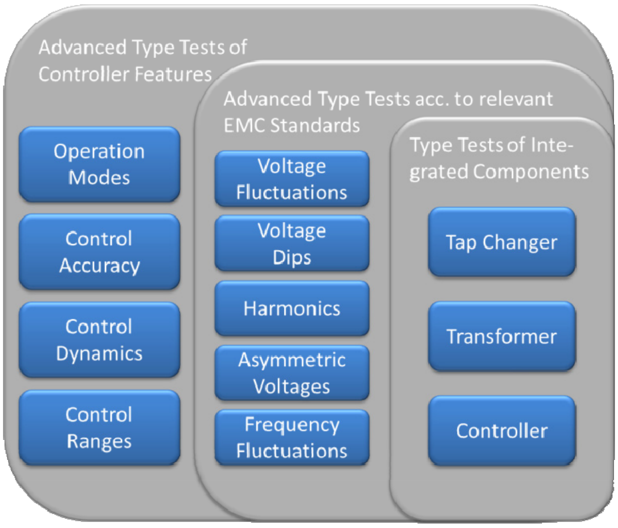

Figure 8: Advanced and product type tests of the VRDT according to FGH testing guideline Z 501 Part IV

Finally the certification includes a conformity check against the specifications and standards of grid operator for the connection to, or operation in electrical power systems with paying attention to legal and technical requirements, if applicable.

Furthermore within the pilot project with Maschinenfabrik Reinhausen a remote controllability of the VRDT by using standardized control protocols like IEC 60870-5-104 was tested and evaluated positively.

In order to extend the certification with respect to an integration of the VRDT into a generation unit further requirements of respective grid codes like response and settling times are taken into account as success criteria of the conformity check.

CONCLUSION

The advantages of supplementary voltage regulating grid units have been introduced and VRDTs were highlighted as effective solution of combined applications. On the one hand VRDTs can be integrated into secondary substations in distribution networks [7] and on the other hand they can be included as a new voltage regulation component in distributed power generating units. In both cases, VRDTs represent an innovative and cost efficient approach that provides advantages in flexibility, performance and costs. With application of VRDT in PGUs even stringent requirements of grid codes with respect to operation voltages or reactive power capability can be fulfilled. The application of OLTC as regulating component for variable shunt reactors is in addition to VRDT a new solution for reactive power regulation in wind and pv parks on the medium voltage level.

Hence, new verification standards were developed and certification was firstly and successfully carried out for the VRDT. This paper emphasizes correspondingly the used procedure and assessments in the context of grid regulating components. The independent verification contains type evaluation of individual integrated components as well as special grid compatibility testing and scrutiny of control capability of VRDT in case of normal and disturbed operation conditions. For grid operator the successfully concluded certification means the provision of the independent and proved evidence, which describes the compliance of the product with guidelines and standards. For manufacturers of PGUs, not only the certification as component is possible, but also as combination with the PGU. The combined certificate includes additionally the standards of grid connection like e.g. the German BDEW medium-voltage directive without the necessity of repeating the entire verification procedure.

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