TESTING OF COMPLIANCE WITH GRID CODE REQUIREMENTS IN IWES-SYSTEC TEST CENTRE

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1. Introduction

Today the installed capacity of Distributed Energy Resource (DER) units in Germany is considerably high (e.g. PV systems: $P_{PV,\ inst.} > 18\ GW_p$, wind power plants: $P_{Wind,\ inst.} > 27\ GW$). Considering the German peak demand of about 80 GW the contingent of feed-in from DER units / plants must not be neglected any longer. For instance, a loss of generation of a large amount of DER can lead to severe stability problems.

Due to the large growth in the amount of installed DER units, the adaptation of interconnection requirements has been under discussion, at the national and international level, between network operators, manufacturers, DER plant operators and research institutes. A paradigm change of the role of DER units is occurring. Commonly, in the past, DER units were not permitted to take an active role, but nowadays all DER technologies are asked to support the network in terms of static and dynamic issues (Degner et al., 2009). In Germany, similar to the requirements for the high voltage (HV) level (VDN, 2007), since January 2009 the new BDEW guideline (BDEW, 2008) for interconnection of DER units to the medium voltage (MV) network has been in force. From the beginning of August 2011, advanced interconnection requirements for the low voltage (LV) networks also come into operation. Thus, DER units / plants connected to the German HV, MV or LV network have to provide extended grid supporting features, in order to support network operation and stability.

In addition to the release of the new BDEW MV guideline, a certification process for all kinds of DER units and plants has been introduced. In order to guarantee an assumed coordinated behavior of all DER units, so called plant certificates are required for new installations. As a basis for these plant certificates unit certificates of the deployed DER units are a prerequisite. A unit certificate is achieved by validation of measurements and simulation results. The procedure of the certification process is already familiar for wind turbines, but had to be extended to all other DER technologies with all the associated implications. This has resulted in several temporary regulations since, on the one hand, the development of the advanced inverter functionalities required a lot of time and resources from the manufacturers and, on the other hand, adapting the existing certification guidelines for wind turbines to other types of DER units with different primary energy sources posed a challenge.

In order to gain new experience on behavior of DER units and to cope with the growing demand for testing of DER units, Fraunhofer IWES has upgraded its lab facilities. With its new reference laboratory in IWES-SysTec (Systems Test Centre) Fraunhofer IWES can perform testing of new grid components and DER units up to a rated power of 6 MVA. The lab infrastructure of the reference lab in IWES-SysTec can be used for reproducible testing of the static and dynamic behavior of all different kinds of DER units. Moreover storage units, loads, novel grid components and charging systems of electric vehicles can be tested. Innovative system approaches and coordinated control concepts can be tested and developed for both normal and disturbed network operating conditions. The lab infrastructure comprises a MV low-voltage ride-through container (6 MVA), a tap transformer, a LV AC-Source (1 MVA), a DC-Source (750 kW), a signal generator (and automatic relay test system respectively), adjustable resistive, inductive and capacitive loads and, as planned in the near future, outdoor MV and LV test networks.

This article focuses on introducing the different testing possibilities featured by the reference laboratory in IWES-SysTec test centre. An overview of the general certification procedure is given first, followed by a description of new test procedures. Then requirements for testing DER units regarding laboratory infrastructure are discussed. Finally the lab infrastructure of the new reference lab in IWES-SysTec is described, indicating how the different testing requirements can be satisfied.

2. Procedure of unit certification according to FGW TR8

As evidence of compliance with the BDEW MV guideline, it is mandatory to obtain unit and plant certificates. Therefore the procedure of certification according to FGW TR8 (FGW, 2011b) will be briefly described as follows.

Since January 1st, 2009, the grid-conformance behavior of distributed generating systems (such as a solar or wind farm) connected to the public MV network must be validated by a so-called unit certificate. Additionally, for plants above 1 MVA rated power, a plant certificate based on the unit certificate/s is required. The temporary regulation allowed PV units to delay the fulfillment of the static requirements stated in the BDEW MV guideline until July 1st, 2010, and of the dynamic requirements until April 1st, 2011.

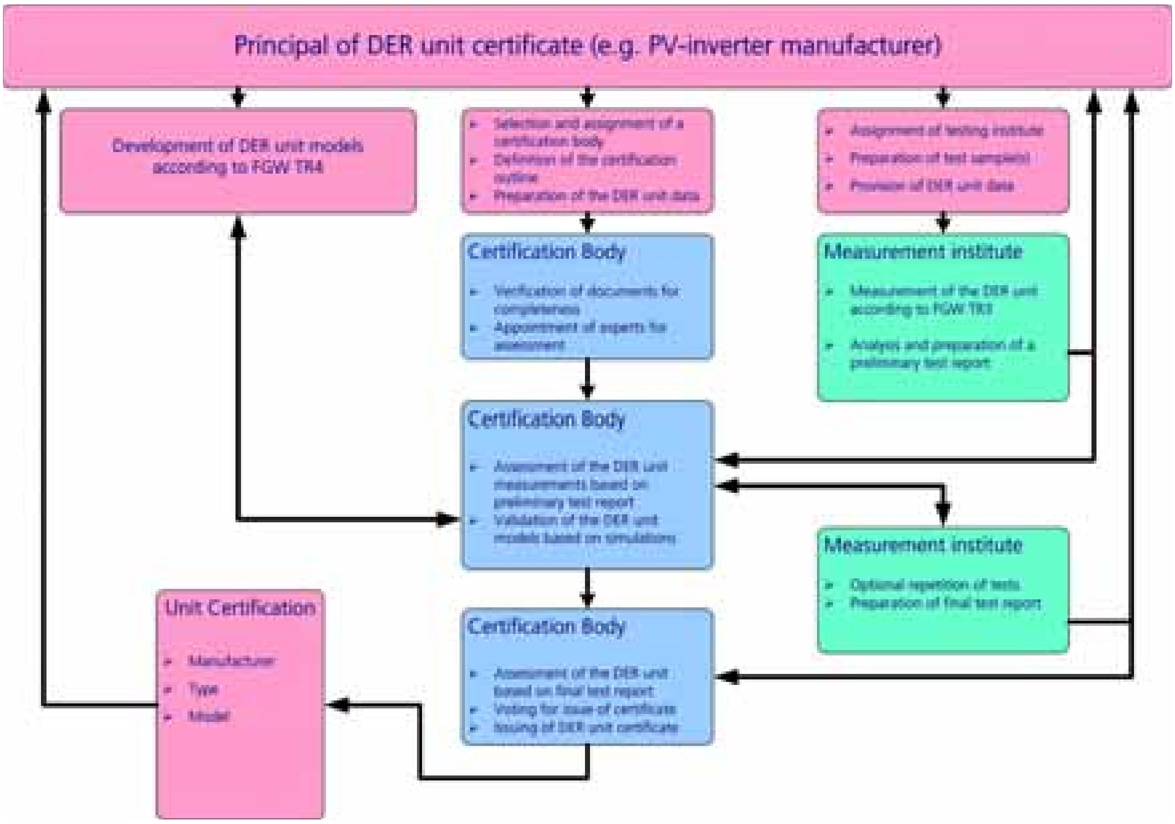

Fig. 1: Flow chart of the process of unit certification

By nature, the principal of the unit certificate (typically the manufacturer of the DER unit) plays a decisive role within the certification process. Figure 1 shows the significant steps of the procedure and the participants, i.e. the manufacturer, the certification body and the measurement institute. For achieving conformance with the BDEW MV guideline, measurements according to FGW TR3 (FGW, 2011a) and validation of simulation models according to FGW TR4 (FGW, 2010) have to be carried out. Based on these results a certification body is allowed to issue a unit certificate guaranteeing that the requirements of FGW TR8 have been fulfilled.

3. Laboratory infrastructure for measurements according to FGW TR3

3.1. General measurement set-up for a PV inverter

Figure 2 shows a general set-up of a PV inverter for taking measurements according to FGW TR3. Besides the acquisition of voltages and currents on the DC and AC sides of the PV inverter inputs and outputs, the set points supplied to the communication interface of the PV inverter have to be recorded synchronously. Since several kinds of set point signals are commonly used – e.g. RS 485 (for internal farm communication), digital signals from a ripple control receiver or analogue signals – the measurement equipment should provide various flexible inputs for the acquisition of set point signals.

Usually, RS 485 signals are generated via manufacturer-specific software commands and sent from the PC to the PV inverter. If digital or analogue interfaces are used, the set point signals can be easily generated in the laboratory via a programmable logic controller (PLC).

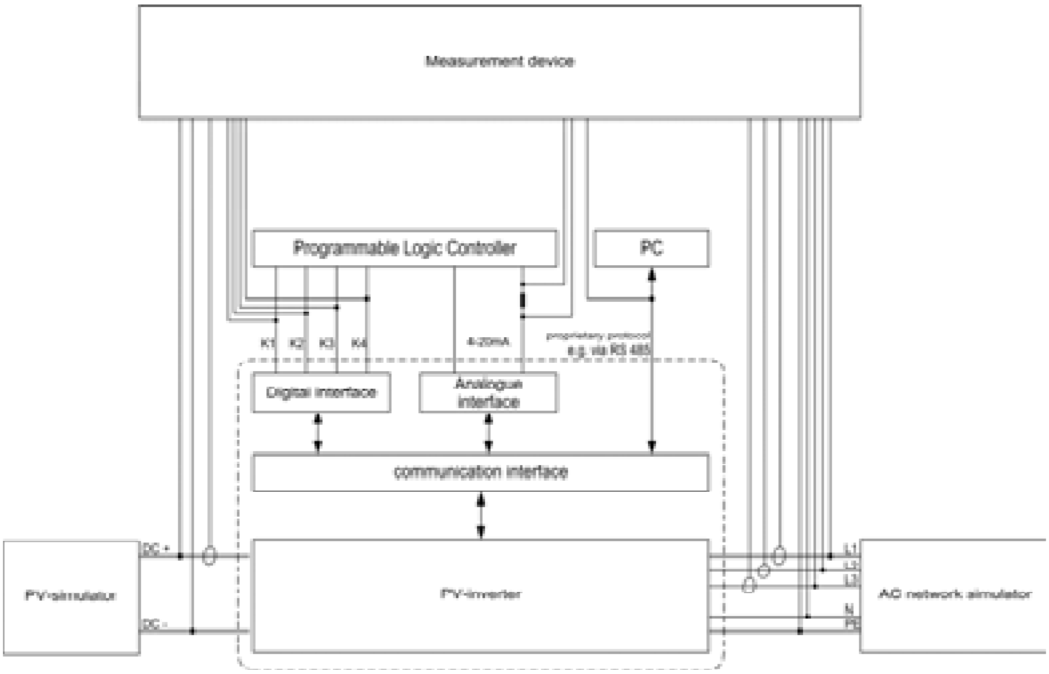

Fig. 2: General measurement set-up of a PV inverter for measurements according to FGW TR3

3.2. Requirements for the DC source

Using a PV generator is not mandatory for the supply of the PV inverter at the DC terminals, since FGW TR3 states that module-independent tests are sufficient for the determination of the behavior on the AC side. Instead of a PV generator, it is possible to use a variable DC voltage source which fulfills the requirements of Annex E of FGW TR3 regarding power and voltage range, control mode and dynamics. This simplification is especially meaningful with regard to high-power applications, since a real PV generation in this power range proves to be quite costly. For testing string inverters, the use of PV simulators is quite common. This ensures that the characteristic curve of a PV array is provided to the PV inverter, even during transient events such as radiation changes or network faults.

3.3. Requirements for the AC network simulator

If the power rating of the DER unit is of the order of a few kilowatts, it makes sense to use a network simulator for the measurements instead of connecting the DER unit to the public network. This procedure offers advantages, especially for the test of power quality parameters and of low-voltage ride-through (LVRT). Of course, the network simulator has to fulfill certain requirements in order to achieve a behavior comparable to a public network. A basic requirement is that each phase of the simulator can be controlled independently regarding amplitude and phase angle; controlling the frequency should also be possible. Furthermore, the usage of a physical impedance network for emulation of a network connection point with certain parameters – short-circuit power S_k and network impedance angle ψ_k – is mandatory.

For DER units with power ratings up to 90 kVA, the laboratory at Fraunhofer IWES offers a network simulator with the aforementioned requirements. This 4-quadrant AC network simulator, consisting of linear amplifiers, provides the possibility of reproducing any desired network behavior.

3.4. Test infrastructure for high-power applications

For economic reasons, it is nearly impossible to provide a high-class test environment for DER units with higher power ratings. A balance has to be struck as to which kind of test infrastructure is used for certain power levels. It is obvious that a general solution cannot be given. However, Fraunhofer IWES has set up a reference laboratory for testing DER units in the higher power range; the developed concept is described in the next chapter.

4. Scope of research and infrastructure for testing at IWES-SysTec

The BDEW MV guideline comprises several requirements concerning static and dynamic behavior of DER units. These requirements can broadly be grouped as follows:

- Active power provision, including set point control and power reduction in an over-frequency condition
- Reactive power provision by set point or characteristic curve (Q(U), cosφ(P))
- Power quality issues such as switching operations, flicker, harmonics, interharmonics and higher frequency components
- Grid protection
- Connection conditions
- Response to voltage drops (low-voltage ride-through / fault ride-through, LVRT / FRT)

The new reference laboratory in IWES-SysTec test centre offers an extensive laboratory environment for measurements according to FGW TR3, verifying the ability of DER units to fulfill the aforementioned requirements. New testing procedures are developed and, as Fraunhofer IWES participates in standardization committees, experiences gained may contribute to standardization processes. Furthermore other types of power system equipment, like e.g. novel grid components or charging systems for electric vehicles, can be tested. The testing infrastructure of the reference laboratory in IWES-SysTec is described in the following.

4.1. Overview on the reference laboratory

The reference laboratory is integrated within Fraunhofer IWES' new test centre IWES-SysTec for Smart Grids and Electromobility (see Fig. 3).

Fig. 3: IWES-SysTec: New test centre of Fraunhofer IWES for Smart Grids and Electromobility (Source: Fraunhofer IWES, Frank Hellwig)

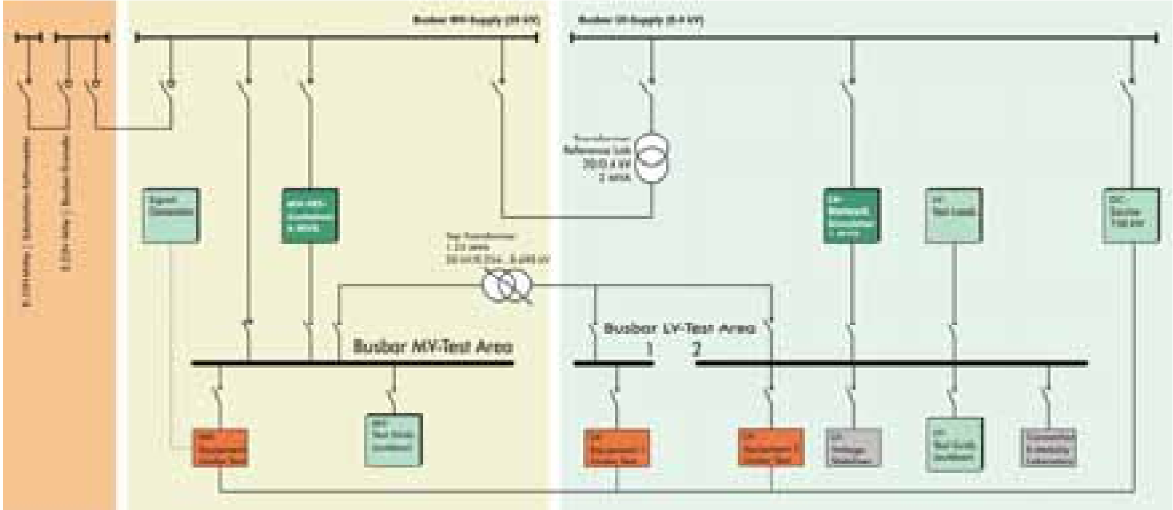

Fig. 4: Schematic of the new reference laboratory in IWES-SysTec for testing of DER units in the higher power range

The concept of the reference laboratory for testing DER units in the higher power range is shown in Figure 4. It offers the possibility of testing DER units rated up to 1.25 MVA on an LV level and up to 6 MVA on an MV level. Testing is not limited to PV inverters; moreover, novel grid components such as voltage stabilizers or controllable transformers can be integrated as equipment under test (EUT) into the reference lab. Different test beds on the LV and MV levels for static and dynamic requirements have been developed and set up. In the following paragraphs the different lab components and possible testing arrangements are described.

4.2. Low voltage AC network simulator and DC-Source

At the LV level, the static requirements for testing of DER units are covered by using an AC network simulator with a nominal apparent power of 1 MVA. Figure 5 shows the relationship between the different functional parts of the AC network simulator.

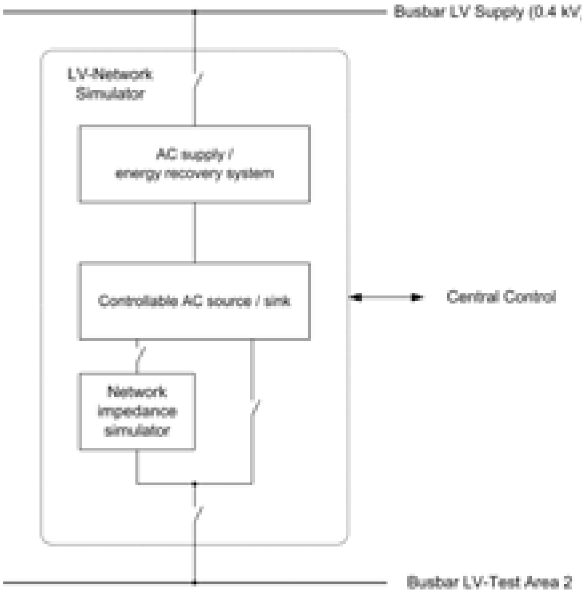

Fig. 5: Low voltage AC network simulator

The DC-Source, which is shown in Figure 6.1 below, has a rated power of 750 kW and can be used for e.g. feeding the DC terminals of an inverter or testing of charging systems for electric vehicles. The DC-Source consists of two parts, collectively five power units of 150 kW each. Various settings, like e.g. solar irradiation profiles (see Fig. 6.2), can be implemented to the DC-Source.

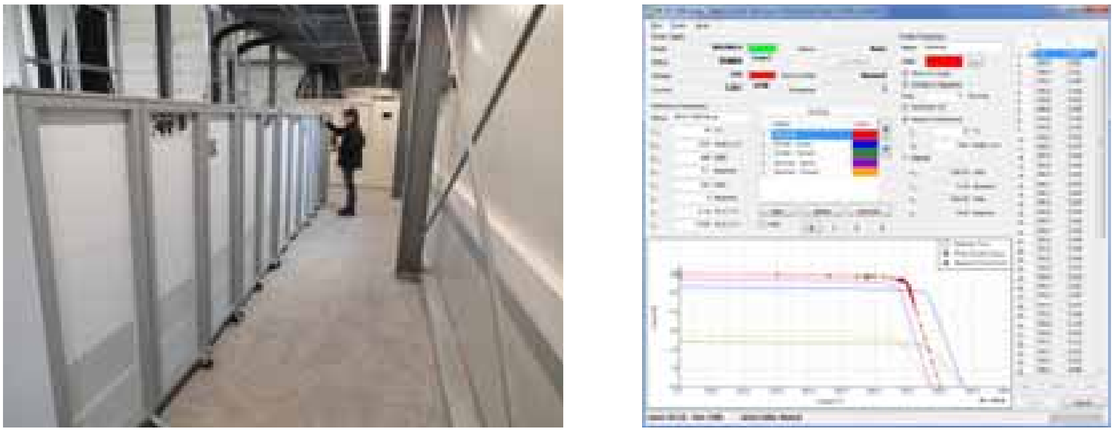

Fig. 6.1 and 6.2: DC-Source (left picture) and PV emulation / solar irradiation profiles (right picture)

4.3. Low voltage test loads

As shown in the schematic of the reference lab (Fig. 4), LV test loads can be connected to “Busbar LV-Test Area 2”. These test loads (see Fig. 7) comprise resistive (3 x 200 kW), inductive (3 x 200 kvar) and capacitive load units (3 x 200 kvar), which are freely adjustable in steps of 1 kW and 1 kvar respectively. The resistive load units can be adjusted phase by phase, which allows testing under unbalanced conditions.

Fig. 7: Capacitive, inductive and resistive load units (from left to right)

4.4. Medium and low voltage test grids

To extent the lab facilities of the reference laboratory and to allow for further testing configurations, outdoor installations of MV and LV test grids are planned. These installations will comprise MV/LV secondary substations, LV line sections (cables) of different lengths and diameters, different types of DER units and locally distributed test loads representing load profiles of typical consumer groups, e.g. residential.

4.5. Voltage stabilizer

A voltage stabilizer with a nominal apparent power of 200 kVA is also available in the lab. Two points / grid nodes with different values of LV voltage can be coupled by connecting them to the terminals of the voltage stabilizer. For performing tests the voltage stabilizer can be placed between “Busbar LV-Test Area 1” and “Busbar LV-Test Area 2” (cp. Fig. 4). Thus, at one side of the voltage stabilizer the tap transformer (see subsection 4.7) is connected. At the other side the “LV Test Loads”, a DER unit (“Equipment 2 Under Test”) and/or the “LV Test Grids” may be connected. An exemplary test set-up is shown in Figure 8 below.

Fig. 8: Test set-up for network stability studies, deploying the voltage stabilizer

4.6. Signal generator / Automatic relay test system

At the MV level, for testing static requirements, a signal generator and automatic relay test system respectively is connected to the secondary systems (controller, protection etc.) of the DER unit. As shown in Figure 9 the signal generator can also be used for testing operation or settings of MV protection relays.

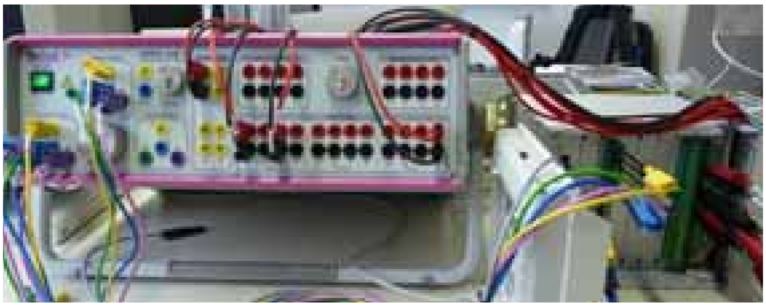

Fig. 9: Signal generator / automatic relay test system during a test of a multifunctional MV protection relay

4.7. Mobile MV low-voltage ride-through container and MV/LV tap transformer

The dynamic requirements are tested by using a so-called LVRT (or FRT) container, which is shown in Fig 10.1. This mobile container is connected in series between the DER unit (equipment under test, EUT) and the public MV network and generates network faults (voltage dips) on the MV level without disturbing the public grid. In the LVRT container twelve large coils (inductances) are used to decouple from the public grid and to create definite values of short-circuit impedances. Besides three-phase faults also two-phase faults can be simulated. The simplified schematic of the developed test system is shown in Figure 10.2. In Table 1 some data on technical details of the LVRT container is given.

Tab. 1: Technical details of the mobile LVRT container developed by Fraunhofer IWES

Parameter	Value
Nominal network voltage	10 / 20 kV
Rated power of the EUT	0.25 to 6 MVA
Short-circuit power at the point of common coupling (PCC)	80 to 350 MVA
Ambient temperature	–25 to +60 °C
Operating temperature	0 to +50 °C
Humidity	≤ 70 % average per day
Test bed assembly	40-feet Maritime High Cube container

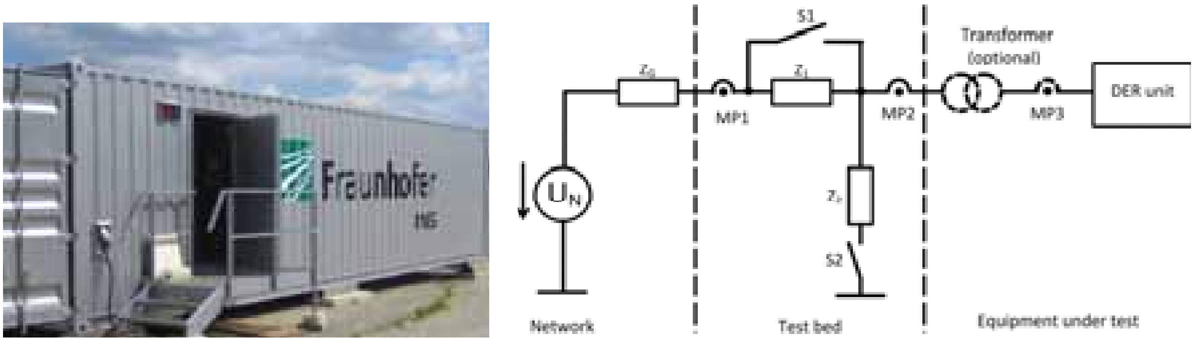

Fig. 10.1 and 10.2: Mobile MV LVRT container (left picture) and simplified schematic of the LVRT container according to FGW TR3 (right picture) with measuring points MP1 to MP3, decoupling / short-circuit impedances Z_G, Z_1 and Z_2 and switches / circuit breakers S1 and S2

A testing sequence with the LVRT container is performed as described in the following (the initial state of the switches / circuit breakers is “closed” for S1 and “open” for S2). In order to limit the short-circuit contribution from the public grid and at the same time the magnitude of voltage dips for other customers, initially the decoupling impedance Z_1 is activated by opening circuit breaker S1. Then the short-circuit impedance Z_2 is energized by closing circuit breaker S2. Finally, after expiration of a time span specified in grid codes (e.g. BDEW, 2008), the MV switchgear returns to its initial state.

For DER units with LV outputs, a tap transformer with a wide voltage range (from 254 V to 690 V) is used for connecting these units to the LVRT container (see Fig. 11).

Fig. 11: Taps and adjustable star point at the secondary side of the tap transformer

Acknowledgements

The authors would like to thank the German Federal Ministry of Economics and Technology for the support of the project ‘Erprobung Neuer Netze – Aufbau eines Referenzlabors für neue Netzkomponenten und Netzbetriebsmittel’ (FKZ 03KP203).

5. References

BDEW (Bundesverband der Energie- und Wasserwirtschaft e.V.), 2008. Generating Plants Connected to the Medium-Voltage Network – Guideline for generating plants’ connection to and parallel operation with the medium-voltage network, Berlin.

Degner, T., Arnold, G., Braun, M., Geibel, D., Heckmann, W., Bründlinger, R., 2009. Utility-scale PV systems: Grid connection requirements, test procedures and European harmonization. Photovoltaics International, 4th Edition, pp. 132-136.

FGW (Fördergesellschaft Windenergie und andere Erneuerbare Energien e.V.), 2010. Technische Richtlinie für Erzeugungsanlagen Teil 4 (TR4) – Anforderungen an Modellierung und Validierung von Simulations-modellen der elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen, Revision 5, Kiel.

FGW, 2011a. Technische Richtlinie für Erzeugungsanlagen Teil 3 (TR3) – Bestimmung der Elektrischen Eigenschaften von Erzeugungseinheiten am Mittel-, Hoch- und Höchstspannungsnetz, Rev. 22, Kiel.

FGW, 2011b. Technische Richtlinie für Erzeugungsanlagen Teil 8 (TR8) – Zertifizierung der Elektrischen Eigenschaften von Erzeugungseinheiten und -anlagen am Mittel-, Hoch- und Höchstspannungsnetz, Rev. 5, Kiel.

VDN (Verband der Netzbetreiber e.V. beim VDEW), 2007. Transmission Code 2007 – Network and System Rules of the German Transmission System Operators, Berlin.