High-Voltage-Ride-Through Test System Based on Transformer Switching

Rainer Klosse

WindGuard Certification GmbH

Oldenburger Straße 65; Germany; 26316 Varel

r.klosse@windguard.de

Abstract—**The test laboratory of WindGuard Certification GmbH is in the process to build up an FRT-test facility. This test container is able to simulate as well HVRT events or many other possible dynamic grid faults. A 10 kW hardware model has already been tested and has confirmed this assumption.**

Keywords: FRT, HVRT, OVRT, LVRT, ZVRT, IGBT, test equipment, test container, short circuit power, multi mega wind turbines, auto transformer, tertiary winding, voltage dips, VDE-AR-N 4120

I. Introduction

This All-round Fault-Ride-Through test equipment (Al-FRT) connected at the low voltage side of a unit's terminals, is based on an auto transformer controlled by an IGBT switchgear. The rating of this Al-FRT allows to measure units up to 3 MW rated power. By parallel switching of several Al-FRTs and transformer adjustment, wind turbines in the multi mega-watt category (>9 MW) can be tested. Due to the utilised transformer configuration, no own short circuit power, compared to standard test equipments, is consumed. Thus, Fault -Ride-Through (FRT) tests at grids with relatively low short circuit powers are possible.

Possible applications are Low-Voltage- (LVRT) and High-Voltage-Ride-Through (HVRT) tests in the range from 0% to 150% pre-fault voltage. HVRT tests are required according to the draft of the German grid code for high voltage connection E VDE-AR-N 4120. With 48 available transformer taps at each phase, more than 100.000 different symmetrical and unsymmetrical configurations can be set. These sets cover unbalanced 1-phase as well as 2-phase voltage dips. By use of a tertiary winding configuration, lagging or leading vector jump tests are possible.

Compared to commonly utilised test equipments, reproducible switching moments can be generated. Also, different configurations of double dips or step functions are possible.

The main specifications of Al-FRT will be explained. The realisation of Al-FRT is based on a hardware model in the range of 10 kW, were the first test are available.

II. Technical Relevance

Blackouts of electrical transmission grids can be triggered by relatively small disturbances of the transmission lines, such as short circuits. In case of a high penetration of renewable energy, the respective power plants must support the grid stability during voltage dips. Many grid codes require from utility companies low voltage ride through tests in order to gain a higher certainty in managing this type of grid unbalance. A commonly utilised test equipment, based on an inductive voltage divider, is able to provide standard test results, which are sufficient for many guidelines. However, they are limited to the simulation of the following physical effects during voltage faults:

- Dynamical overvoltage in the grid (HVRT, High-Voltage-Ride-Through equal to OVRT, Over- Voltage-Ride-Through)
- Connection groups of transformers (Dy-transformers change the phase angle of the different voltages);
- One-phase error;
- Range of power;
- Phase angle jump of all three phases in *pre* or *post* direction due to a change of the reactive to active relationship during the grid fault;
- High reactive power load *before* and *after* the grid fault;
- Sequences of switching in the grid, such as automatic re-closing or at a failure of operate;
- Change of the grid impedance at the same test set up.

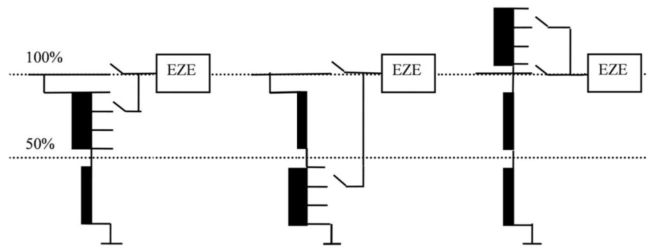

Figure 1: Al-FRT to simulate voltage dips, LVRT 50% to <100% (left), LVRT 0% to 50% (middle), HVRT >100% to 150% (right). (EZE=unit under test)

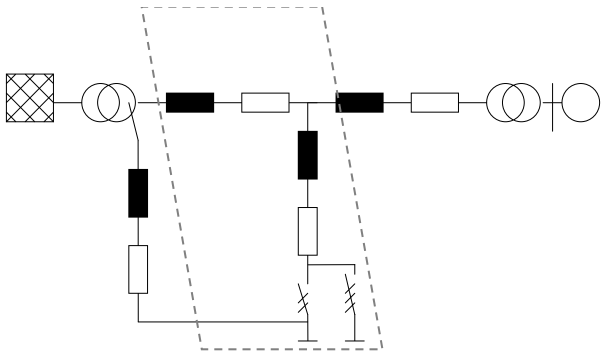

Figure 2: Grid topology, which can be tested by a conventional test unit based on a voltage divider (dashed line).

III. Technical Benefits of Al-FRT

Many insufficiencies of the conventional test set up can be solved with the newly developed voltage dip generator based on an auto transformer and an IGBT switch gear. The most relevant characteristics are described in the following.

A. Consumption of grid capacity

Classical voltage dip generators are able to simulate grid distortions as marked with the dashed line of Figure 1. These tests can be carried out, only at grids with a high amount of short circuit power and only at single wind turbines. During the test, a high current from the grid is required to supply the voltage divider. The short circuit power at the terminals of the test object is highly limited by the length impedance of the test unit.

The newly developed test unit Al-FRT, fully covers the IEC 61400-21 and the German extension FGW TR3. 2 and 3-phase drops can be simulated at different amplitudes. In deviation to a conventional system, the voltage will be simulated by transforming and not by dividing the voltage. The short circuit power of the grid will be 'handed over' with more or less no own consumption to the wind turbine. The short circuit voltage is dependant upon the transformation level but less then uk ≤ 3%.

B. Variance of short circuit power

Generators show different behavior at different short circuit powers. Conventional test units, based on a voltage divider require grids with high short circuit power. However, due to the length impedance at the terminal of the generator under test, the resulting short circuit power is quite less. This also implies a limited variation of the short circuit power. The new test facility, at a strong grid, can be extended with a additional length impedance. Due to this, a high range of short circuit powers can be tested at the same connection point to the grid. A change of short circuit power can be simulated if different length impedances are added at the different connection of the transformer, see Figure 3.

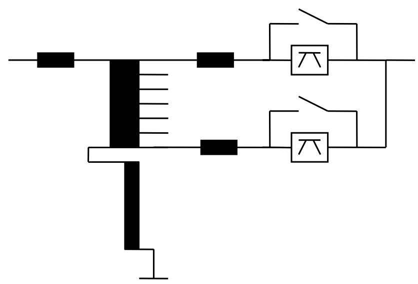

Figure 3: Variance of short circuit power

C. High dimension generators under test

In the case that only a medium voltage connection is available, a medium to low voltage transformer at each side can be adjusted the voltage as shown in Figure 4. In this case, also wind turbines can be tested with tree winding transformers as often used in double feed induction generators. Out of the possibility to control the IGBT in less of milliseconds two or more test units can be connected in parallel. Due to the unlimited number of test units which can be work in parallel multimegawatt wind turbines also higher than 6 MW can be tested.

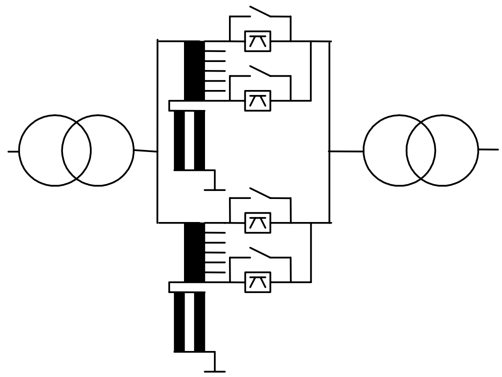

Figure 4: Parallel connection of two or more FRT-Test-Units framed of medium voltage transformer.

D. Dynamic overvoltage (HVRT)

In the industry, mainly conventional LVRT test units are available. Out of transforming the voltage, high voltage ride through (HVRT) test can be performed, (cf. Figure 1, right). Due to the possibility to configure each phase separately, a combination of LVRT and HVRT can be realized. This can be used to for simulating unsymmetrical dips.

E. Connection groups of transformers

The classic voltage divider is limited in case of 2-phase faults to only a one-phase relationship, (cf. /Bollen/, vector group C). In the usual case of a Dy-transformer is in between the short circuit and the wind turbine this vector group change to D. It is allowed to assume that inverter technics can be react on a different way to different vector groups of phase angles. The main reason to provide LVRT capability, is to support the grids during faults in the high voltage network. In between the generator and the drop there are some times one or sometimes two Dy transformers. Thus it should be test that both vector groups are be able to manage by the wind turbine.

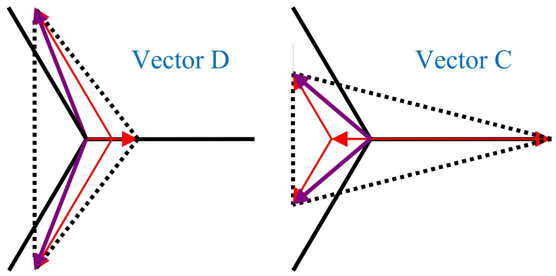

Figure 5. Classification of voltage dips according: M. H. J. Bollen „Understanding Power Quality Problems“ (*red line*: voltage at transformer coils; violet: resulting voltage; *black line*: voltage prior to transformation, *dotted black line*: resulting phase-to-phase voltage)

Due to the possibility to modify each phase of the auto-transformer, all numbers of vector groups can be simulated, (cf. Figure 5). This vector groups can be simulated with or without considering grid losses. 1-phase errors can be simulated as well.

F. *Vector jumps in pre or post direction*

During voltage dips, all three phases can be rotated in one direction during a voltage dip start and after the end of dip back to the original position. This will always occur when the impedance relationship X/R changes during the dip. In some situations, the corresponding change of voltage phase position can be reach values of more than 30°. The test unit provides the possibility that a part of the coils will be connected to another phase in a kind of full transformer mode, see Figure 6.

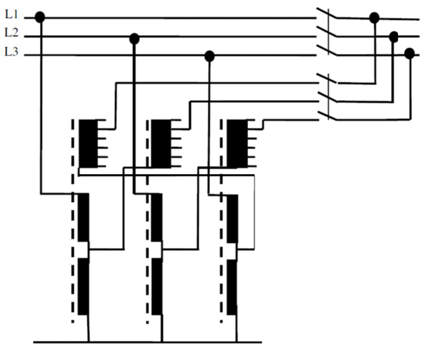

Figure 6: Vector jump in pre or post direction

G. *Reactive power before voltage drop*

The main number of renewables generators are running in an operation mode in which they are delivering or consuming reactive power, in some cases more than $\pm\cos\varphi = 0{,}95$. Due to the high length impedance of the conventional test unit, the voltage at the terminals of the test unit might possibly exceed the allowed range for normal operation. This is the reason that in the FGW TR3 guideline, as an example, such kind of tests are limited to a partial load of up to 0,3 of nominal power only. Due to its ‘own’ low impedance, the new test unit is able to increase the possible range of testing. If required, the voltage before the drop can be adjusted by the auto-transformer as well.

H. *Switching sequences in the duration of grid faults*

Malfunction of fault clearance in the grid, cause short changes of voltage drops, in some cases with different levels. By use of the IGBT, the voltage dip can be controlled precisely and fast. In the case that during a dip different levels are required, a high number of this can kind of switching sequences can be realized with an additional switch gear setup, see figure 7.

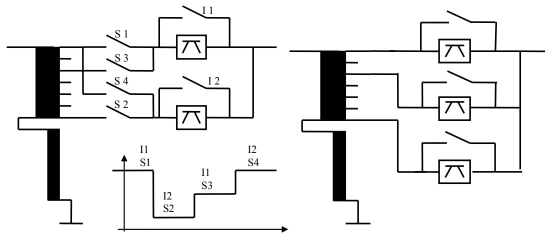

Figure 7: FRT step function by use of a switch gear (*left*) or an additional IGBT switching unit (*right*).

I. *Controllable switching moment*

The conventional test system is usually switched via a mechanical power switch. Both the connection and disconnection times of the short circuit impedance are somewhat random. In case that the behavior of the generator under test is dependant upon the phase position at the switching moment, this cannot be tested sufficiently. The IGBT switchgear, together with a phase detection can control the coupling in and out times of the voltage dip. Out of this, reproducible test can be performed.

J. *Comparison of variants comparing the auto-transformer*

Also conventional test units or others can realize some of the before described functionalities.

- **Conventional** test units can be supplemented by capacities to provide as well HVRT functionalities, however, the setting range will be limited. Resistances can be added to simulate the vector jumps; in which case overheating problems must be managed. The own consumption will be still an issue.
- **Full inverter** and setup or down inverter reaching only very slowly the required voltage change. In case of an operation stop of the wind turbine, it is not 100% clear, whether or notthe test unit is part of the problem.
- **Transformer** switched **via tap changer** by use of additional resistances such as a tap changer of a conventional MV or HV-transformer are causing a parasitic additional step.

One of the main advantage of the test unit is that this test system can be realized in a compact size. Due to the low voltage, no special trained staff for MV is necessary.

IV. VERIFICATION BY MEASUREMENTS

The transformer setup was tested by an hardware model with 10 kW power and with a resistant consumer load, see Figure 8. Exemplify one 2-phase voltage dip measurement down to 50% is shown in Figure 9 as a time series and in Figure 10 as an vector diagram phase to neutral.

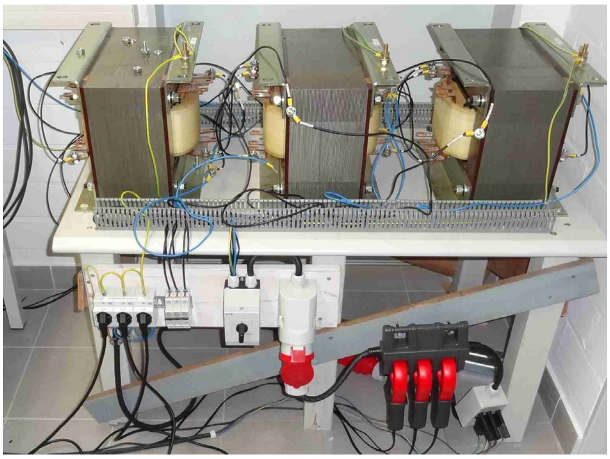

Figure 8: 10 kW Modell FRT step under test

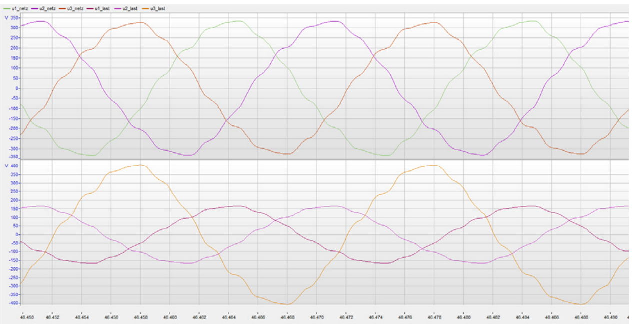

Figure 9: Times series of voltage during a 50% 2-phase-voltage-dip measured at the 10 kW Modell FRT step under at load. (one phase voltage was increase to 125%)

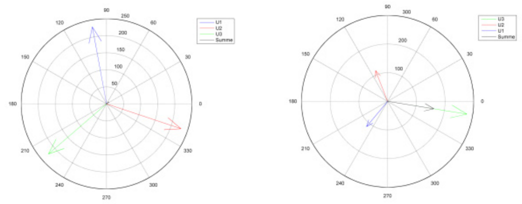

Figure 10: Vector diagram of voltage during a 50% 2-phase-voltage-dip measured at the 10 kW Modell FRT step under at load. (one phase voltage was increase to 125%)

SUMMERY

The generator under test is connected via 3 or 4 lines to the electrical environment. The voltages can be simulated by the new test equipment Al-FRT for voltage drops and peaks in a vide range. The stand of measurement at a 10kW models show a large accordance to the assumption

STANDARDS

[1] BDEW MSR “Generating Plants Connected to the Medium-Voltage Network” Guideline for generating Plants’ Connection to and parallel Operation with the Medium-Voltage Network, June, 2008, issue

[2] TC 2007: Distribution Code 2007, Rules for the Access to Distribution Grids

[3] E VDE-AR-N 4120:(2012-11) Draft, Technical requirements for the connection and operation of customer installations to the high voltage network (TAB high voltage)

[4] FGW TR3 Technical Guidelines for Generator Units of the FGW, Part 3: Determining the Electrical Properties of Generator Units at Medium-, High- and Extra-High-Voltage

[5] IEC 61400-21, Ed. 2, “Wind turbine generator systems – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines”

REFERENCES

[6] J. Jahn, F. Santjer*, R. Klosse Fault Ride Through Tests based on Low Voltage Measurements and their Feedback to the Medium Voltage Equipment, EWEC 2011 Brussels, Belgium

[7] Rainer Klosse, Fritz Santjer, Fault Ride Through Test based on Transformer Switching 8th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well Transmission Networks for Offshore Wind Power Plans, Paper 82, Bremen 10/09

[8] Mathias H. J. Bollen, Understanding Power Quality Problems: Voltage Sags and Interruptions (IEEE Press Series on Power Engineering). The Institute of Electrical and Electronics Engineers, New York, 2000, ISBN 0-7803-4713-7