FRT Test System compact for 27 MVA with less Grid Burdens

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***Abstract*— Technically, this test system switches from a series impedance to an autotransformer at the moment of fault simulation. By using the transformer effect, the network load is considerably lower for most numbers of test cases compared to conventional test equipment. For example, in the event of a 50% drop, the ½ short-circuit current at the same longitudinal impedance must be expected compared to a conventional voltage divider. In addition to UVRT, OVRT can also be simulated. Because of not using capacitors the usual problem with resonance points is not given. The wave form of the voltage is much more consistent. This test system is also suitable for simulating not only pure amplitude changes but also vector jumps of the voltages.**

Keywords-component; HVRT, OVRT, LVRT, UVRT, FRT, test unit, rotor displacment angle stability, voltage dip, grid fault, voltage divider, autotransformer, air coils, grid codes, measurement of impedance, model validation, transient.

I. INTRODUCTION

The newly developed FRT test system of WindGuard Certification is now completed and in use since March 2018. The test system is designed for networks up to 30 kV and rated currents up to 630 A. These results in possible devices under test (DUT) up to 27 MVA rated apparent power. Due to a very small number of components, a single ISO container is sufficient to store all electrical components together.

II. COMMISIONING OF THE TEST SYSTEM

The optimal location of all main components was found out by comparing a lot of different CAD drawings, see Figure 1.

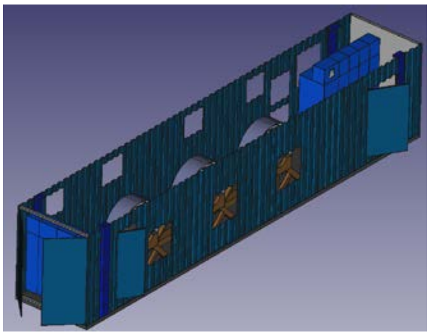

Figure 1: CAD drawing of the FRT test system

The main cirquit diagram is similar to a conventional voltage divider, compare Figure 2. In this case only one cirquit breaker is installed at the grid side for emergency cut off. At the DUT side this was not nessessary in the first project. Two event switches were installed for carrying out as well double dips. A bypass assembly allowed to change the transformer configuration while keeping the DUT in operation.

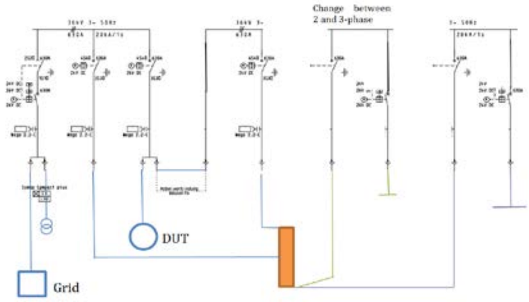

Figure 2: Main circuit diagram of test system.

First measurements were carried out at a multi megawatt wind turbine, compare Figure 3.

Figure 3: Test device installed close to a multi megawat wind turbine.

Three multi pole coils working as an autotransformer can connected in different ways to generate UVRT or OVRT events, see Figure 4.

Figure 4: Multi pole coils generate voltage changes.

Gas isolated switch gears were used for controlling the main circuit, Figure 5. They are compact and resistant against dirt. A protection relay is able to stop the switching sequence in case of any unexpected voltage or current behavior at grid or DUT side of the container.

Figure 5: A 30 kV medium voltage switch gear including a grid protection relais.

III. Requirements from Grid Codes

According new guidelines not only UVRT tests are necessary, also OVRT tests have to be carried out. This requirement is stated for Europa in the network code of requirements for generators (NC-RfG) [7] from the European commission. Based on this, a set of national grid codes also for Germany were coming in to force in April 2018 [8] and [9]. Parallel to the new IEC 61400-21-1 CDV [10] the German specification of the measurement procedure FGW TR3 [5] were ready in beginning of September 2018. New versions of German model validation guidelines FGW TR4 and certification guidelines FGW TR8 were expected to be ready at the end of 2018.

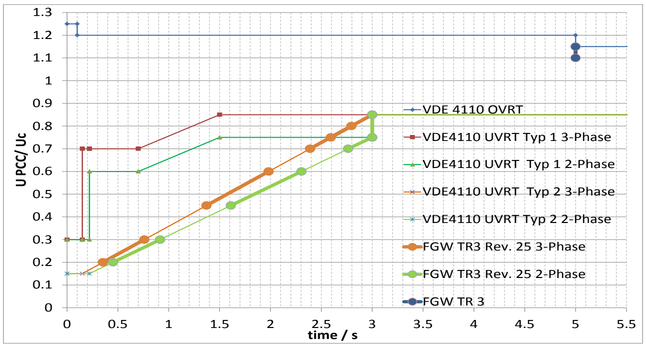

Figure 6: FRT requirements for medium voltage connetion according VDE AR-N 4110 [8] and FGW TR3 [5] tests for wind turbines

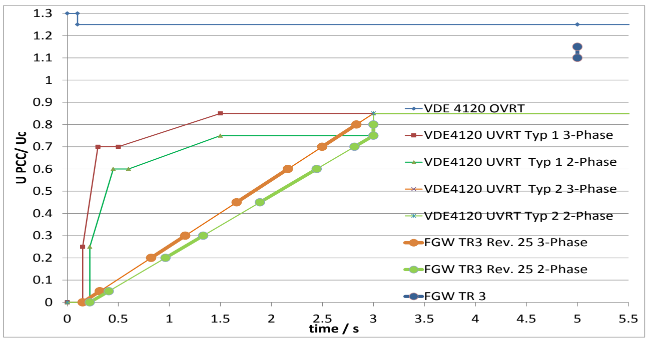

Figure 7: FRT requirements for medium voltage connetion according VDE AR-N 4120 [9] and FGW TR3 [5] tests for wind turbines

In general it can be remembered that the FRT tests for the new grid codes [8] and [9] have been changed to:

- Higher OVRT level
- Longer test. (some permanent test up to 60 s)
- At medium voltage [8] only tests above 20 % residual voltage
- Vector jump tests are still not required

IV. Operation of the Transformer Configuration

The configuration to simulate short-duration voltage variations is based on the three transformers. It thus differs from conventional "Low Voltage Ride Trough" (LVRT) or "Under Voltage Ride Trough" (UVRT) test installations, which are based on the principle of a voltage divider.

In addition to undervoltages, the configuration with the transformers allow generation of overvoltages, namely "High-Voltage-Ride-Through" (HVRT) or "Over-Voltage-Ride-Through" (OVRT).

Along with the configuration, the grid impedance has to be taken into account. Before and after a voltage change event the length impedance $Z_{T\ long}$ part of the transformer have to be added to the grid impedance Z_{gird} to get the overall grid impedance from the view of the DUT, compare Figure 8 for OVRT tests and Figure 10 for UVRT tests.

To activate the FRT event, the switch S_k has to be closed, compare Figure 9 for OVRT tests and Figure 11 for UVRT tests.

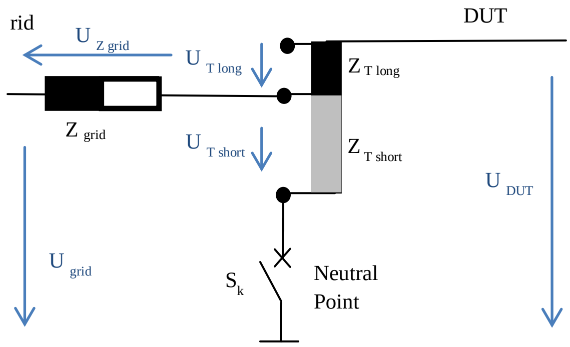

Figure 8: Generation of OVRT with Transformer, Single-phase Basic Circuit with Grid Impedance bevore or after event. Switch S_k is open.

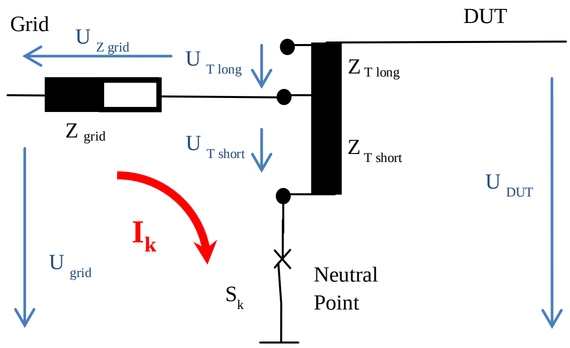

Figure 9: Generation of OVRT with Transformer, Single-phase Basic Circuit with Grid Impedance during event. Switch S_k is close.

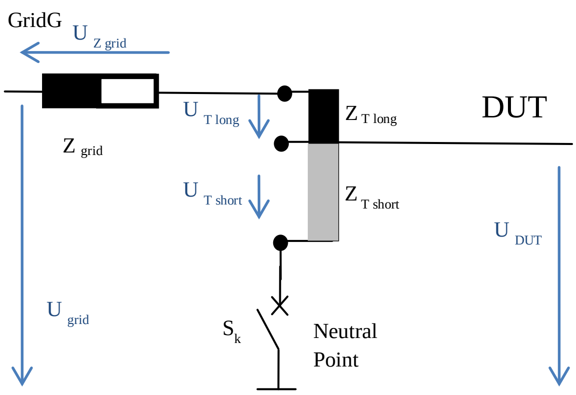

Figure 10: Generation of UVRT with transformer, with Grid Impedance bevore or after event. Switch S_k is open.

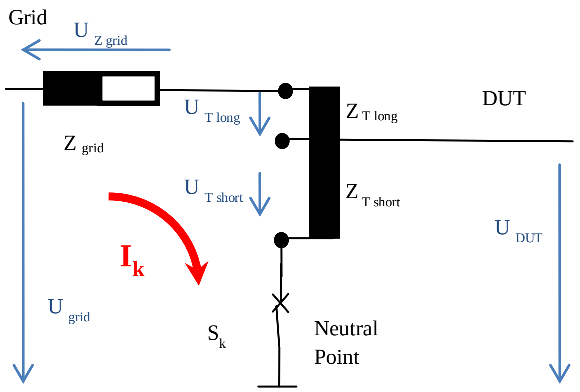

Figure 11: Generation of UVRT with Transformer Single-phase Basic Circuit with Grid Impedance during event. Switch S_k is close.

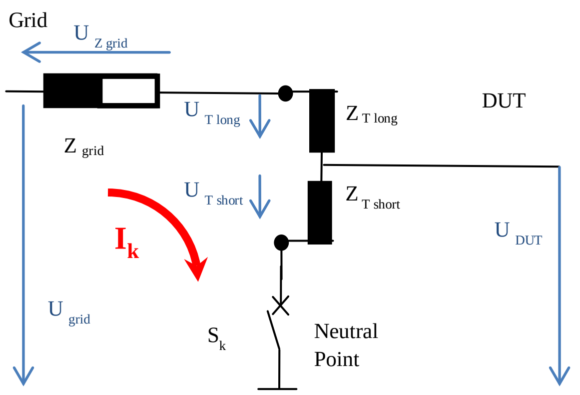

Figure 12: Generation of UVRT with conventional voltage devider by use of two independent coils

In contrast to a standard voltage divider, compare Figure 12 the voltage generated during the “event” results not from the impedances but it results from the number of windings of the autotransformer that had been configured by connections.

During the event, the impedance $Z_{T\,short}$ has to be chosen in such a way that the current through the switch “I_k” is as low as possible to keep the grid impact to a minimum. High impedances result in increasingly higher longitudinal impedances $Z_{T\,long}$. The maximum longitudinal impedance is limited by the DUT to the value in that the DUT still can maintain normal operation. Using the transformer connections, the optimal situation with regard to the grid load can be found with the possibilities of the DUT.

In comparison with a voltage divider a 50% voltage dip has the same longitudinal impedance also at the autotransformer setup’s. A voltage divider setup needs in the short circuit phat the same impedance as in longitudinal direction. The autotransformer needs the same number of windings to get the 50% voltage drop. Out of the square relation between the windings of the autotransformer the overall impedance from the view of the grid is the double at the autotransformer compared to the voltage divider. Therefore the short circuit current I_k is the half. At voltage drops to zero residual voltage only a longitudinal impedance is needed, which effects the same behaviors of both test set ups are the same. But at all other tests the grid demand is less at the autotransformer. At medium voltage drops power units are allowed to switch off because the grid distortion is close by, compare [7] and [8]. At high voltage connections this test is still required [7] and [9].

V. Praxis of Using the New FRT Test Rig

The inside windings of the transformer have a lower impedance due to their smaller radius and are to be used for the longitudinal impedance. The outside transformer windings are thus to be used for the event path, compare Figure 13.

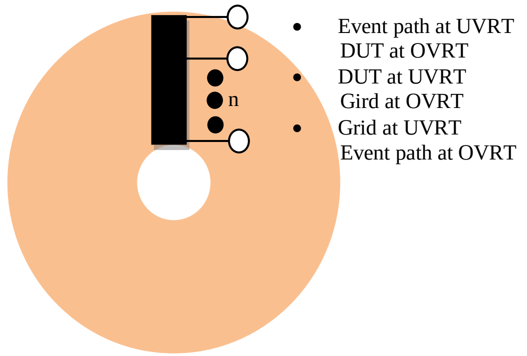

Figure 13: Symbolic autotransformer with n numbers of connectors to the windings from outside to inside

The coil is divided in a lot of steps over the overall range. Therefore a high number of different configurations are possible. The overall impedance between step 0% up to step 100% is expected high enough to perform tests also at weak grids. At stiff grids only a part of the coil needs to be used.

The thermal design load allows for the following repetitive sequence, compare Table 1.

Sequence	Times
t_0: Bypass open, maximum Z_{long} load of 1/3 I_{ks}	
t_1: Event switch closes, maximum UVRT Z_{short} and Z_{long} load of I_{ks}	t_1-t_0
t_2: Event switch S_k opens, Z_{long} under load only	t_2-t_1
t_3: Bypass closes, no impedances under load	t_3-t_2
t_{0b}: Start of new events (rest time)	t_{0b}-t_3

Table 1: Basic Design Timed Sequence

Sequence	Case 1	Case 2	Case 3	Case 4	Unit
Current I at t_1-t_0	630	630	630	630	A
Current I at t_2-t_1	4 000	5 500	800	2 000	A
Current I at t_3-t_2	630	630	630	630	A
Longitude operation bevore Event t_1-t_0	10	10	1	10	s
Event intervall t_2-t_1	1	1	60	7.5	s
Longitude operation after Event t_3-t_2	10	10	1	10	s
Maximal permanent current $I_{max\ permanent}$	250				A
Rest time t_{0b}-t_3 with I=0A	383	611	627	607	s

Table 2: Example of sequences of maximal current at one part of the transformer

Overload situations are dependent on

- the continuous feed of the DUT
- the event feed of the DUT
- the event configuration
- the ambient temperature
- the temperature of the components as a result of them having been in operation previously.

Initially, the transformers are released for a $I_{max\ permanent}$ continuous load. The permitted switching sequences are calculated according to the following formulas separately for the two sections of the transformer (long and event).

$$Ith\,long = \sqrt[2]{\frac{I_{1i}{}^2 * (t1 - t0) + I_{2i}{}^2 * (t2 - t1) + I_{3i}{}^2 * (t3 - t2)}{(t0b - t3)}} \leq Imax\,permanent$$

$$Ith\,event = \sqrt[2]{\frac{I_{2e}{}^2 * (t2 - t1)}{(t0b - t3)}} \leq Imax\,permanent$$

Double events are to be treated in the same manner.

To achieve an optimal utilization of the transformer,

- temperature sensors are installed (the delay of temperature transfers between sensor and component must be taken into account).
- the power balance between the transformer input and output is calculated in the measurement equipment, as long as the online calculation of the measurement equipment allows it.

These can only be analyzed after an event has been recorded to plan the subsequent event.

Thus, observation of the temperature measurements is imperative.

VI. Summary

Depending on the mains conditions, voltages of up to 130% of the input voltage can be achieved by the transformer. Initial measurements have already been carried out on the medium-voltage grid. These show that the basic assumptions are correct. However, the test system also uncovered properties that make correction factors necessary in addition to rough calculation. Due to the mixture of a simple coil and a transformer, there are no standardized models available. Out of not using capacitors there are no problems with resonances with the grid during OVRT tests as it can be observed by capacitor inductance assemblies. Due to the cost-effective design with the enormously increased application possibilities, a quick replacement of conventional voltage dividers is expected.

VII. Outlook

This test rig is designed also to carry out voltage vector jump tests. Due to the high project pressure and no requirements out of the actual guide lines, this kind of tests are still open to check in real conditions.

Due to the cost-effective design with the enormously increased application possibilities, a quick replacement of conventional voltage dividers is expected.

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