FRT Tests Considering Time to Market Requirements

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Abstract—

Fault ride-through (FRT) tests at wind turbines but also at other renewable generation units are required by grid codes since many years. In the past, mainly technical issues of FRT-tests were relevant, to simulate most realistic voltage dips. Today not only voltage dips are required, but also voltage swells and other requirements are also relevant.

Apart from the new technical challenges, nowadays the time to market for new developed wind turbines is more and more critical for the manufacturers. Thus, also the testing period of the FRT capability of the wind turbine should be as short as possible.

FRT test campaigns must be quick and easy to manage. They have to be spontaneous and affordable from a commercial point of view. From a physical and electrical point of view, the test system should be realistic and designed in such a way that it can be modeled. After the decision to carry out an FRT test for a wind turbine, there are many organizational and practical things to arrange.

Keywords-component; HVRT, OVRT, LVRT, UVRT, FRT, test unit, voltage dip, grid fault, voltage divider, autotransformer, air coils, grid codes, model validation, transient.

I. Introduction

An FRT test plan has to be designed and adapted to the test options, which result from the interaction of the wind turbine, network and test system. The possibilities of the test system often decide whether tests can be carried out at a specific location. The coordination with the network operator must be suitable to deal with the situation of his network, which requires among others a test equipment, that allows a wide range of short-circuit power and impedance angle of the grid . Once the location and a start date have been determined, the test system must be transported to the site in short time, where compact and light test systems have advantages in terms of transportation costs, space requirements, duration of installation etc. The connection of the test system to the wind turbine and the grid should be done with standard components (e.g. connectors/plugs), which can be easily found in the market. Commissioning should not take longer than 2 days. For speeding-up the progress of the test plan, it would be helpful if as many different configurations of the FRT test system as possible could be set at the same time. The performed tests should also be as realistic as possible. The models that describe the test system are also important. These must describe the existing network together with the test facility in front of the wind turbine and must be accepted in the context of the guidelines. The developer of the wind turbine needs the highest quality of the measurement data recording. Test sequences that go far beyond standardization for verification are increasingly required.

Taking all the above into account, this publication will include the new requirements on FRT tests campaigns and will show the realization of the requirements by the new developed FRT test system.

II. FRT Test equipment

A. Specifications of the FRT Test equipment

EESyst developed a newly revised version of a mobile medium voltage FRT test equipment.

With this compact FRT system, both UVRT and OVRT up to 30 MVA at 30 kV rated voltage can be carried out compressed in a standard ISO 40 feet HC container.

The main specifications of the new system are:

- Rated apparent power up to 30 MVA
- Rated nominal voltage up to 33 kV
- Under- and overvoltage ride through testing (UVRT and OVRT)
- One standard ISO 40 feet container
- Combined usage of voltage divider and transformer method
- Optimized handling to reduce times for commissioning of the test equipment and change of dip/swell levels
- Less system perturbations in the grid
- Overvoltage protections can be adapted to the specific grid voltage level for optimized protection of the test equipment and of the device under test (DUT).
- Special configurations also allow the generation of vector or phase jumps, both leading or lagging. Such measurements allow conclusions about grid forming behavior of the DUT.

- Own power supply and battery backup for auxiliaries, that allows it to be operate without an external supply.
- Suitable current and voltage transducers for the measurement of high frequency phenomena up to 9 kHz
- Optimized Safety concept.

Figure 1: Photo of the presented FRT Testsystem for UVRT and OVRT Compact in one standard ISO 40 foot container

Fault patterns can be set according to a Dy interconnection scheme of a transformer. The positive and negative system components of single-phase or two-phase faults to ground are adjustable. In addition, many other unsymmetrical vector settings can be approached.

With the exception of the Zero Voltage Ride Trough Test (ZVRT), the impedance of the overall test system is significantly higher due to the overall concept compared to a conventional voltage divider. The short-circuit current from the grid is around half of the 50% residual voltage test. Even with 125% overvoltage, the event current is around the half compare to the conventional LC resonant circuit. Since it does not contain any capacitors, the tendency to oscillate is considerably lower. Due to the reduced impact on the network, getting the approval by the network operators for a location can be achieved more easily.

Calculation tables allow to get quickly the right configuration for the specific tests. An integrated grid calculation provides information about the expected grid distortions such as voltage drops in the upstream grid or the expected current during the event test.

B. Feature: Time to market

The following measures reduce the testing period:

- Fast installation and commissioning of the test equipment
- Tests at different fault levels without changing the hardware configuration of the test equipment
- Tests of two and three-phase faults without changing the hardware configuration
- For those tests, where it is necessary: fast and simple change of the hardware configuration
- Simplified change between UVRT and OVRT
- Fast onsite analysis of test results

In practice, the new test facility has been optimized to the extent that the time and effort for the installation of the test facility and also the change of one configuration to another is reduced.

The transport and commissioning technology allow the new test system to be fully operational within 2 days. The process for entering and exiting the coil room is optimized, so that a conversion to other configurations can take place quickly. Since only 3 coils have to be connected, thus it is easy to hold an overview about all connections.

Thanks to the switching design, the following functions can be carried out via remote control without further entering the container:

- Disconnection and earthing of the DUT
- Operation of the DUT in the bypass to the container. The coil room can still be entered, and configurations can be set while the DUT is in operation
- 4 configurations of 3-phase faults
- 4 configurations of 2-phase faults (Bollen Type C, [17])
- 4 configurations of 2-phase faults but with a different selection of phases (Bollen Type C, [17])
- Idle (no load) tests at all configurations can be carried out with the DUT running.

A configuration can generate an OVRT or a UVRT event.

Due to the many design details, measurement campaigns can be accelerated significantly.

III. Modeling

A. General equivalent circuit diagram

Compared to the form of representation from the last contribution in the Wind Integration Workshop [2], the equations of the generic model could be simplified significantly. In general, the electrical behavior of the testing device together with the network can be represented as a switch between two Thevenin equivalent voltage sources (two different states), one before and after the FRT event and one during the event, as shown in Figure 2. The vectors of the two voltages are at a certain phase angle to one another and the impedances Z_{length} and Z_{FRT} are complex quantities.

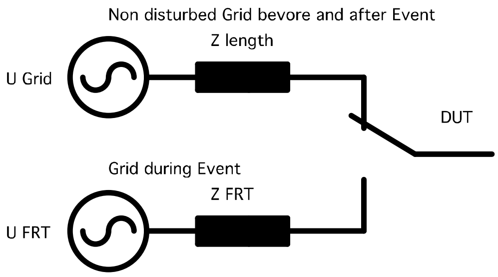

Figure 2: Switch between two Thevenin equivalent voltage sources

The same behavior can also be achieved using a voltage source and 3 impedances that are shown in a T-equivalent circuit diagram. In both equivalent circuit diagrams there is the reference no-load voltage U_{Grid} and 3 complex values.

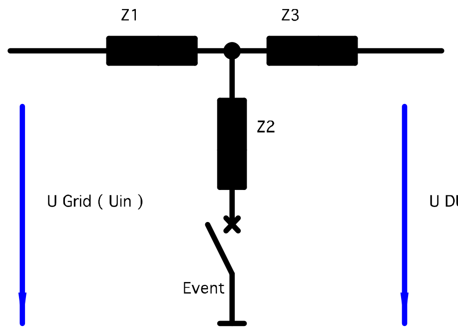

Figure 3: T equivalent circuit diagram Switch over by closing the Event switch

$\underline{Z}_{length} = \underline{Z}_1 + \underline{Z}_3$ (1)

$\underline{Z}_{FRT} = 1/(1/\underline{Z}_1 + 1/\underline{Z}_2) + \underline{Z}_3$ (2)

$\underline{U}_{FRT} = \underline{Z}_2 / (\underline{Z}_1 + \underline{Z}_2) * \underline{U}_{Grid}$ (3)

The representation of individual voltage sources in T-equivalent circuit is done though the following formulas:

$\underline{Z}_1 = (\underline{Z}_{length}-\underline{Z}_{FRT})/(1- \underline{U}_{FRT}/\underline{U}_{Grid})$ (4)

$\underline{Z}_3 = \underline{Z}_{length} - \underline{Z}_1$
$= \underline{Z}_{laength} - (\underline{Z}_{length}-\underline{Z}_{FRT}) / (1- \underline{U}_{FRT}/\underline{U}_{Grid})$ (5)

$\underline{Z}_2 = \underline{Z}_1 / (\underline{U}_{Grid}/\underline{U}_{FRT}-1)$
$= (\underline{Z}_{length} -\underline{Z}_{FRT}) / (\underline{U}_{Grid}/\underline{U}_{FTR} + \underline{U}_{FRT}/\underline{U}_{Grid} - 2)$ (6)

Both representations include also the grid impedance, i.e. they do not show the test system as an individual component.

B. Transformer equivalent circuit diagram

An extended equivalent circuit diagram is required to display the test equipment in the network. Before and after the event the coil of the test equipment is only used in part, acting as a length impedance. A series impedance is used between two contacts “Uin” and “Uout” in the same way as in the conventional inductive voltage divider. In the event, the third contact of the "Event" coil is switched to a common star point. The transformer effect then occurs. The voltage in the event of an incident results mainly from the winding ratio “$r_{winding}$”. Since the impedance must remain low in longitudinal operation, the impedance in the short-circuit path is also so low that the leakage inductance and the main inductance “Z_{main}” cannot be neglected. The primary and secondary leakage impedances “Z_{prim}” and “Z_{sec}” are also not symmetrical to one another, see Figure 4.

If the number of turns or the winding ratio $r_{winding}$ is known, and this is assumed here, the characteristic values of the coil can be determined by individual measurements. The current between the taps of the coil "U_{in}", "U_{out}" and "Event" is measured each by applying a known voltage. If the active component is too small, it must be determined separately using a DC measurement.

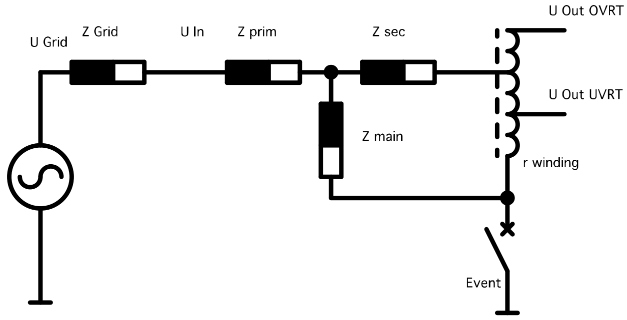

Figure 4: FRT by connecting a voltage dividing autotransformer.

Z_{IE}: Impedance between U_{in} – Event

Z_{OE}: Impedance between U_{out} – Event

Z_{IO}: Impedance between U_{in} – U_{out}

Note

- The three impedances Z_{IE}, Z_{OE}, Z_{IO} are not representatives of a delta connection!
- The winding ratio $r_{winding}$ does not represent the transmission behavior of the entire coil, but only the ideal part in the equivalent circuit diagram!
- If the impedances are determined at a frequency other than the fundamental frequency considered here, they must be converted accordingly!

Determination of the coil characteristics

$\underline{Z}_{main} = (\underline{Z}_{IE} + \underline{Z}_{OE} - \underline{Z}_{IO})/(2* r_{winding})$ (7)

$\underline{Z}_{pim} = \underline{Z}_{OE} - \underline{Z}_{main}$ (8)

$\underline{Z}_{sec} = \underline{Z}_{OE}/r_{winding}^2 - \underline{Z}_{main}$ (9)

To determine the series impedance according to the 2 Thevenin equivalent voltage sources according to Figure 2, the impedance of the grid must be taken into account in addition to the impedance of the coil.

$\underline{Z}_{length} = \underline{Z}_{Grid} + \underline{Z}_{IO}$ (10)

The determination of the impedance at the FRT event Z_{FRT} the following method is used: "short-circuiting all voltage sources and adding up all impedances from the point of view of the output connections". In an intermediate step, the impedance in front of the ideal transformer can first be determined and then offset against the square of the turns ratio.

$$\underline{Z}_{FRT} = \left(\frac{1}{\frac{1}{\underline{Z}_{Grid}+\underline{Z}_{prim}}+\frac{1}{\underline{Z}_{main}}} + \underline{Z}_{sec}\right) * r_{winding}^{2} \quad (11)$$

To determine the no-load voltage, the voltage upstream of the ideal transformer is first determined and then transformed to the secondary side via the turns ratio of the transformer. Since the output current is zero in the no-load case, the secondary leakage impedance Z_{sec} has no effect and does not apply here. Their influence is limited to the internal impedance Z_{FRT}.

$\underline{U}_{FRT} = (\underline{Z}_{main}/(\underline{Z}_{Grid}+\underline{Z}_{prim}+\underline{Z}_{main}))*\underline{U}_{Grid} * r_{winding}$ (12)

Due to the complex impedances, the voltages also have an angular difference to one another. In practice, the angle difference can be neglected if the impedances are all strongly inductive, i.e. the network also has hardly any active components. This is often the case but does not have to be. The calculation of the impedances for the T equivalent circuit is then carried out analogously to Figure 3 and the associated equations, as described above.

Depending on the configuration, especially in the case of overvoltage, negative values for inductances can also occur. If only the fundamental frequency is considered, these impedance can be replaced by capacitances. By dynamic calculation or calculation in the frequency range, a negative inductance has a different behavior than a capacitance. This simplification is not permitted here.

The conversion described here was submitted by the authors to the draft of FGW TR 3 Rev. 26, [8] as an explanation and is currently being voted on.

IV. Summary

In this publication, a new FRT Test System is presented with special design characteristics that make it advantageous in comparison to other systems currently available in the market. The new system can satisfy the need for testing of very large-scale MW wind turbines (up to 30 MVA) so it is suitable for field testing of state-of-the-art wind turbines. Of course, the lack of wind for a field measurement of a wind turbine can't be conjured up even with the best test equipment. However, space reduction, higher current maximum capacity and several other optimized parameters could substantially speed-up testing times so that even short summer winds can be used to carry out a complete measurement campaign. Approvals from grid operators can be shortened through significantly lower network perturbations. The representation of the test equipment in form of an equivalent circuit diagram for simulations, especially for the validation process of the simulation models of power generation units, has now also found their way into regulations so that the data analysis has now also been further standardized.

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Organizations

UL International GmbH (UL) previously DEWI has long time experience in the implementation of FRT tests, so special requirements on the part of network operation can always be dealt with. UL has several test systems which can then be used adapted to the task. In coordination with the certification body, processes can be run through, starting with the planning and implementation of measurements, implementation of the model validation and, if necessary, issuing of corresponding certificates. UL is represented in national and international committees to update the measurement regulations and therefore has measurement templates that require all common grid codes.

EESyst Energie Elektrische Systemtechnik GmbH, previous "delta energielösungen" was founded in 2019 based on long term experience in power quality measurements. Several FRT Test Systems have been built by her employees in different concepts for low and medium voltage.