With an ever greater share of electricity produced by wind power, the behaviour of wind turbines during grid faults is of critical importance. An increasing number of international grid code specifications require wind turbines to be able to ride through all types of grid faults. Fault ride-through capabilities have come as a result of the large increase in installed wind capacity that feeds into transmission systems, making it necessary for wind generation to stay operational in the event of a network fault. The ultimate objective is to have a wind turbine behave like a conventional power plant. In this article, Lasse Kankainen from The Switch discusses grid codes and fault ride-through requirements in general, and the testing of the company's full-power converter (FPC) technology.

By Lasse Kankainen, R&D Engineer, The Switch, Finland

Meeting Fault Ride-Through Requirements

A Constant Response to the Grid Code Jungle

Large Historical Differences in National Grid Codes

As the proportion of wind power in the energy generation mix has increased in countries around the world, so too has the need to create grid codes to match the national power systems. Without any coordination, early attempts ended in a complex jungle, making it challenging to define a single set of specification criteria for the full-power converter (FPC) system when being connected to the grid.

The EntsoE project funded by the EU is aiming to create new harmonised grid codes for all European member countries to support smart and super grids. EntsoE seeks to promote better security, an electricity market that works well, and more renewable energy in the grid in the future.

However, until the results of such harmonisation projects are ready, the latest, and increasingly more stringent, grid code requirements typically apply to large wind farms connected to the high voltage transmission network. Local operators can still set their own requirements for wind turbines connected to the distribution network.

Nowadays, all new grid codes stipulate that the wind turbine should contribute to the power system control (both frequency and voltage) in a manner similar to a conventional power station. Therefore, the codes focus on wind farm behaviour during network fault situations. The main emphasis is on the requirements for wind farm interconnection, which includes wind farm behaviour during grid disturbances (fault ride-through), active and reactive power regulation, system voltage/frequency limits, voltage and power factor regulation and frequency control.

The Purpose of Fault Ride-Through

The growing share of installed wind capacity in transmission systems now makes it necessary for wind generation to remain in operation in the event of network disturbances. Therefore, according to all national codes, wind farms must withstand voltage drops and swells to a certain percentage of the nominal value for a specified period of time. In the case of some national grid requirements, this percentage can be all the way down to 0%. Such requirements are known as fault ride-through (FRT) or low voltage ride-through (LVRT). The requirements depend on the specific characteristics of each country's own power and protection system.

FRT requirements include fast active and reactive power restoration to the pre-fault values after the system voltage returns to normal operation levels. Some codes require that the network is supported during a network fault by feeding a reactive current into the network and distributing a short-circuit current during the fault.

Although grid codes vary a lot, FRT requirements normally apply to the connection point of the network at the high voltage level. Taking typical impedance values for step-up transformers and interconnecting lines into consideration, the corresponding voltage drop at lower levels near the wind turbine terminals is likely to be above 5–15%, whereas the voltage drop can be down to 0% at the medium voltage level. Some grid codes even require protection against several voltage drops during a rated time span, and dedicated fault-type detection.

Reactive Power Support and Active Power Restoration

Included in the FRT requirements is fast active and reactive power restoration to pre-fault values after the system voltage returns to normal operation levels. Some grid codes additionally demand active and reactive power support during a fault.

Reactive power support means that wind farms have to support a grid voltage with increased reactive power generation during a voltage drop (capacitive reactive current) or with increased reactive power consumption in the event of a voltage swell (inductive reactive current).

If the grid code demands both active and reactive current injection during a voltage drop, the network's short-circuit current is increased by the generating plant's active current. Feed-in of short-circuit current during a voltage drop is always agreed upon by the network operator. Active power restoration rates are also specified in various ways. This requirement is based on local grid characteristics for which active power restoration is more crucial for stabilising the system in weak grids.

Active Power and Frequency Control

Active power and frequency control refer to the ability of wind farms to regulate their power output to a predefined level, known as active power curtailment, either by disconnecting turbines or by pitch control action. Additionally, wind farms are required to provide a frequency response that regulates their active output power according to the frequency deviations with some ramp rate. Nearly all grid codes state that some active power curtailment or power ramp rate limitation should be used to control different frequency deviations in the wind farm level.

Voltage and Frequency Operating Range

Voltage and frequency operating ranges for wind turbines ensure that they remain in operation when the voltage and frequency exceed normal

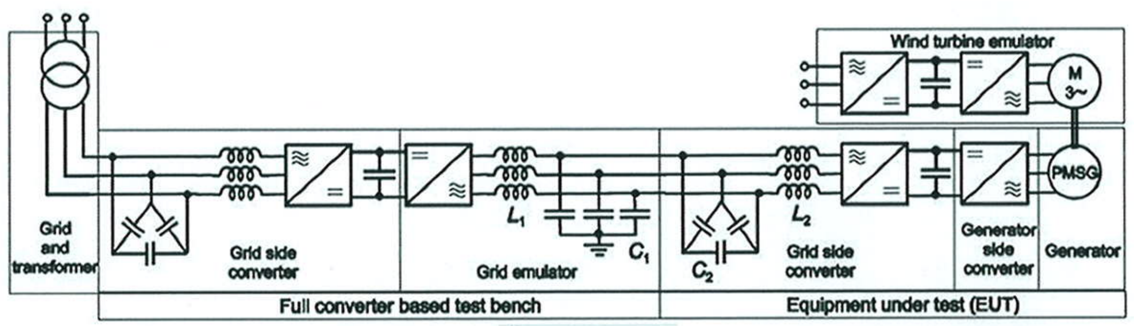


Figure 1. Test topology used for FPCs at The Switch

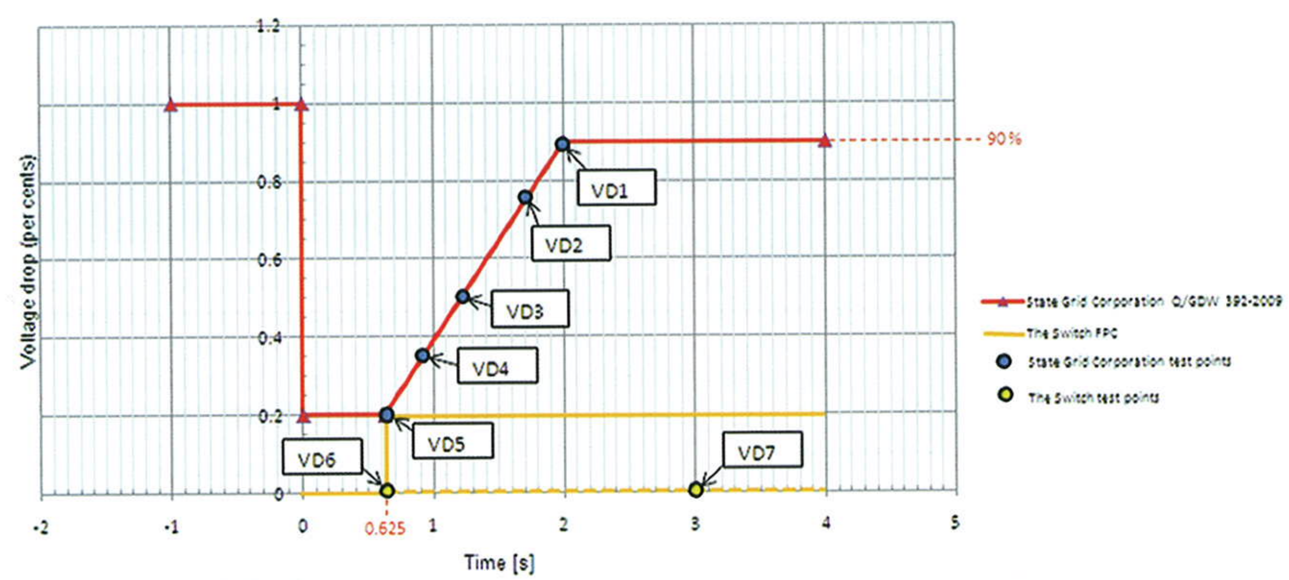


Figure 2. Test points and borderlines in low, medium and high voltage level for different grid codes

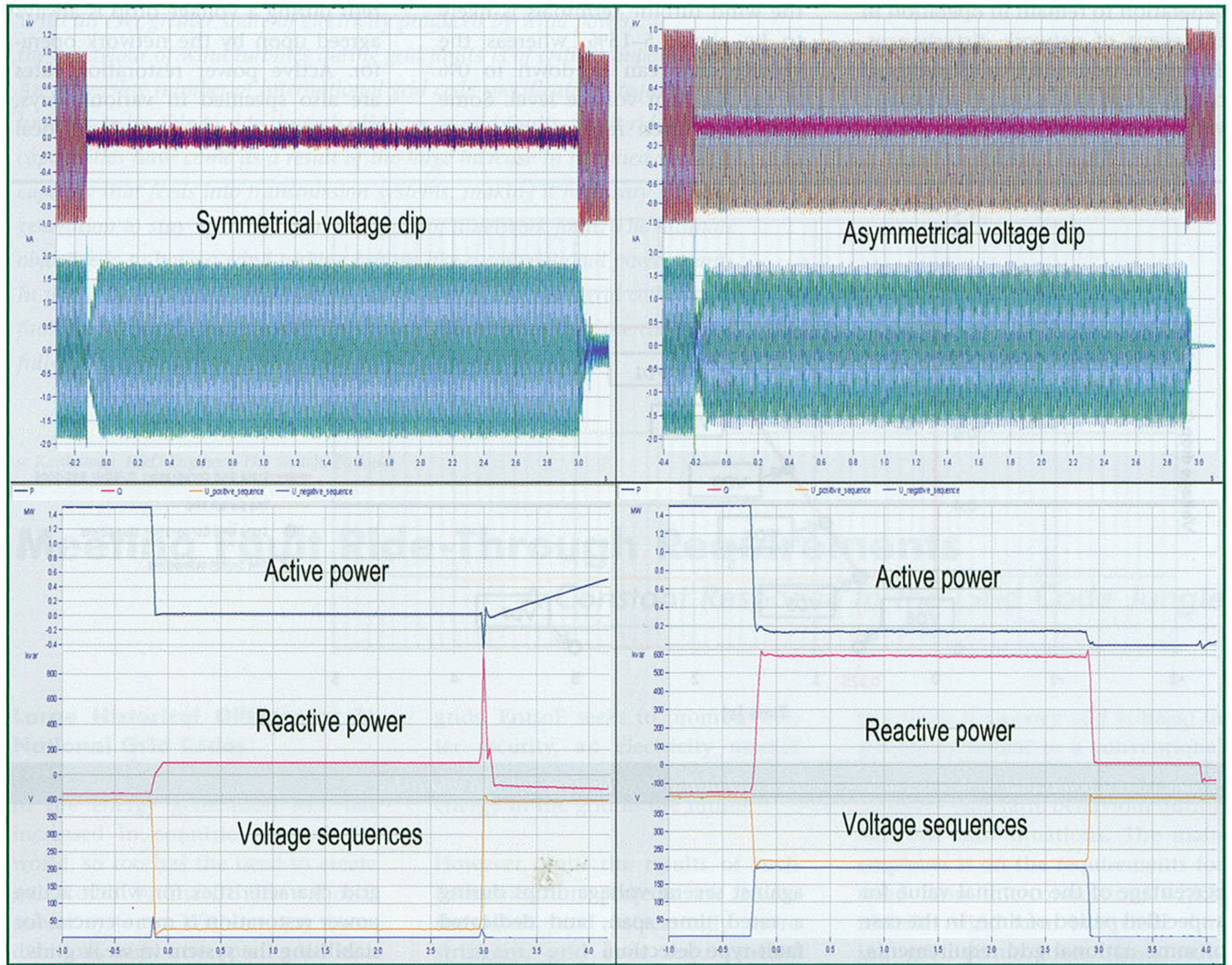


Figure 3. Test results show exceptional stability of the FPC. The operation here is at over 0.9 Pn and dip level is 0% of nominal voltage for 3 seconds

operation limits for a limited time or at a reduced power output capability. Network operators specify some frequency and voltage limit values at the point of connection when generating plants must be automatically disconnected from the network within a given time limit. The codes determining voltage and frequency operating range vary greatly among the different grid codes and can even differ within a single country.

FRT Testing by The Switch

The purpose of an FRT performance test is to provide information about the power quality characteristics of the voltage drop response for a full-power converter (FPC). Normally, FRT tests are carried out in conjunction with the wind turbine installation as a certification test, but The Switch factory test is able to show that its FPC is capable of staying connected during even the toughest grid fault situations.

The FRT tests carried out by The Switch in Vaasa, Finland, in January 2011 met predefined documentation and grid code specifications for 1.5MW converters. The test measurements and analysis procedures created by The Switch provide consistent and replicable results.

FRT Test Setup

The test topology uses a full-power converter connected to a permanent magnet (PM) generator as a back to back setup. Power is supplied using an identical full-power converter for which both symmetrical and asymmetrical voltage faults can be emulated in point of connection (EUT) (see Figure 1).

The Switch FRT tests match the most stringent grid codes in the world, to date. These include E.ON 2006, Transmission Code 2007 and Chinese grid code 2008, as well as the BDEW 2008, currently the strictest European requirement. The target is to ensure that The Switch fault ride-through capabilities fulfil all existing international requirements.

Tests for FRT functionality cover symmetrical three-phase voltage drops, asymmetrical two-phase voltage drops, and a fully controllable voltage level.

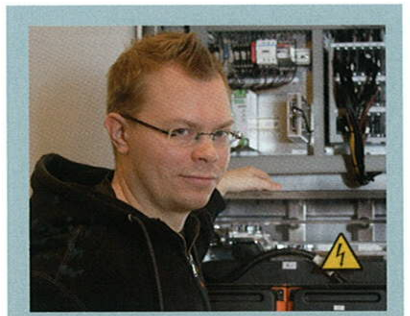
Test Procedures

The response of the wind turbine to voltage drops was recorded for the FPC operating between 0.1 Pn and 0.3 Pn and above 0.9 Pn. Results were used from two consecutive tests to include an extensive number of test points to repeat enough different fault types.

The test arrangements were for measurements to be made at the FPC terminals, when the operation was over 0.9 Pn. The response of the converter to the temporary voltage drop VD7 was made with capacitive-reactive current compensation activated during a voltage drop. The very long and stable operation of the FPC with waveforms, active power, reactive power, and positive and negative voltage sequence curves during a symmetrical and asymmetrical voltage drop is depicted in Figure 2. From here, we can see the unquestionable stability of the FPC for as long as the voltage drop continues.

FRT Tests Show Excellent Dynamic Power Control

The results of the tests show that The Switch FPC technology had dynamic power control during grid faults. The converter stayed connected during various kinds of grid faults and even demonstrated its capability for zero voltage ride-through. Additionally, the FPC supported the grid with a reactive current during a voltage drop, stabilising the grid voltage. The active current stabilises the grid frequency, whereas the reactive current stabilises the grid voltage (see Figure 3). ∎



Affiliation
Lasse Kankainen
R&D Engineer
The Switch Drive Systems Oy
Salpausselänkatu 291
53850 Lappeenranta, Finland
lasse.kankainen@theswitch.com
www.theswitch.com