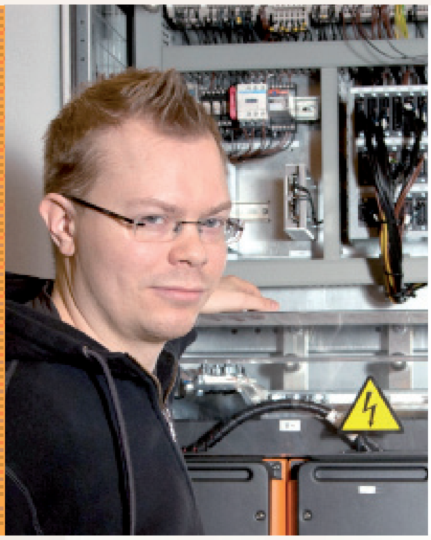
Fault ride-through



"With an increasing share of electricity produced by wind power, the behavior of wind turbines during grid faults is of critical importance. An increasing number of international grid code specifications requires that wind turbines are able to ride through all types of grid faults."

Lasse Kankainen
R&D Engineer at The Switch

Meeting fault ride-through requirements:

A constant response to grid code jungle

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.

Huge historical differences in national grid codes

As the share of wind increased in countries across 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 harmonized grid codes for all European member countries to support smart and super grids. EntsoE seeks to promote better security, a well-working electricity market and more renewable energy in the grid in the future.

Until the results of such harmonization projects are ready though, the latest and increasingly more stringent grid code requirements apply typically to large wind farms connected to the high voltage transmission network. Still, local operators can 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 control, in a similar manner as a conventional power station. Therefore, the codes focus on wind farm behavior during network fault situations. The main emphasis is on requirements concerning wind farm interconnection, which includes wind farm behavior 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. And even for some national grid requirements, this percentage is 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 so much, FRT requirements apply normally to the connection point of the network at the high voltage (HV) 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 MV level. Some grid codes even require 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 stabilizing 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 in case the voltage and frequency exceed normal operation limits for a limited time or at a reduced power capability output. 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.

Objective of FRT testing

The purpose of the FRT performance test is to provide information about the power quality characteristics of the voltage drop response for The Switch FPC. Normally, FRT tests are carried out in conjunction with the wind turbine installation as a certification test, but The Switch factory test proves even the toughest situations where the FPC is capable of staying connected during different kind of grid faults.

The FRT tests carried out in Vaasa, Finland in January 2011 meet predefined documentation and grid code specifications for 1.5 MW 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 back-to-back converter connected to a permanent magnet (PM) generator. Power is supplied using an identical full-power back-to-back converter for which both symmetrical and asymmetrical voltage faults can be emulated. *See Figure 1.*

Test specifications

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

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

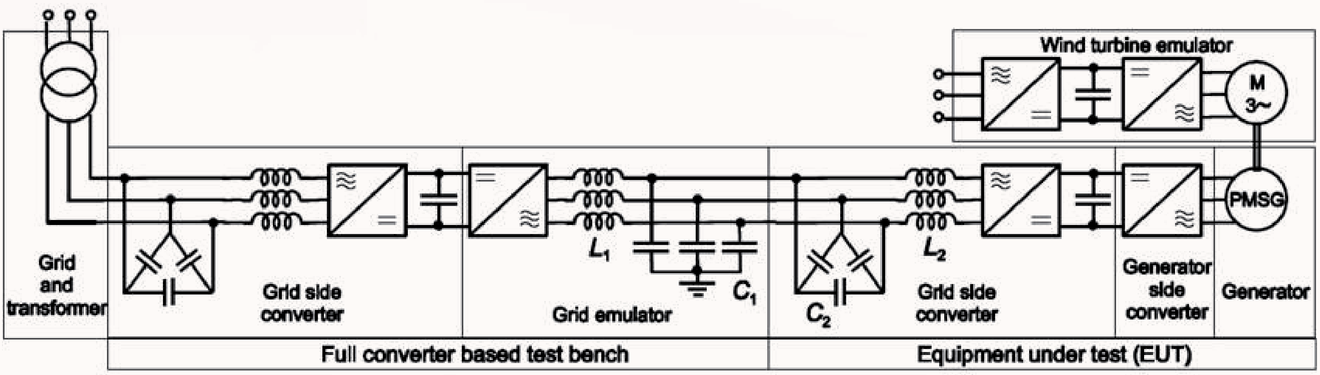


Figure 1. FRT test bench for FPCs at The Switch

Test procedures

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

Test arrangements with operation over 0.9 P_n measurements were made at the FPC terminals. The response of the converter to the temporary voltage drop VD7 was made with capacitive reactive current compensation activated during a voltage drop. This very long and stable operation of the FPC with wave forms, active power, reactive power, 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 proved to have dynamic power control during grid faults. The converter ensured electrical connection 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. The active current stabilizes the grid frequency, whereas the reactive current stabilizes the grid voltage. *See Figure 3.*

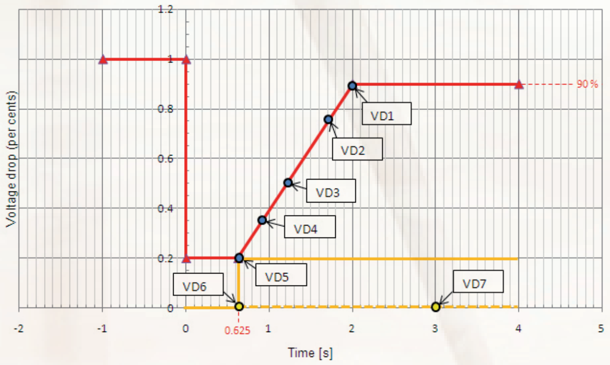


Figure 2.
Test points and borderlines in LV/MV/HV level for different grid codes

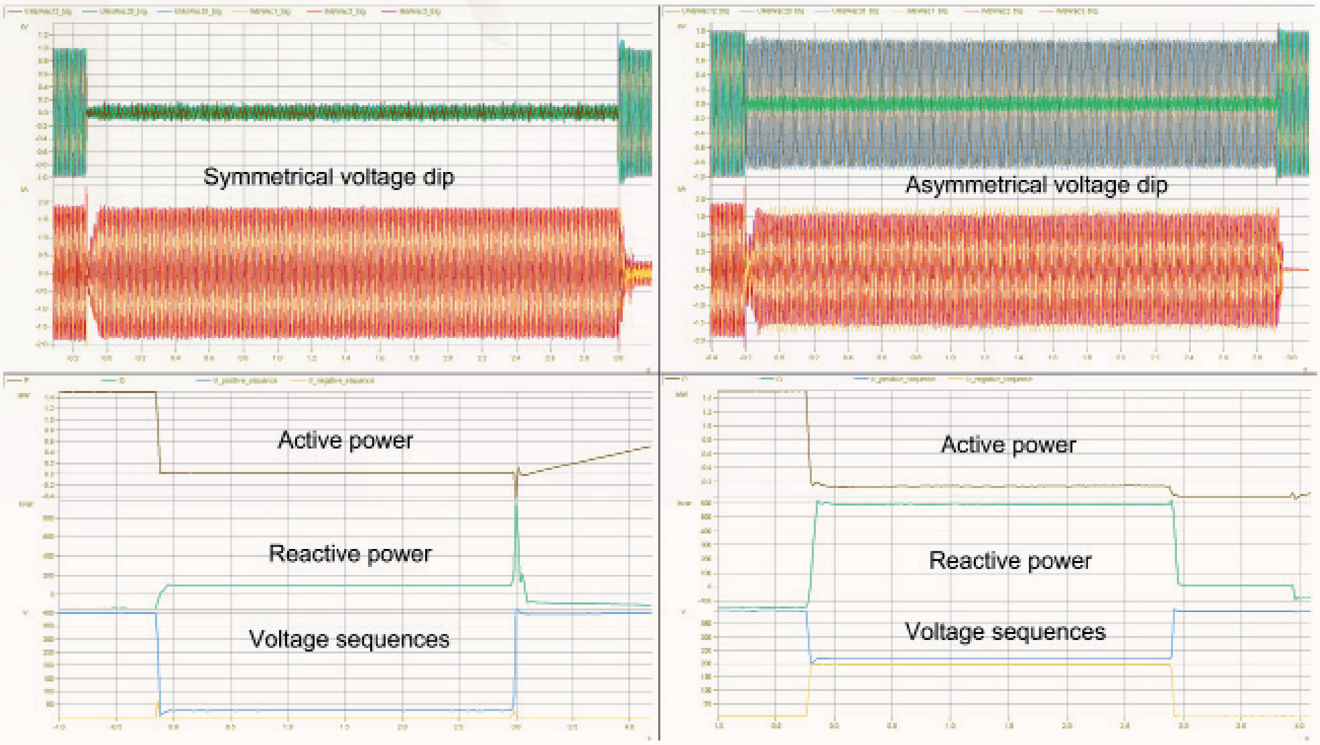


Figure 3.
Test results show exceptional stability of the FPC. Operation here at over 0.9 P_n and dip level is 0% of nominal voltage for 3 seconds

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