AUTOMATIC CERTIFICATION TESTING OF THE SYSTEM AUTOMATICS OF WIND POWER PLANTS

Hendrik HARTENBACH
KoCoS Messtechnik AG – Germany
hhartenbach@kocos.com

Dr. Hendro RIJANTO
KoCoS Messtechnik AG – Germany
hrijanto@kocos.com

Jochen MÖLLER
M.O.E. GmbH GridCert – Germany
info@moe-service.com

ABSTRACT

The subject of this paper is the automatic certification testing of the system automatics in wind power plants with special reference to testing under-voltage dependent directional reactive power relays. Wind power generating plants are required to upgrade their system protection capabilities by adding this protection function in order to obtain the allowance to resume operation.

1 INTRODUCTION

The share of renewable energy sources in worldwide power generation has risen sharply in recent years. Seen against the scale of worldwide human requirements, renewable energy sources, unlike fossil fuels, are inexhaustible, they are not subject to the limitations of time and do not have an irreversible impact on the environment. In Germany the share of renewable energy sources in electricity consumption has risen from 5% in 1996 to over 16% today. According to the industry forecast "Power Supply 2020" it is realistic to expect this share to increase still further to reach 47% by 2020. Wind energy is expected to account for over half of this increase. The forecast predicts an increase in the share of electricity generation from wind energy alone from the current level of 50 TWh to approximately 150 TWh per year [1].

The increase in the number of remotely distributed renewable energy sources which feed into the grid leads to longer power transmission distances. Load flows of this type involve additional losses and endanger network stability. And to make matters worse, load flows generated from renewable energy sources can also be difficult to predict with any great degree of accuracy. Stability, safety and reliability are typical criteria for the quality of a power system. CIGRE and IEEE [2] define the stability of electrical power systems as follows:

“Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.”

The connection conditions for power plants in Germany and the necessary contribution to system stability are laid down in the VDN Transmission Code [3] of 2007 (VDN = Association of German Grid operators) which is cited by more recent guidelines and ordinances such as the BDEW guideline "Generating plants connected to the medium-voltage network" [4] of 2008 (BDEW = German Association of Energy and Water Industries) and the Ordinance on System Services by Wind Energy Plants of 2009 (System Services Ordinance - SDLWindV) [5]. As a result of the BDEW guideline, fundamental connection requirements for generating plants stipulated in the Transmission Code now also apply to the connection of distributed generating plants to the distribution network. The SDLWindV specifies some of the requirements in greater detail and extends their application to the compensation defined in the Renewable Energy Sources Act of 2009 (EEG 2009).

As a consequence, every generating unit requires a type-specific unit certificate. This unit certificate specifies the electrical properties of the generating unit in order to furnish proof of the conformity of the generating unit with the requirements of this guideline. The design and the engineering of the generating unit shall be based on FGW TG3 (FGW = Federation of German Wind Power, TG = Technical Guideline).

2 CERTIFICATION OF THE PGU

In Germany the certification process for the integration of the power generating units (PGUs) in the medium and high voltage systems generally consists of three steps:

- Type certification
- Project certification
- Site approval by inspection (final confirmation).

2.1 Type certification process

The scope of this process is the certification of PGUs commissioned after 01.01.2009 in accordance with the German grid code and the Ordinance on System Services by Wind Energy Plants [5]. First of all, complete documentation of the type testing demanded by FGW TG 3 is to be issued by a test lab which is accredited according to EN 17025. Subsequently, verifications related to the corresponding PGU model issued by a certification authority according to EN 45011 [7] shall be provided. It shall consist of a comprehensive computer model of the PGU, which is encapsulated as a black box model. The model has to be validated by comparison of the simulation results in a specific range of defined set points and/or grid conditions with the measured data given in the test report. Finally the certification author-

ity according to EN45011 summarizes the results of conformity testing and model validation in a comprehensive report which will conclude a clear verdict for or against the PGU certification.
The type certificate will include detailed technical and software specifications which adhere to the grid connection regulations as well as tests results of the PGU. As a result, the certificate is valid for 5 years, provided no relevant changes are made to the properties of the PGU and the corresponding connection point. Besides, as listed below, the general requirements on the electrical properties as mentioned in [3, 4 and 5] must be assessed too.
- The provisions of maximum active power provided by the PGU and active power reduction by defined set point scope is to be adhered to. Other provisions, namely the control of active power control based on set points between 0 and 100% of rated power are to be taken into consideration as well. The largest set point is to be achieved within 1 minute and the power reduction with a gradient of 40 % is to be carried out to to verify the frequency deviation per Hz.
- The increase of the active power gradient after reconnecting is to be observed and verified on the PGU in accordance with FGW TG3.
- The verification of reactive power data as a function of feeding power and the maximum of reactive powers for inductive and capacitive reactive power consumption must be checked including the step responses within a specified time according to FGW TG3.
- The parameters for the power quality according to FGW TG3 must be available as test report.
- Finally, the report of the verification of the PGU at system frequency between 47,5 Hz and 50,5 Hz with at least 0.95 of rated voltage is to be provided accordingly.
In addition the performance during system faults on the grid shall be verified as well as listed below:
- The low-voltage ride through (LVRT) – documentation for 2 and 3 phases must be provided with a minimum k-factor of 2. From mid 2011 on, the k-factor shall be a variable between 0 and 10. For asymmetrical fault conditions the evaluation is to be performed at the smallest value of the 3 line voltage.
- The evaluation of the reactive power profile and determination of the proportionality constant k-factor is to be carried out. The evaluation is performed on the dynamic transient response of the reactive power at the k- factor used in the field test and the voltage drop.
The determination of short-circuit current contributions for 2 and 3 phase faults using the following data mentioned in the certificate for the following times:

- Current rms value at fault occurrence after 1 period
- Current rms value at 150 ms after fault occurrence
- Current rms value at 20 ms before voltage recovery

After fault rectification it is, according to [3], required to have power enhancement of at least 20% of the rated power per second until power levels prior to the fault have been attained and is to be considered compliant, provided the PGU attains the full power at the latest 5 s after fault rectification and the tolerance shall be at most ±5%.
To be able to disconnect the PGU from the grid system in case of faults, the following protection functions shall be incorporated in the PGU:
In case of over- and under-voltage protection, the setting range is to be checked at the lowest and the highest definable values. A shut-down value in the tests must coincide with the defined value to ± 5% of the rated voltage for the protection function. Especially the under-voltage behaviour has to be optimized due to the needs for running through a voltage dip as shown in Figure 1

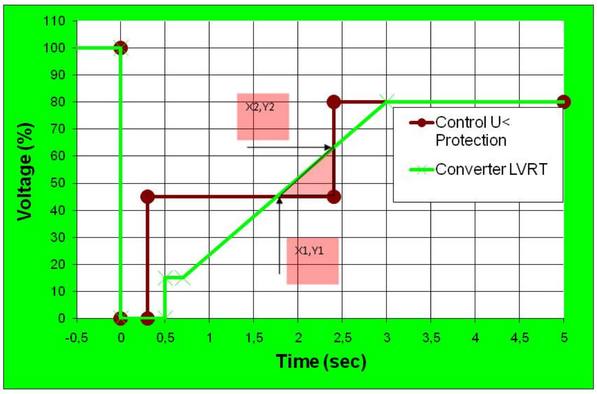

Figure 1: Under-voltage protection versus LVRT

In over- and under-frequency protection, the setting ranges at the lowest and the highest definable values shall be tested. The tested shut-down value must coincide with the defined value to ±0.1% of the rated frequency.

2.2 Project certification process

The scope of this process is to verify adherence to the requirements including the load capability of the equipment for the specified active and reactive power and the impact of the connected system voltage variation on the feeding of the power generating system (PGS) e.g. wind or solar farm. In addition, compliance to power quality, flicker and harmonics up to the 180^{th} (9 kHz), reduction of active power according to the specifications of the system operator and reduction of active power at over-frequency range are the topics of concern in the certification process.
The following assessments will be considered with regard to the necessary protection functions:

- Current protection PTOC
- Voltage protection PTOV and PTUV
- Frequency protection PTOF and PTUF
- Under-voltage controlled reactive power protection (new function required by [5]).

Furthermore the specific procedure instructions are to be checked as well:

- Tasks must correspond to the accredited scope of tasks of the certification authority

- Details must be provided regarding the grid connection or legal specifications
- Clear definition of PGS must be provided
- Submission for inspection is to be carried out by providing details on PGUs connected to PGS, electrical components, system connection control.

The assessment of the conformity requires that the test documents and the related validated models for all existing PGUs are checked by the certification body in charge. Once a positive verdict has been reached, the certificate will be issued. As mentioned above, the maximum validity period for a certificate is 5 years, providing the PGU remains unchanged. Otherwise the certificate will be declared invalid. The documents will also be retracted by the certification body in the case of subsequent malfunctions.

The certification authority must monitor the certificates it issues. If difficulties arise during operation the measures taken are to be documented properly. If the issues are related to the certified PGS, this may raise questions on the validity of a certificate and the system operator must prepare an appropriate declaration including a technical explanation. Moreover, the requirements according to [2, 3 and 4] for the system connection and the VDN guideline for digital protection systems [8] must be monitored too. This implies that the all the protection functions of the PGUs are to be tested after 4 years at the latest.

2.3 Site inspection

An on-site inspection is required during commissioning in order for the wind energy project to be integrated and connected to the electrical system. The aim of this is to have a confirmation that all requirements are fullfilled and parameters are set according to the preceding project certification mentioned above. Moreover the serial numbers of all the units installed are to be listed in the final certification documents. The grid and system protection are the special focus of the on-site inspection.

3 AUTOMATIC TESTS OF THE QU PROTECTION

The share of renewable energy sources in power generation is already large and is expected to grow further in future. As a consequence, a great number of protection functions must tested for the certification of wind power plants. The VDN guideline [7] stipulates that these tests must be carried out every 4 years. Testing just one of the protection functions is quite time consuming without an automated test module (also known as a test monitor). The test systems of the ARTES range developed by KoCoS Messtechnik AG consist of a test instrument and testing software which enable these protection functions to be tested fully automatically. This paper describes in detail the test procedure for the new under-voltage dependent directional reactive power relays (QU protection) required by [5]. KoCoS Messtechnik has developed a special test monitor for this purpose which allows the operator to test and document this protection function fully automatically and meet the criteria for certification.

Figure 2: Testing the under-voltage dependent directional reactive power relays

Figure 2 shows a type test on a relay with built-in QU protection. Although it is possible in principle to test the new protection function with the VD (Vector Diagram)- - Monitor which is included in the standard version of the ARTES software, experts responsible for testing protection functions have called for a fully automatic test monitor which would drastically reduce errors, particularly during routine protection tests.

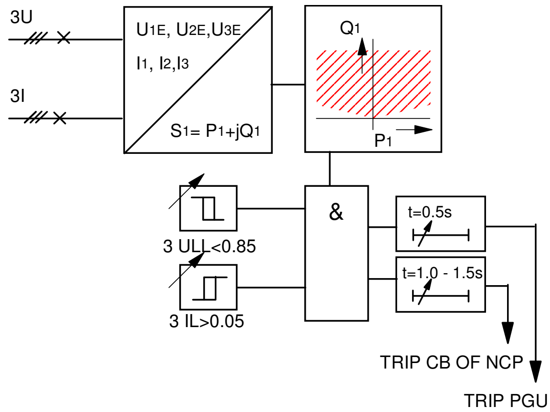

Figure 3: Block diagram of the new QU protection function

The basic principle of the new QU protection function is shown in the block diagram in Figure 3. Line currents and line voltages must be measured in order to determine the reactive power. The discriminating elements of the QU protection must be linked with the AND operator. This means that all the measurement voltages must have dropped below the start value in order for the under-voltage relay to start. Guide values for the settings are under-voltage $U<0.85\ U_r$ (U_r = rated voltage) and reactive power $Q>0.05\ S_N$ in an under excitation state over a period of time t>500 ms. The parameters must be configurable across a wide range and it is important to ensure that the reactive

power is seen as positive-sequence power.
The user interface of the test monitor for testing the new QU protection function automatically is shown in Figure 4. The test monitor features a number of different test modes for carrying out the operating tests required for certification.

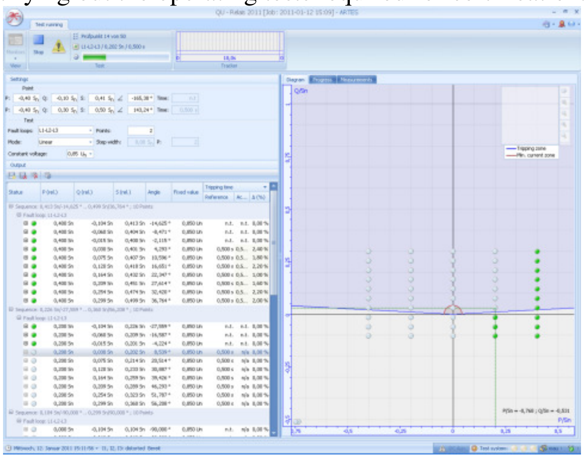

Figure 4: Test monitor for automatically testing the QU protection

The tests are based on determining starting. The test values are ramped and these ramps are run until the relay trips. The resetting ratio can then be determined by ramping the values again until the appropriate signal has dropped off again.
In order to test the under-voltage condition, the voltage of the three phases is lowered. The start and end values are entered to define the ramp. The operator can choose whether either the minimum current or the minimum reactive power should be set at a constant value. The other value is then calculated automatically by the test monitor and, in the case of constant minimum reactive power, for example, the current output is varied accordingly.
Verification of the AND link is carried out in a similar way to the under-voltage test. However, first one of the three line-line voltages is lowered to 0 V. Then two of the line-line voltages are lowered to 0 V. The protection function should not trip in the process.
In order to check the trip angle, all line voltages are set to 0.84 U_r and the line currents are set at a value greater than the minimum current I_{min}. First the currents are rotated in a clockwise direction from the third to the second quadrant (load reference arrow system). The protection function is supposed to trip at a certain angle in the second quadrant and not before. Afterwards the resetting ratio is determined. Then the current is rotated in an anti-clockwise direction through the fourth quadrant into the first quadrant. The protection device is not supposed to trip in the third or fourth quadrants, but must trip in the first.
To test the enable current, the line-line voltage is set to a constant value again (0.84 U_r, for example) and the current is set at a phase displacement of ± 90° to the voltage. The current amplitude is increased symmetrically until the protection device trips.
When verifying the tripping characteristic, the test points can be positioned in a diagram, in this case in the P-Q plane, similarly to the procedure familiar to users from other test monitors. The corresponding voltage and current values are determined automatically, one value must be set at a constant level (0.84 U_r, for example). The values can also be typed in using the keyboard. The user can choose whether to enter the values for active power (P) and reactive power (Q) or whether to enter the values directly for apparent power (S) with the appropriate angle. In either case the other values are calculated automatically and entered in the appropriate text boxes. Here, again, the user has the choice between entering individual test points in "manual" mode and entering multiple test points in the "series" or "sequence" modes.
A particularly convenient feature of this test monitor is that all the above-mentioned test modes can be used in one test plan and can be run one after the other. At the end of the test, a test report can be generated and printed out for certification. This test report includes all the data and results which are required for plant certification and presents them in a clearly structured form, thus enabling an assessment of the correctness of the test to be made. The test report is then forwarded to an accredited certification body, such as Moeller Operating Engineering GmbH.

4 REFERENCES

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