CONFIRMATION OF EXTENDED ELECTRICAL PROPERTIES OF PV-INVERTERS ACCORDING TO GERMAN MV-GRID CODE – EXPERIENCES IN THE CERTIFICATION PROCESS

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ABSTRACT

In Germany Distributed Energy Resources (DER) connected to the Medium Voltage (MV) network have to provide extended electrical properties according to the renewed BDEW MV-guideline [1]. The intention of these additional functionalities is the support of network operation and stability. In order to guarantee an assumed coordinated behaviour of all DERs units, plant certificates are required for new installations.
Unit certificates of the deployed DER units are the bases for these plant certificates. This unit certificate is achieved by validation of measurements and simulation results.
This paper describes the certification process with a focus on the extended electrical properties of Photovoltaic (PV)-inverters connected to MV network.

INTRODUCTION

Since January 2009 the new BDEW guideline for interconnection of DER units to the MV network is valid. From 01.04.2011 new installed PV units have to fulfil the static requirements stated in the BDEW MV-guideline, by 01.04.2011 also the dynamic requirements have to be provided.
The conformance with the BDEW MV-guideline has to be proved for single DER units by a unit certificate. This is achieved by measurements according to FGW TR3 [2] and validation of simulation models according to FGW TR4 [3]. Based on these results a certification body is allowed to issue a unit certificate assuming that the requirements of FGW TR8 [4] are fulfilled.
In this paper experiences with measurements and simulations within the certification process of the PV-inverter PVI-55.0-Central by Power-One are discussed. The measurements for the unit certificate are carried out by Fraunhofer IWES as an accredited measurement lab according to DIN EN ISO/IEC 17025.

REQUIREMENTS OF THE BDEW MV-GUIDELINE

In the BDEW MV-guideline several requirements concerning static and dynamic behaviour of DER units are described. They can be grouped as follows:

- Active power provision including set-point control and power reduction at over-frequency
- Reactive power provision by set-point or characteristic curve (Q(U), cos φ (P))
- Power Quality
- Grid protection
- Connection conditions
- Response to voltage drops (Low Voltage Ride Through)

TESTING OF PV-INVERTERS FOR MV-CONNECTED PV PLANTS

MV-connected PV plants can have different system concepts. Whether central inverters with high power ratings are used or a modular concept with string inverters having lower power ratings comes into operation. Depending on the power rating of the inverter, different kind of test equipment is suited.

MV-connected PV-plants with central inverters

Figure 1 shows an typical example of the electrical diagram of a standard station of Power-One used for MV-connected PV-plants with central inverters.

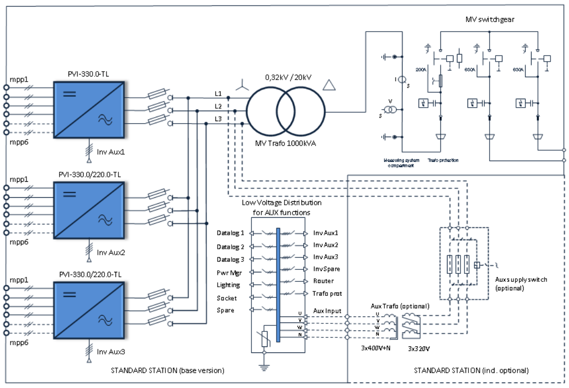

Figure 1: Typical example of electrical diagram for Power-One MV-connected PV plants.

Typically the AC Power is made available at the output of central inverters in the voltage range between 270Vac-360Vac, and is injected and stepped up to the MV level (15kV or 20kV) by means of a Dy or Dd connected transformer. The PVI-central inverter itself has a modular concept. It can be configured in power steps of 55 kW up to 330 kW. Therefore the measurement results of the 55 kW unit can be transferred to the other available power configurations.
In regards to the vector group of the transformer, despite a

Dd connection is in general the most convenient and appropriate arrangement for this application. Most of the nowadays installations are made with Dy-connected transformers, because these are most popular and readily available from the traditional manufacturers in the supply chain of electrical distribution equipments. Other factors also influence the selection of the vector group of the transformer, which are not relevant for the purpose of this work. However both vector groups (Dd and Dy) shall be considered during the grid code compliance testing, especially during the assessment of the dynamic behaviour in case of voltage dips at the MV level, because they affect the amplitude and phase relationship of the residual phase voltages available at the inverter output terminals on the LV side, in case of unbalanced faults occurring at the MV level.

Test equipment and adopted test procedures for PV-inverters

The norm IEC 61400-21 [5] describes test procedures for wind turbines in detail. Also test procedures given in FGW TR3 were developed for wind turbines. Unfortunately all kind of DER units have to be tested according to this guideline. Therefore an adaptation of test procedures is unavoidable. Mainly reasons are the different characteristic of the prime mover, as well as different power ratings of the single DER units.

Fraunhofer IWES is actively involved in several committees, e.g. PV working group of FGW TR3, for developing test procedures for PV-inverters according to BDEW MV-guideline. For proving the feasibility of new test procedures several test facilities are available.

For DER units with power ratings up to 90 kVA the DeMoTec laboratory provides extended testing possibilities. A 4-quadrant AC-network simulator consisting of linear amplifiers offers the possibility to reproduce any desired network behaviour.

For higher power ratings it is hardly impossible to provide such high class test equipment due to economic reasons. In this power range normally so-called LVRT-test containers are used. They are connected in between the DER unit and the public MV network.

Fraunhofer IWES is setting up a reference laboratory called IWES-SysTec, where DER units up to 1.25 MVA on LV-side and up to 6 MVA on MV-side can be tested. The test equipment is shown in Figure 2.

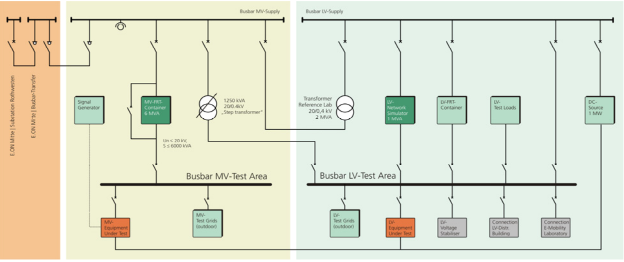

Figure 2: Electrical layout of new test laboratory SysTec of Fraunhofer IWES for high power applications

EXPERIMENTAL RESULTS OF STATIC REQUIREMENT

Active power

The new functions for active power control enable the DER unit to reduce the actual power output in terms of network instabilities. Whether this power reduction is done locally and automatically due to an over-frequency situation in the network or it has to be done remotely by the network operator.

Power reduction at over-frequency condition

A surplus on generation capacity in the network leads to a frequency rise. If frequency control of the network is no longer capable to keep the frequency in acceptable range, DER units can support the network by reducing active power injection. The BDEW MV-guideline asks for an active power reduction with 40% per Hz starting at 50.2 Hz. A re-rise of active power injection is allowed if the frequency is less than 50.05 Hz.

Figure 3 shows measurement results when the network frequency is varied by the AC-network simulator. It is obvious that inverters are well suited for providing this functionality.

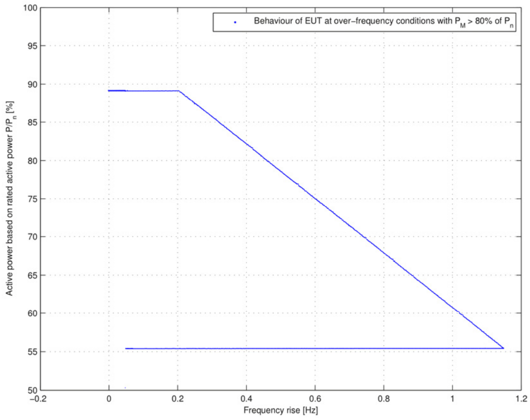

Figure 3: Over-frequency behaviour PVI-55.0-Central

Power reduction by network operator

In contrary to the autonomous reduction of active power at over-frequency, the power reduction by network operator occur remotely and selective. In case of e.g. network transmission capacity shortages or overloading of network equipment the network operator is allowed to reduce the active power injection of DER plants in order to secure network operation.

The DER units must be able to reduce the active power output to set-points given as percentage of the rated active power. Most common values are 100%, 60%, 30% and 0%. Response time of the DER units should be faster than 1 minute. It has to be considered that this time range have to cover the whole communication line beginning from the receipt of the set-point signal at the plant controller until the alignment of the reduced active power output at the DER unit.

Figure 4 shows the power reduction capability of the PV-inverter. Set-point signal can be given by relay, analog or RS485 interface.

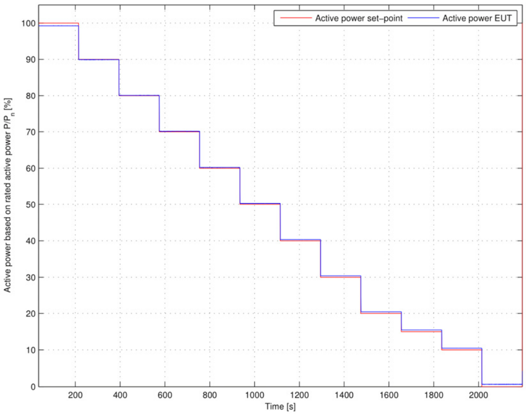

Figure 4: Active power reduction by network operator. Set-point signal is provided by RS485 to the inverter.

Reactive power

Through the rising penetration of the DER units, voltage control becomes an important issue nowadays. DER units did not provide reactive power inherently in the past. With extended reactive power control functionalities the DER units are able to support the network and to increase thereby the integration capacity of DER units into the network.

The current-carrying capacity of the semiconductors is the limiting factor for reactive power provision of inverters. An over-dimensioning of the inverter is required if a simultaneous injection of reactive power at rated active power is desired. Otherwise the maximal active power injection has to be limited. This could involve higher system costs to the manufacturer.

The BDEW MV-guideline demands a power factor of 0.95 leading and lagging at the Point of Common Coupling (PCC). In order to fulfil this requirement, inverters should be able to provide a lower power factor than 0.95, since the reactive power demand of internal network equipment as cables or transformers also has to be considered.

The network operator has following possibilities for setting the reactive power:

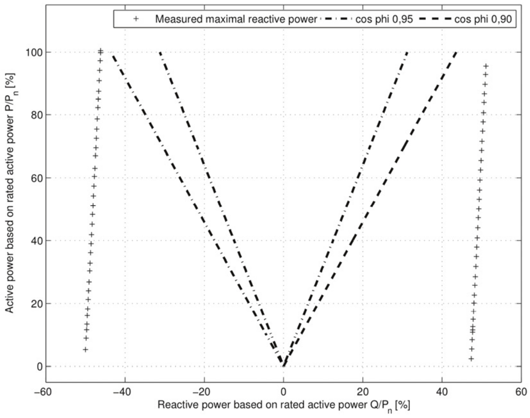

Figure 5: Reactive power capability of PVI-55.0-Central

- Fixed power factor cos φ
- Fixed reactive power in MVAr
- Characteristic curves:
  - Power factor and active power cos φ(P)
  - Reactive power and voltage Q(U)

Figure 5 shows the reactive power capability of the PVI-55.0 central inverter. A power factor below 0.9 is reached over the whole active power injection range up to the rated active power of 55 kW. A control of the power factor as well as the reactive power can be done by analog interface or RS 485. With these functionalities a plant controller is able to provide characteristic curves for Q(U) at the PCC.

MEASUREMENT AND SIMULATION RESULTS OF DYNAMIC REQUIREMENTS

Network faults causes voltage dips. Depending on the distance to the fault location and the network topology and parameters, this dip has different magnitudes. In the past DER units had to disconnect from the network very quickly in terms of under-voltages due to grid protection settings. Due to the rising number of DER units network operators are afraid of an abrupt loss of large numbers of distributed generating capacities. Therefore also DER units should technically be able to ride through faults in order to continue active power injection instantly after fault clearance. Figure 6 shows the LVRT-curve according to the BDEW MV-guideline and the test areas of FGW TR3 used for the measurements of the DER unit.

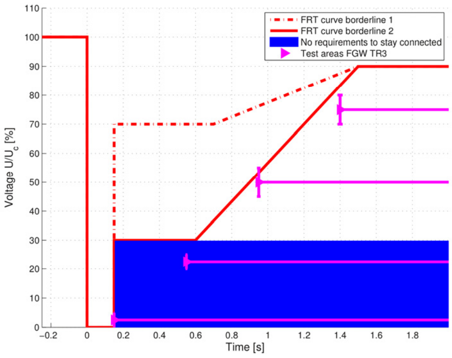

Figure 6: German LVRT-curve for generators type 2 according to [1] and FGW TR3 test areas.

Adopted test procedures for LVRT tests

According to IEC 61400-21 [5] LVRT tests have to be carried out by creating network faults on the medium voltage level. Especially for PV-inverters with low power ratings these test procedures are not meaningful. Therefore FGW TR3 also allows testing the LVRT behaviour by providing the network faults on the LV level. However it has to be assured that the faults have the same behaviour as if they would be generated on MV level. Especially for unbalanced faults the vector group of the MV/LV transformer has to be considered. Figure 7 shows the difference during the fault for a Dd and a Dy transformer. If the LVRT tests are conducted with a network simulator it must be possible to control the voltage amplitude and the phase angle of each line independently with very high slew rates (> 30 V/µs for the used network simulator). In order to provide realistic network conditions, a physical impedance network for setting up the short circuit power and the network impedance angle is used. For the impedance calculation beside the network impedance also the impedance of the transformer and the cables of the DER plant should be taken into account.

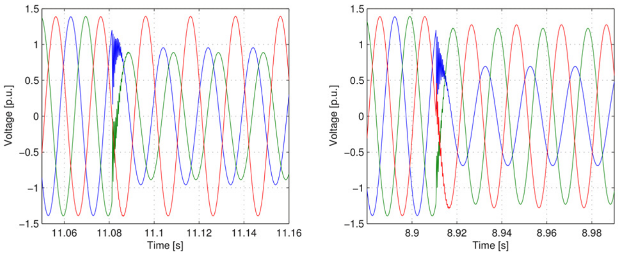

Figure 7: Measured voltages during unbalanced faults. Left side Dd and right side Dy as MV/LV transformer

Voltage support through reactive current

Voltage support during network faults is a further request for DER units. Depending on the magnitude of the voltage dip and the k-factor characteristic (Figure 8) an additional reactive current has to be injected. The DER unit must be able to inject at least their rated current as reactive current. Reactive power injection as well as voltage deviations before the fault have to be taken into account for the calculation of the reactive current set-point.

Figure 9 compares measurement and simulation results of a balanced network fault with reactive current injection.

The voltage is reduced to 75% of the nominal voltage. By applying a k-factor of 2, the DER unit has to inject about 50% of its rated current as reactive current.

For both measurement results as well as the simulation results the reactive current injection is within the tolerance band. Also the response time of the DER unit fulfils the requested control response time of 20 ms according to [6]. Measurement results and simulation results show an accurate correlation. This assures that simulations carried out for plant certificates provide reliable results for the behaviour of the planed DER plant during critical network situations.

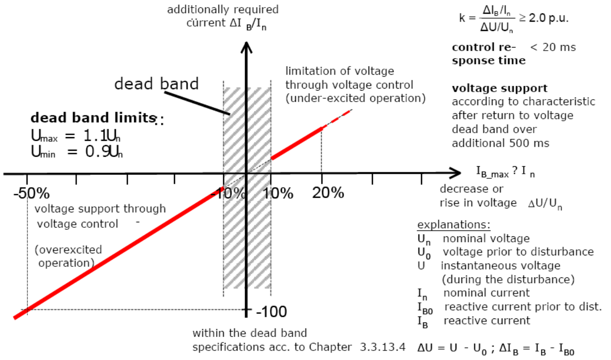

Figure 8: Reactive current injection from DER units during balanced network faults according to [6]

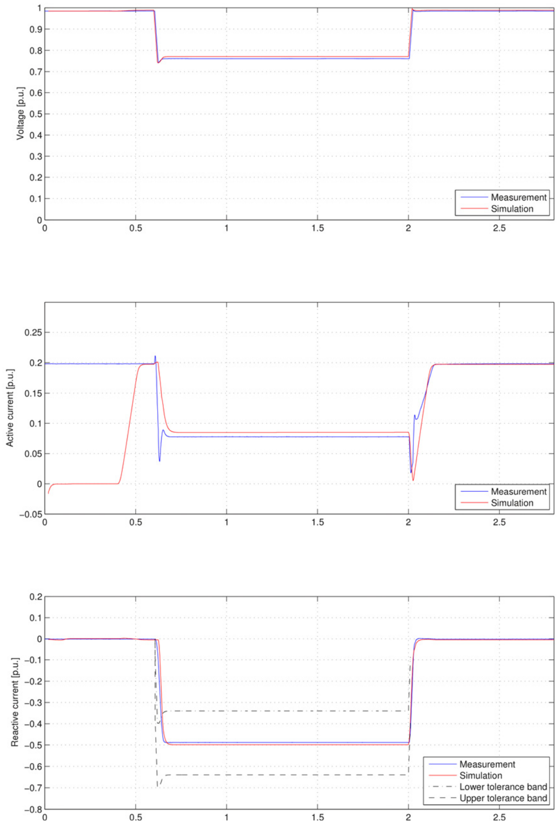

Figure 9: Comparison of measurement and simulation results for a balanced fault with k-factor of 2.

CONCLUSIONS

The new German BDEW MV-guideline requests static and dynamic functionalities from DER units in order to support network operation and stability.

PV-inverters in general are able to fulfil the static as well as the dynamic requirements. The test campaign with Power One PVI-55.0 central inverter has confirmed that on the bases of properly designed inverter power architectures combined together with modern digital control architecture the fulfilment of the BDEW MV-guideline can be achieved by the development of dedicated control functionalities in the inverter firmware with no significant impact on the inverter hardware design.

A high need of PV specific test procedures and test equipment had been determined during initial certification processes. Within this certification process a LVRT test procedure using a LV network simulator with physical impedance network was successfully applied.

REFERENCES

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[3] FGW Technical Guideline 4 Rev. 4, 2010
[4] FGW Technical Guideline 8 Rev. 4, 2010
[5] IEC61400-21 Edition 2.0 2008-08
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