Utility-scale PV systems: grid connection requirements, test procedures and European harmonisation

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ABSTRACT

New interconnections requirements for utility-connected photovoltaic systems are coming into force in several European countries, armed with the task of supporting the grid operation and stability. This approach to better integration of photovoltaic systems into the electric power system enables a larger dissemination of renewable energies. This paper presents the new grid code in Germany as an example for improved integration, complemented by a brief report regarding activities currently being undertaken to ensure European harmonisation of interconnection requirements.

Introduction

Facing the enormous growth of decentralised generation connected to the distribution systems, the year 2009 brings fundamental changes for new PV systems in a number of European countries. While in the past, generators connected to the distribution system were commonly not permitted to take over an active role and had to "disconnect at the first sign of trouble", the new guidelines now require the units to actively support the grid during normal as well as disturbed conditions. This step is being regarded more and more as absolutely necessary to guarantee reliability and quality of supply in the mid- to long-term.

This new approach has already been adopted in France (April 2008 [1, 2]) and Germany (June 2008 [3]) using the latest revisions of the national guidelines for the connection of generators to the low- (LV) or medium-voltage (MV) networks. Consequently, the change has also been recognised by other countries as being trend-setting for the new role that PV and other distributed energy resources (DERs) are going to play in the future. Among these, Austria recently (January 2009) adopted the new approach and incorporated a number of key requirements into its guidelines for the connection of generators to the distribution networks [4].

While the new guidelines are currently mainly relevant for MV connections and thus PV systems in the 100kW+ range, the same approach is already being incorporated into the recent drafts for the upcoming new low voltage interconnection specifications. All new PV installations will from then on be directly concerned and will have to fulfil the new requirements.

European harmonisation

National laws, standards and recommendations in different countries have naturally different characteristics as practises have grown and developed from local needs and conditions. The absence of harmonised interconnection specifications is one of the most severe obstacles to the wide deployment of DERs and the subsequent inclination towards active electricity networks in Europe. The objective of addressing this diversity has been taken on board by the research community and is also one of the key objectives of DERlab, the European

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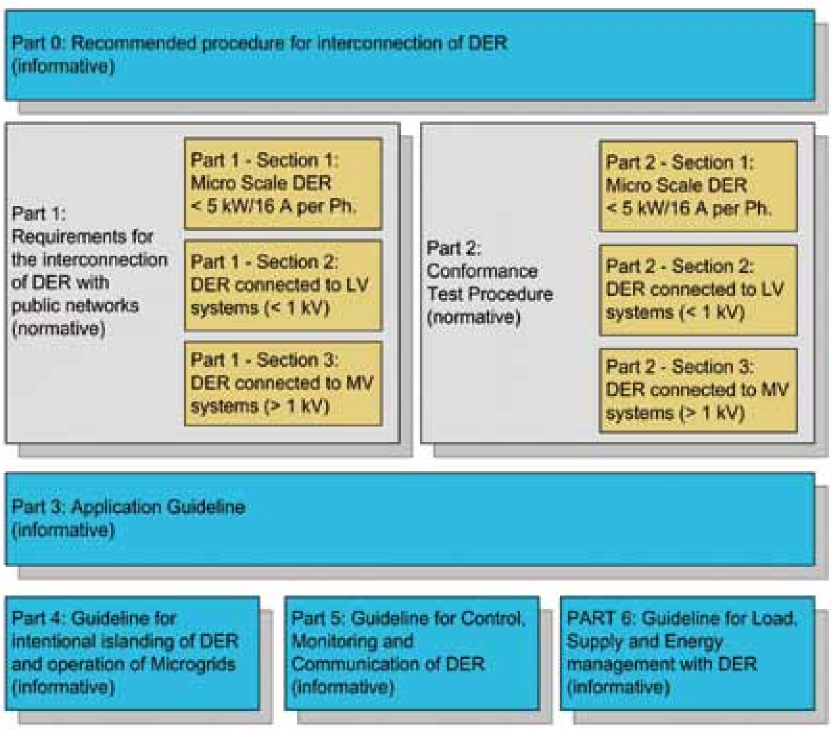

Figure 1. Proposed structure of Technical Specifications by DERlab to CENELEC TC8X WG03 working group [7].

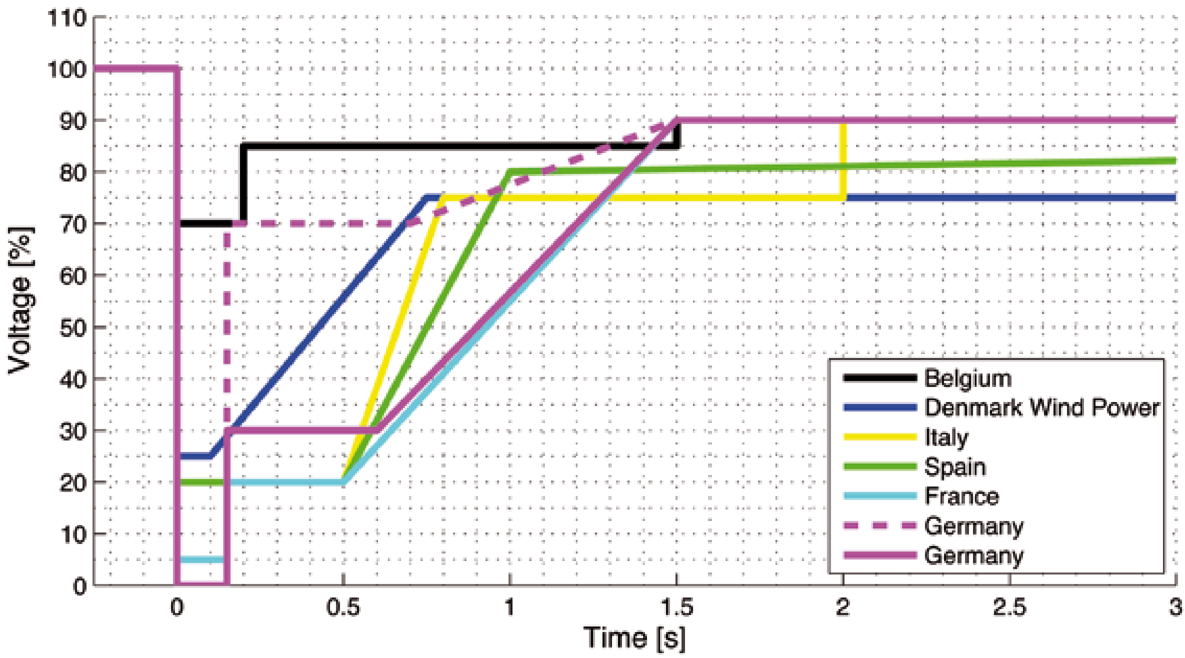

Figure 2. Requirements in national grid codes for decentralised generators connected to the distribution system during a grid fault.

Network of Excellence of independent laboratories working on the integration of DER [5].

As part of the DISPOWER project, the interconnection specifications of nine European countries were compared to give recommendations and to investigate standardisation needs [6]. Since then, other research projects commenced investigations comparing the interconnection specifications of different countries and defining the gaps. Analysing these results, DERlab has presented to the relevant standardisation committees a solid structure for a future European Standard for Interconnection of DER (EDIS) [7], as shown in Figure 1. This European approach intends to overcome the current lack of standardisation and testing procedures in this area, resulting in additional costs for manufacturers and project developers. Two European DERlab workshops, one in May 2009 in Salzburg, Austria, the second in September 2009 in Łódź, Poland will be performed in order to give additional support for the development of harmonised interconnection requirements.

For this purpose, DERlab has set up the "DEDIS - Database of European DER Interconnection Specifications" to create more transparency in the clutter of the different specifications and to support their European harmonisation. DEDIS is publicly available on the DERlab internet portal (www.der-lab.net) and is searchable by country, segment, or energy source. The survey given in DEDIS will be the basis for further investigations. Exemplary comparisons between interconnection specifications of different countries using DEDIS will help to clarify the current situation and illustrate the harmonisation needs. In addition, DEDIS users are given the opportunity to report on their own experiences, deviations from the national guidelines or other important feedback directly via a web-based interface. Based on this feedback, DEDIS will become a unique source of comprehensive information on DER implementation practise in Europe and thus make the complex interconnection issue more transparent.

European interconnection standard developments at CENELEC

Besides the aforementioned different national requirements, there is a European initiative at CENELEC, the European Standardisation organisation, in the field of electrical engineering to develop common European interconnection requirements. The CENELEC TC8X WG03 is charged with providing a Technical Specification for "Requirements for the connection of generators above 16A per phase to the LV distribution system or to the MV distribution system".

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It is important to harmonise these requirements in order to guarantee a common behaviour of all generators connected to the UCTE grid. Several DERlab members are actively participating in this working group.

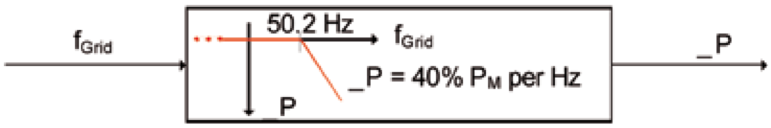
A major working point within the TC8X WG03 is grid support of distributed generators. On the one hand, in the steady-state case, grid support should be provided by contributing to the voltage control through the injection of reactive power. In the transient case, on the other hand, grid support can be performed by staying connected (so called Fault-Ride-Through (FRT) behaviour) and by injection of short circuit current during a grid fault. Working group activities show that many challenges have been occurring due to the varying needs of European countries and their network systems. This can be exemplified inter alia by different FRT curves (see Figure 2) of existing European grid codes.

The Technical Specification also handles testing and commissioning. The intention is to describe common test procedures that can be carried out in European testing laboratories with comparable results. Therefore, DERlab is also carrying out Round-Robin-Tests with PV inverters with the aim of identifying differences in the interpretation of testing procedures as well as differences in test setups.

Interconnection requirements in Germany: the new medium voltage grid code

The developments in Germany are presented here as an example to illustrate new grid code requirements.

Based on the TransmissionCode 2007 and the "Guideline for connection and parallel operation of generators using renewable energy at the high voltage (HV) and extra high voltage (EHV) network", similar requirements concerning the



$$\Delta P = 20\ P_M \frac{50.2\,Hz - f_{Grid}}{50\ Hz} \quad at\ 50.2\ Hz \le f_{Grid} \le 51.5\ Hz$$

P_M Currently Available Power

_P Power Reduction

f_{Grid} Grid Frequency

No restrictions in the range of $47.5\ Hz \le f_{Grid} \le 50.2\ Hz$

Disconnection at $f_{Grid} \le 47.5\ Hz$ and $f_{Grid} \ge 51.5\ Hz$

Figure 3. Active power droop characteristic in case of over frequency according to the German guideline for connection to the medium voltage distribution network [3].

grid-supporting electrical behaviour of distributed generators have been transferred to the Medium Voltage (MV) network [3]. PV systems that are installed after 1st January 2009 and grid-connected to the MV level are obliged to meet the following grid-supporting requirements in normal operation conditions:

- Limitation of power quality characteristic parameters
  - Limitation of steady-state voltage change of 2% of the nominal value
  - Limitation of voltage fluctuations due to switching operation
  - Limitation of long-term flicker
  - Limitation of current harmonics, interharmonics and higher frequency components up to 9kHz.
- Active power control (reduction)
  - Remote set point control by the DSO for power generation limitation in case of network congestions or danger of power system collapse
  - Automatic reduction of active power generation according to active power droop characteristic (Figure 3) in situations of over-frequency.
- Reactive power control
  - Set point control for voltage stability, also remotely by network operator
  - Minimum power factor of 0.95.

Figure 3 depicts the active power droop characteristic in case of over-frequency. All distributed generators must have the capability to reduce their power generation when the grid frequency exceeds the value of 50.2Hz. The reference value for the active power reduction ΔP is the currently available power generation value (PM) at the point in time when the grid frequency is equal to 50.2Hz. This active power reference value must be reduced at least with a coefficient of 40 %/Hz grid frequency deviation from 50.2Hz. If either the grid frequency increases to values equal to or higher than 51.5Hz or decreases to values equal to or less than 47.5Hz, the generation unit has to be disconnected.

"Distributed generators have to contribute to voltage stabilisation in order to avoid disconnection in the case of voltage dips."

The dynamic (transient) grid-supporting features are requested from January 1st 2010 in case of voltage dips at the MV level due to grid faults at the HV and EHV network. In detail, the requirements are:

- Fault-Ride-Through Capability, with:
  - No disconnection of the generation due to the voltage dip
  - No change of active power generation

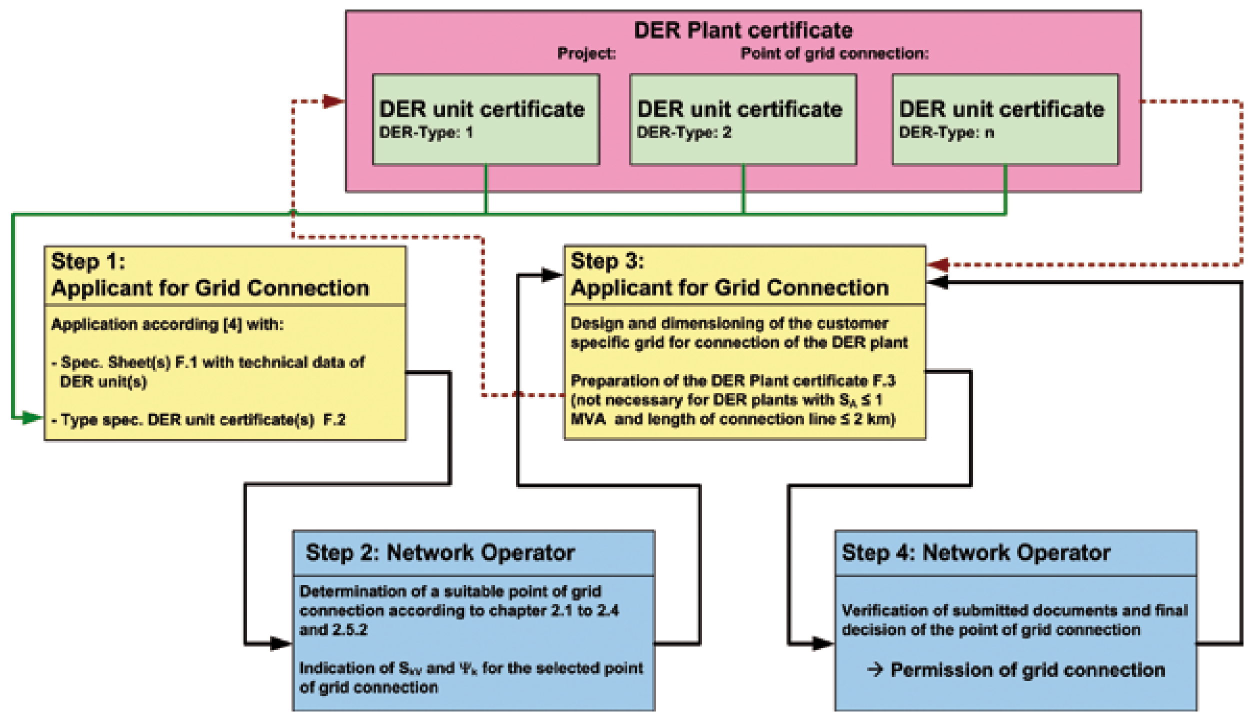


Figure 4. New procedure for the realisation of an interconnection of generators to the MV grid according to the German MV guideline.

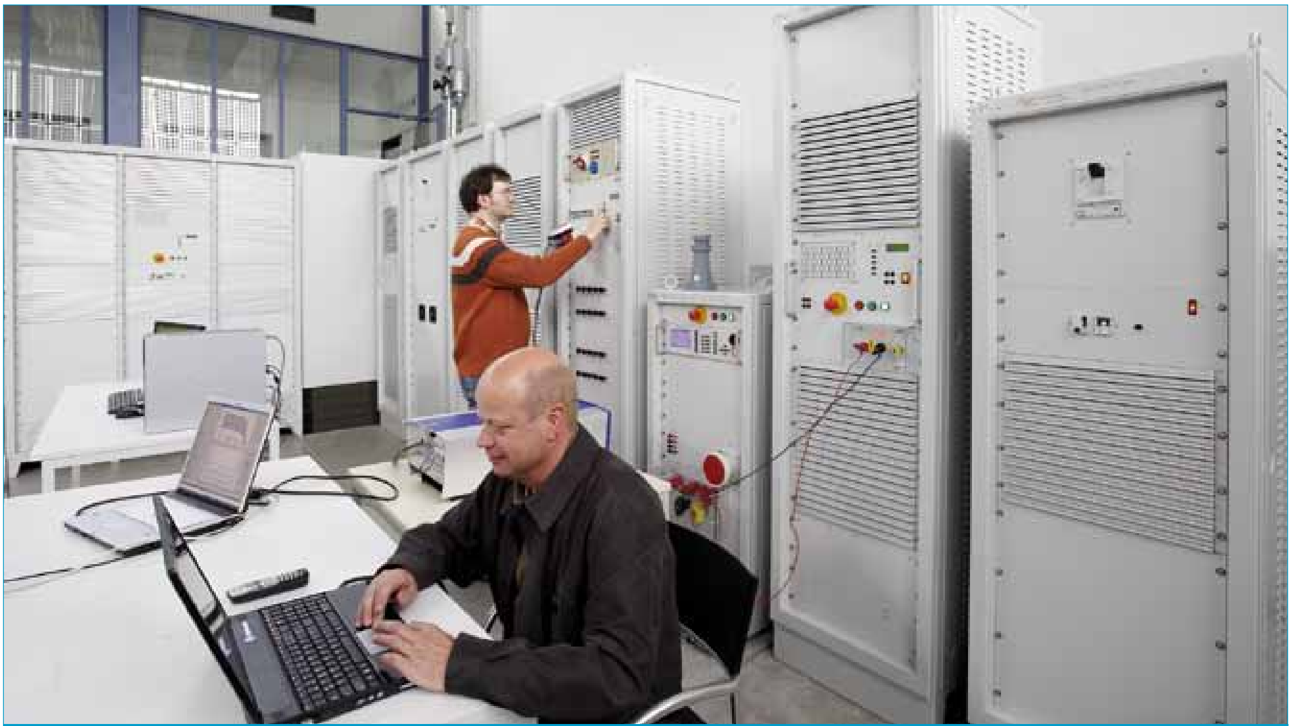


Figure 5. ISET's facility for PV inverters to test conformance with interconnection requirements.

before and after the fault for frequency stabilisation

- Feed-in of reactive power during the fault for voltage stabilisation
- Limitation of short-circuit current if necessary.

Thus, in addition to the stationary voltage support, distributed generators also have to contribute to voltage stabilisation in order to avoid disconnection in the case of voltage dips. The objective of this requirement is to prevent large power system collapse when a sudden power loss challenges the limited primary reserve for frequency stabilization. Depending on the fault conditions (voltage depth and fault duration), distributed generators are requested to "ride through the fault"; they are not allowed to disconnect from the grid and must feed in the same active power directly after the fault as before.

Proving compliance with the German grid code requirements

According to the BDEW guideline, a proof of compliance with the requirements is requested for all generating units versus generating plants. A "generating unit" is a single energy-generating unit, while a generating plant is the combination of several units including internal network and additional equipment to realise the grid connection.

For single generating units with rated power less than 1MVA and a connection line less than 2km, it is sufficient to show compliance with the requirements by a type-specific generating unit certificate. In the case of photovoltaic systems, this could be a certificate provided to the customer or by the manufacturer of the PV inverter. For systems consisting of several units, a site-dependent plant certificate is required that confirms the conformance of the plant with the requirements. Figure 4 shows the procedure to follow for a grid-connection request.

The German grid code requires testing according to 'FGW-TR3' procedures [8]. These were originally developed for wind generators and are currently being extended to be applicable to other generating technologies. In November 2008 a working group was founded to address photovoltaics-specific questions. A first finding of this group is that the test of a PV generating unit can be done independently of the type of modules used only by testing the PV inverters. The revision of two other FGW technical guidelines was recently finished and have been coming into effect from May 2009. In addition to FGW-TR3, there is an 'FGW-TR 4' guideline concerning simulations [9] – of importance for the plant certificate, which is partly based on simulation calculations. For these calculations, validated models of the generating units have to be used. Finally, the 'FGW-TR8' [10] describes the procedure of the certification process.

Beyond grid codes: the DERlab white book on static grid converters

Further to the new grid-code requirements, a DERlab initiative has been initiated to produce an "International White Book on the Grid Integration of Static Converters". The aim of the white book is to describe medium- to long-term harmonisation needs for the behaviour and technical interfaces of grid-connected static converters. The white book should support the preparation of international standards that describe controllable power units for:

- Grid operators to assure grid compatibility of the new power devices that might contribute with ancillary grid services;
- Manufacturers of static converters for producing products that are applicable for the world market; and
- Operators of such devices to have devices available that are of well-defined quality/compatibility and that can be used efficiently.

> "The new requirements will in many cases require fundamental changes to the design of devices in order to realise the additionally required functionality."

The white book on static converters features the following three sections:

- Ancillary services
- Behaviour under fault conditions
- Communication and control

The draft of the white book is available for international discussion via the DERlab web site and open to further contributions.

Conclusions

New grid-code requirements recently introduced in some European countries are an important step towards a better integration of distributed power generation and renewables into the electric power system. However, for a wide deployment of distributed generation and renewables, it is also vital to harmonise DER interconnection requirements on a European level and to bring in line the different interests of manufacturers, decentralised power producers and network operators.

Further to the repercussions for PV systems and particularly for the inverters, which incorporate the interface to the network, the new requirements will in many cases require fundamental changes to the design of devices in order to realise the additionally required functionalities.

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