New German Grid Codes for Connecting PV Systems to the Medium Voltage Power Grid

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***Abstract* – The penetration of renewable energies in the power grids has been increasing in the last couple of years due to successful regulations like the Renewable Energy Law (Erneuerbare Energien Gesetz – EEG) in Germany and comparable regulations in Spain and elsewhere. This expansion of renewable energies, especially photovoltaic (PV) systems, can only happen due to an unlimited access to the power grid. A high penetration of renewable energies harbors the risk of grid instability in case the generating plants are not able to support the grid. On this background, the German Association of Energy and Water Industries (BDEW) introduced in 2008 the new grid codes for connecting power plants to the medium voltage power grid. This paper will outline the new rules with respect to PV systems.**

***Index Terms* — Grid Code, Medium Voltage**

I. Introduction

Photovoltaic systems play a special role amongst other renewable energies: most of the generated power is feed-in decentralized in the low- or medium-voltage network close to the consumers, thus transmission lines are hardly loaded by PV power. Further on, PV power is produced during the day, when the electricity demand is high, thus it is valuable peak current. Today generating plants connected to the low- and medium-voltage power grid do not contribute to the grid stability. To prevent grid instability due to a high penetration of renewable energies, the new German directive for connecting generating plants to the medium-voltage power grid [1] has been released. It summarizes the main points that have to be taken into account when connecting generating plants to the medium-voltage power grid. The grid code serves the network operator as well as the project designer and the manufacturer as a planning document and decision guidance.

Basis for the directives are the findings during the development of the grid codes for connecting renewable energy plants to the high-voltage grid [2]. This has been adapted to the needs of the medium-voltage grid.

As in the high-voltage level, the generating plants connected to the medium voltage networks have to support the grid stability and must not disconnect from the grid during a fault, as was common practice previously. This fact substantially influences the plant design.

The aim of this directive is to keep the safety and reliability of the network operation with a growing share of decentralized generation plants in accordance with the requirements of the Energy Economy Law (Energiewirtschaftsgesetz – EnWG) and to keep the voltage quality in accordance to the limits formulated in the DIN EN 50160.

II. Scope of Directive

Generating plants in accordance to this directive are for example:

- Wind power plants
- Hydropower plants
- Combines heat and power plants
- PV systems

A generating plant may consist of a single or multiple generation units (e.g., a PV park). The electrical energy can be produced by synchronous or asynchronous generators (with or without converters) or DC generators (e.g., PV) with inverters.

The requirements of this directive can also be achieved by connecting additional equipment (such as stabilizers, etc.). These are then part of the generating plants and have to be considered during connection, operation and certification of the plant.

The minimum and maximum power at which the plant has to be or can be connected to the medium voltage network depends on the respective network conditions. A blanket claim is not possible. Possible values are in the range of 500 kW up to over 100 MW. In some cases this can only be determined by a calculation of the network operator.

All requirements of this directive have to be complied with from 1st of January 2009 (for PV 2010). Exceptions are the requirements to the dynamic grid support (Fault-Ride-Through). This will be valid from 1st of January 2010 (for PV 2011). Existing generation units operate in non-compliance under a continuation permit.

III. Dynamic Grid Support

By dynamic grid support, voltage stability during voltage drops in the overlaying high-voltage grid is meant and often referred to as Fault-Ride-Through (FRT). Due to an increasing penetration of decentralized generating plants in the medium-voltage grid, it is necessary to include these plants in dynamic grid support.

This means generating plants have to be able:

- to stay connected during a fault,
- to support the voltage by providing reactive power during the fault
- to consume the same or less reactive power after the fault clearance

There are two types of generating plants defined. Type 1 plants are all plants with a synchronous generator directly connected to the power grid, whereas type 2 plants are all other generating plants (PV systems, et al.).

Figure 1 shows the limiting curves of type 2 plants during a fault. They must not disconnect during a voltage drop down to 0% U_c with a duration of ≤ 150 ms. Underneath the blue line shown in figure 1, there are no requirements to remain grid-connected. Voltage dips with values above borderline 1 may not lead to disconnection or instability. Voltage dips above borderline 2 and below borderline 1 should also be ridden through. In this area of operation, the following options are available, based upon an agreement with the network operator:

- Feed-in of a short circuit current
- Depending on the concept of grid connection, borderline 2 can be moved
- Short-time disconnection of up to 2 s

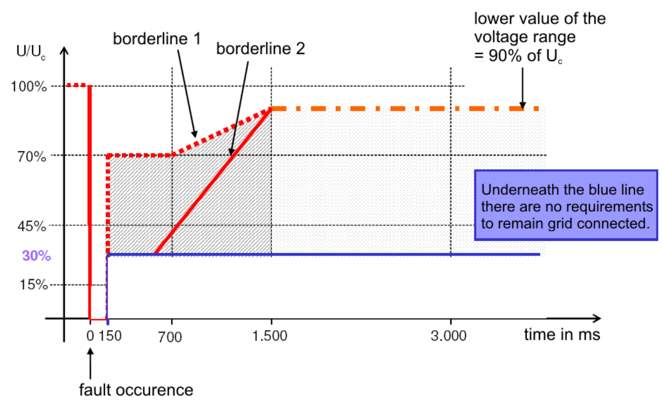

Fig. 1. Limiting curves of voltage at the grid connection point for a generating facility of type 2 in the event of a network fault [1]

Below borderline 2 a short-time disconnection can be carried out in any case. Longer disconnection times are also possible.

During a symmetrical fault, the generating plant must support the network voltage by means of additional reactive current. Voltage control according to Figure 2 shall be activated in the event of a voltage drop of more than 10% of the effective value of the generator voltage. This voltage control must ensure the supply of a reactive current at the low-voltage side of the generator transformer with a contribution of at least 2% of the rated current per percent of the voltage drop. The facility must be capable of feeding the required reactive current within 20 ms into the network. If required, it must be possible to supply reactive current of at least 100% of the rated current.

In case of an unsymmetrical fault the reactive current must not exceed values that cause voltages higher than 1.1 U_c in the non faulty phases.

These requirements do not influence the dimensioning of the PV inverter, but have of course to be included in its control algorithm.

IV. Short Circuit

The short circuit current of the network in the area of the grid connection point is increased by the short circuit current of the generating plant and can thus exceed the limits of the power grid. Thus it is essential to take the short circuit into account when connecting a generating plant to the grid. The short circuit of a synchronous generator is typically eightfold the rated current, whereas generators with converter like PV have typically the same short current as rated current. Thus there is no necessity for PV to limit the short circuit current by e.g. an external current limiter.

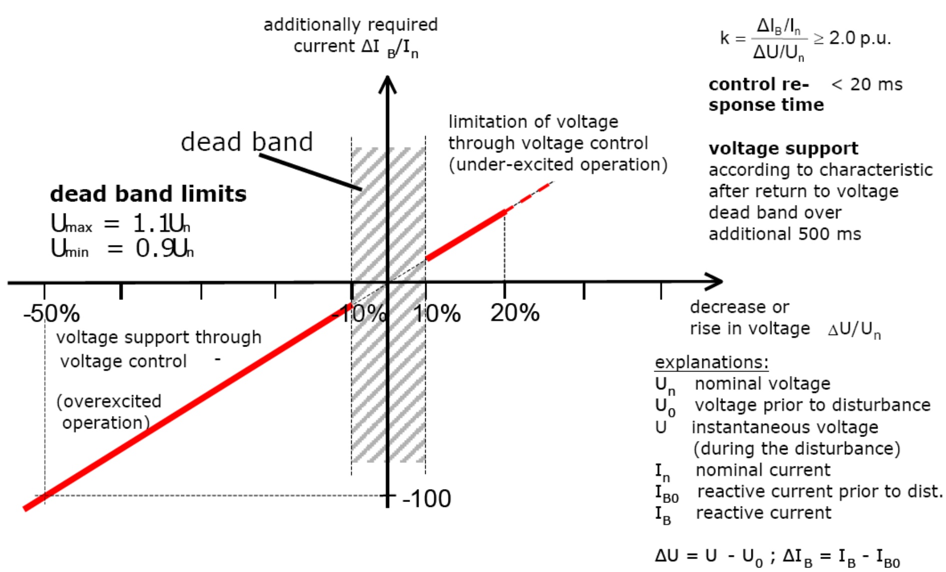

Fig. 2. Principle of voltage support in the event of network faults [2]

V. Active Power Control

The generating plant must be able to reduce its power output. The following cases allow the network operator to temporarily limit the feed-in power or disconnect the plant:

- risk of unsafe system operation,
- risk of bottlenecks and congestion in the network,
- risk of unwanted islanding,
- risk of static or dynamic grid instability,
- risk of instable system due to frequency increase,
- carry out repairs or construction,
- in the context of production management, feed-in management, and network security management.

The plant must be capable of power output reduction steps of 10% (or smaller) of the agreed rated output power. A setpoint given by the network operator must be reachable from any operation point in any operation mode. Commonly used setpoints at present time are 100%, 60%, 30%, and 0%. The network operator does not interfere in the control of generating plant, but only gives a signal for the setpoint.

According to Figure 3, all generating units have to reduce their power output above a system frequency of 50.2 Hz. The power has to be reduced with a gradient of 40%/Hz of the instantaneously available power. The output power is only allowed to increase again as soon as the frequency is below 50.05 Hz. Above 51.5 Hz and below 47.5 Hz the plant has to disconnect from the grid.

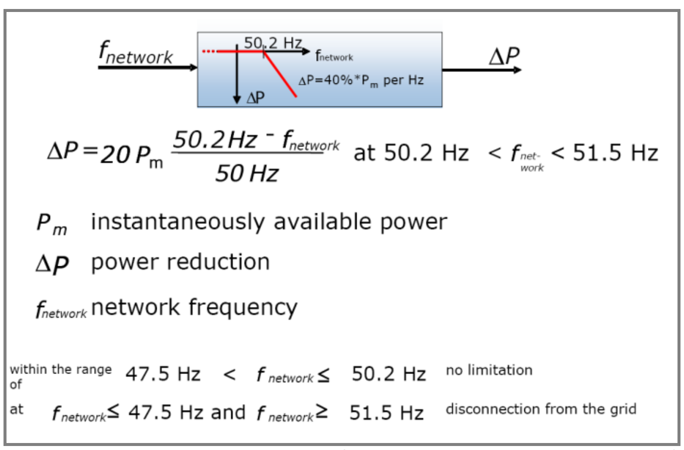

Fig. 3. Active power reduction of generating units in the case of overfrequency [2]

These requirements can fairly easily be fulfilled by a PV system. A new control scheme has to be included in each inverter to control the operation point of the PV string and thus the power output. A communication based solution like sending new setpoints would be too slow to react in sufficient time on a disturbance in the power grid [3].

VI. Static Grid Support by Reactive Power Control

By static grid support voltage stability in the medium voltage grid under normal operation is meant. Slow changes in voltage have to be kept in acceptable limits. In case of operation requirements and on demand of the system operator generating plants have to supply static grid support.

The generating plant has to be able to provide reactive power in every operating point according to the following displacement factor at the grid connection point:

$$\cos\varphi = 0.95_{\text{underexcited}} \text{ to } 0.95_{\text{overexcited}}$$

Today PV systems are designed to produce active power only. Reactive power is avoided due to losses in the inverter, lines and transformers. To meet the requirements of the grid codes, the inverter of a PV system has to be designed bigger. A 500 kVA inverter will then be designed for a rated active power of 475 kW. Overall, an increase of system costs has to be expected. Reactive power has only to be provided during feed-in operation, so there is no need to provide reactive power during the night [3].

The reactive power set point can be either fixed or adjustable by a signal from the network operator. The setpoint value is either

- a fixed displacement factor cos φ or
- a variable displacement factor depending on the active power cos φ (P) (Figure 4) or
- a fixed reactive power value in MVar or
- a variable reactive power depending on the voltage Q(U).

The generating plant must be able to traverse the agreed area of reactive power within a few minutes and as often as required. If the network operator provides a characteristic, each value resulting from this has to be automatically set within 10 seconds.

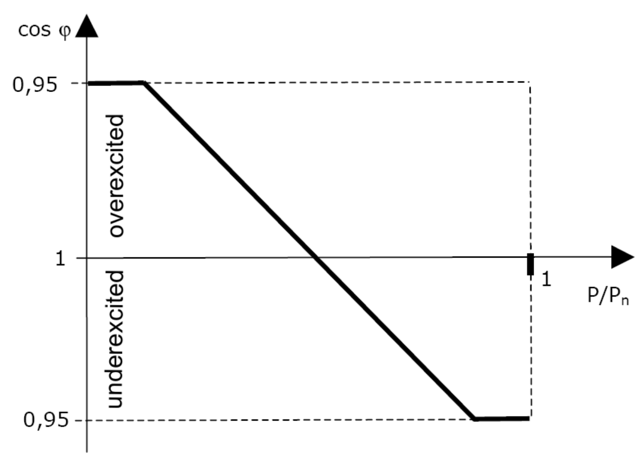

Fig. 4. Example of a cos φ (P)-characteristic [1]

VII. Outlook

Besides the German grid code for the medium voltage level, there are other countries like France who have released their own grid codes. In countries like Spain and Greece, where there are many big PV systems, a directive is expected soon [3].

A German grid code for the low-voltage level is under way. The first draft is very similar to the directive for the medium-voltage level, which is highly controversial, due to the comparably high costs for small PV roof systems.

VIII. Conclusions

PV is ideal for grid integration as it is decentralized power produced close to the consumers and mainly providing peak current.

The new German grid code for connecting PV systems to the medium voltage grid is an instrument for insuring grid stability also with high penetration of PV power and other renewable energies.

The function range to meet the requirements of the grid codes is new ground for PV systems and thus a big challenge for the manufactures of PV systems. The size of inverters, transformers and lines will increase due to required reactive power supply. Otherwise there is no major impact on the design of the inverter, only the control system has to be adapted. Simulations with power system calculation tools like DIgSILENT PowerFactory can help in this process.

The first standard equipments with full functionality will be available in 2010 the earliest, according to [3].

IX. References

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X. Biography

Eckehard Troester was born in Marburg in Germany, on December 7, 1975.

He holds a Master of Electrical Engineering from Technische Universität Darmstadt, Germany. He is currently working on his PhD, which will be finished in 2009. His research focuses on electrical power systems, renewable energies and electrical machines, especially wind power generators. He has worked as a scientific assistant at the Institute of Renewable Energies, Darmstadt. Since 2007 he works for Energynautics.