An Overview of the Present Grid Codes for Integration of Distributed Generation

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ABSTRACT

Power systems are passing through profound changes, mainly due to the liberalization of electricity markets, the depletion of primary energy resources and the concern about climate change. The aforementioned premises have created a favorable frame for development of distributed energy resources. As a result, the level of integration of distributed generation (DG) technologies, especially in distribution networks has increased. In order to counteract the impact of DG on the stability and reliability of power systems, the transmission and distribution systems operators have started to reconsider and update their national grid codes. This paper provides an overview of the most recent and comprehensive grid codes regarding the DG integration at distribution level.

1. INTRODUCTION

Grid codes are not new topics in the power systems literature. They started to appear more than 15 years ago, for transmission systems, as a set of technical guidelines and operation specifications which large conventional power plants needed to comply with. The grid codes differed from country to country due to the different regulations laws and different characteristics of their national power systems. At distribution power system (DPS) level, grid codes were mainly used to specify and design the guidelines which the distribution network operators (DNOs) will apply in the planning and development of DPSs, with the compliance of end users (loads). In today's context, when generation had moved, also to lowest levels of the power systems (medium and low voltage levels), the loads have transformed from passive components into active ones and power systems into entities with a bidirectional energy and informational flow. When this change occurred in the DPS, the DNOs assessed normally the DG integration by conducting simple integration studies (load flow, basic power quality studies) because the amount of DG integration was small and the stipulated technical guidelines were simple or even absent [1]. Currently, when the worldwide share of DG is increasing, awareness grows in the concerns of network operators for the need to revise and upgrade the DG connection guidelines, in order to achieve a stable and proper operation of the overall power systems. In the last years, a harmonization work of grid codes related to DG has been carried out at international level and the results are being shaped into a set of standards and recommendations. Most of them have become part of the national policies regarding DG or reference points for developing new ones (e.g.: IEEE-1547, IEC-62109, IEC-62477, ENTSO-E draft grid code). This paper will give an overview of the grid codes elaborated at DPS level regarding: frequency and voltage operation areas, active and reactive power control, voltage grid support during balanced disturbances and reactive current injection or absorption. The surveyed grid codes are from countries which faces large amount of DG integration, like Canada (Hydro-Québec, Manitoba Hydro), Denmark, Germany, Ireland, Norway, Spain and United Kingdom. Also the draft grid code of the ENTSO-E and IEEE Standard 1547 will be investigated.

2. COMMON REQUIREMENTS FOR GRID CODES RELATED TO DG

In this paper the following set of common technical connection requirements will be surveyed, based on the operation states in which a DPS can be found:

a) Steady state operation:
   - Frequency and voltage ranges
   - Active power output control
   - Reactive power output control

b) Dynamic operation during grid disturbances:
   - Grid voltage support during disturbances
   - Reactive current injection or absorption for fast acting voltage control
   - Synthetic inertial capability or inertia emulation
   - Oscillations damping in DPS

The grid codes reviewed are listed in the Table I.

Table I. Grid codes related to DG reviewed in paper

Country		Grid Codes related to DG
Canada	Hydro-Québec (February 2009)	" Requirements for the Interconnection of Distributed Generation to the Hydro-Québec Medium-Voltage Distribution System " [2]
	Manitoba Hydro (January 2003)	" Interconnection Guideline for Connecting Distributed Resources to the Manitoba Hydro Distribution System " [3]
Denmark (October 2008)		" Technical Regulation for Thermal Power Station Units larger than 11 kW and smaller than 1.5MW " [4]
Germany (June 2008)		" Guideline for generating plants' connection to and parallel operation with the medium-voltage network " [5]
Ireland (March 2011)		" EirGrid Grid Code " [6]
Norway (October 2006)		" Tekniske retningslinjer for tilknytning av produksjons-enheter, med maksimum activ effektproduksjon mindre enn 10 MW, til distribusjonsnettet " [7]
Spain (October 2008)		" Technical requirements for wind power and photovoltaic installations and any generating facilities whose technology does not consist on a synchronous generator directly connected to the grid " [8]
United Kingdom (June 2009)		" The Grid Code " [9] " The Distribution Code " [10]

In addition, two international publications, presented in Table II, related to technical requirements for DG integration was surveyed in this work.

Table II. International grid codes related to DG integration

ENTSO-E (January 2012)	" Requirements for Grid Connection Applicable to all Generators " [11]
IEEE-1547 (July 2003)	" Standard for Interconnecting Distributed Resources with Electric Power Systems " [12]

3. REQUIREMENTS FOR STEADY STATE OPERATION

In steady state operation of a DPS, DG units are required to operate (in ranges) around the rated voltage and frequency desired to be achieved in the point of common coupling (PCC), in order to maintain the security of operation and power quality. Due to the fact that the electrical dynamics associated with DPSs have different time scales with respect to their speed of occurrence [13], the frequency-voltage steady state operation ranges are mainly presented in all surveyed grid codes in the next four operation areas:

- A continuously operation area
- Operation areas where DG can operate but with output reduction (the restrictiveness and scale limits of these operation areas differ from country to country)
- Operation areas where is possible to function but for which no output reduction or no requirements are defined
- Areas where immediate disconnection is required

From the survey it can be concluded that most demanding grid codes regarding frequency ranges are those from the UK, Ireland and Denmark. The span of operation areas are between 47 Hz and 52.0-53.0 Hz. In terms of voltage limitations during normal steady state operation the most comprehensive grid code is that of Hydro-Québec, where the requirements are for a range between 0-140 percent of nominal line voltage.

The ENTSO-E draft code is one of the most comprehensive grid code related to frequency ranges steady state requirements for DG units connected below 110 kV covering almost entire European synchronous area. The voltage and frequency limits are defined by Table 2 and Table 5.2 in reference [11]. Table 5.2 defines voltage ranges for generation units connected above 110 kV, but these limits are also required for DG units connected below 110 kV for black start and island operation capabilities. Otherwise, ENTSO-E draft grid code states that DG units must disconnect for specified voltages. [11] Figure 1 depicts an example for voltage-frequency ranges related to steady state operation of DG units, as defined by Denmark's TSO: Energinet.dk. [4]

Voltage levels presented by Figure 1 are defined in Table 1 and Table 2 in reference [4].

Active power-frequency control in steady state operation can be defined in case of DPSs with DG integration as the capacity of units to control the active power production in order to keep the frequency within rated limits and to maintain the regulatory obligations commissioned from the DSO [9]. This requirement is meant to ensure a stable operation during islanding and is also related to the possibility of DG units to provide ancillary services.

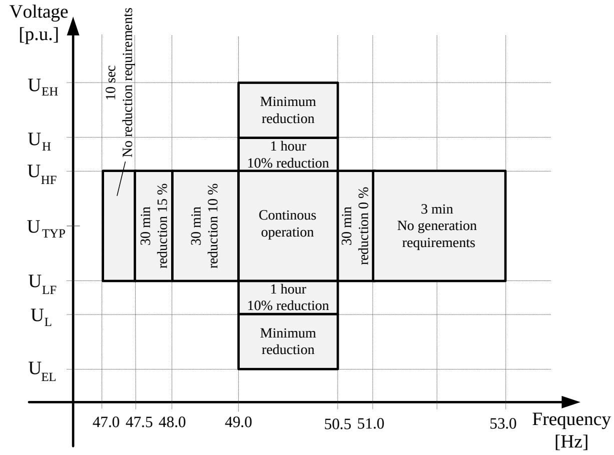

Figure 1. Voltage-frequency steady state operation areas defined by Energinet.dk (for thermal generation units between 11 kW and 1.5 MW) [4]

Some active power curtailment requirements as mentioned in different grid codes are presented in Table III.

Table III. Active power ramp ranges

Country		Active power ramp range
Canada	Hydro-Québec	Ramp up or down in an adjustable 2 to 60 minutes, from minimum 0 MW(stopped) to maximum power plant output [2]
Denmark		For voltages representing 0.9 pu and 1.1 pu of nominal voltage, the reduction of maximum power must not be greater than 10 % [4]
Germany		Must be able to reduce active power in steps of 10 % of the agreed capacity with the network operator [5]
Ireland		Requires from DG units to ramp up and down a capacity of not less than 1.5 % of the registered capacity per minute when the unit is in normal dispatch condition [6]
Spain		The ramp up rate value is maintained at 10 % and the duration of this action is 250 ms [8]
ENTSO-E draft code		Requires from the DG units ramp ranges between 2-10 % with a full activation time frame 6-30 sec [11]

Regarding the second control strategy related to the steady state operation: **reactive power-voltage**, can be define as property of the DG units to maintain the voltage level within limits at the PCC by injection or absorption of reactive power as long as the voltage control equipment is not saturated [9]. In Table IV some reactive power control requirements which DG units need to comply when are summarized:

Table IV. Reactive power control requirements for DG

Country		Reactive power control requirements for DG
Canada	Hydro-Québec	Must have the capability to exchange reactive power with DPS at an over-excited or under-excited power factor less or equal with 0.95 [2]
	Manitoba Hydro	- DG based on synchronous generator, must control the PCC voltage in the ranges within 95-105 % of the rated voltage [3] - DG based on induction generators or a

	power electronics interface must to correct the power factor to ±0.95 or better [3]
Denmark	DG unit must ensure a reactive power production with power factor (related to tan φ) within the range -0.20 and 0.40 with respect to the rated active power and within the rated limits for voltage [4]
Germany	DG unit can be operated with reactive power output corresponding to a power factor (related to cos φ) in the PCC between 0.95-underexcited and 0.95 overexcited [5]
Ireland	DG unit must to ensure at the maximum active power production a reactive power of 30 % with respect to the rated one, in both leading and lagging mode, power factor between 0.85-underexcited and 0.85-overexcited [6]
Norway	DG unit must be dimensioned to ensure a power factor of 0.95-1.0 at maximum active power production [7]
Spain	DG unit must exchange reactive power with DPS at any active power production up to 20 % from the rated value. Lower than 20 % the capacity for reactive power exchange can decrease in a linear dependency down to zero [8]
UK	DG units must ensure a transfer of reactive power in the PCC at rated active power output at a power factor between 0.95-leading and 0.95-lagging. This reactive power limits applies for active power production of DG units up to 20% of the rated active power [9]

ENTSO-E draft code presents a survey of the aforementioned requirements related to reactive power control requirements in steady state operation and in IEEE standard 1547 there are no specifications.

4. REQUIREMENTS FOR DYNAMIC OPERATION DURING RELATED DISTURBANCES

A DPS is a dynamic system and is affected continuously by disturbances. In order to remain stable after being subject to disturbances some transient requirements (during a fault occurrence and post fault state) are imposed to DG units connected in DPS. Most of the reviewed grid codes require that the operation of the unit continues during the fault even if the voltage is dropping to inadmissible values or even to zero.

The **fault ride through (FRT) capabilities** can be defined as voltage-time profiles presenting the course of grid voltage as function of time in the PCC with the DG unit. This grid voltage in the PCC is considered for the phase which sustains the largest voltage drop during the fault [11]. This curve is presented for the overall fault time range: before, during and after the fault occurs. In Table V a summary of FRT capabilities is presented (including also FRT capabilities for wind generators). Moreover, as stated in Table V, the guidelines of Spain, German and ENTSO-E require DG units to support the grid during fault by injecting a specified amount of reactive current.

As this injection must be done fast with the rapid increasing of the reactive power generation, the amount of

Table V. FRT requirements for DG in different national grid codes

Country	Fault ride-through capability: Duration of fault	Voltage drop level	Post fault time recovery	Reactive current injection
Canada Hydro-Québec	150 msec	0%U_{rated}	0.18 sec	–
Denmark	50 msec	20%U_{rated}	1 sec	–
Germany	150 msec	0%U_{rated}	3 sec	Up to 100%
Ireland	600 msec	50%U_{rated}	–	–
Spain	500 msec	20%U_{rated}	0.5 sec	Up to 100%
UK	140 msec	15%U_{rated}	1.2 sec	–
ENTSO-E	40 msec	15%U_{rated}	1.5-3 sec	Up to 100%
IEEE 1547	–	–	–	–

active power can be reduced. Immediately after the fault is cleared, the unit will restore the active power production prior to the fault in a ramp manner within predefined values [5], [8], [11].

In the Spanish grid code the process of reactive current injection or absorption during a disturbance (when the voltage drops below 0.85 pu) is similar with the process of automatic voltage regulator for conventional synchronous generation. In this case the controller is designed as a PI controller, as presented in Figure 2. The controller has as output the instantaneous reactive current I_r limited by the saturation values (dependent of voltage) $I_{r,max}$ and $I_{r,min}$, V_c is the voltage set point, V is the voltage in the PCC (all parameters are rms values). [8]

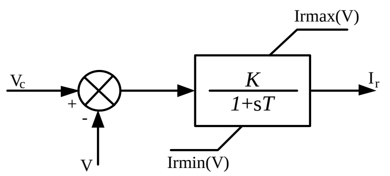

Figure 2. Simplified block diagram of an error proportional regulator for reactive current injection or absorption as defined in the Spain grid code [8]

The ENTSO-E draft grid code defines the reactive current injection or absorption as fast acting voltage control. According to this requirement the control is activated if the voltage is deviating from the steady state value between 0 and ±10 % [11]. By activating the fast acting voltage control, a contribution of reactive current will be supplied at the low voltage side of the first step up transformer. This contribution must be of a least 2 % of the rated current per percent of voltage deviation and DG unit must be capable of providing this reactive current in 40 ms after the occurrence of disturbance. Also according to the same reference [11], the supplied reactive current during the fault duration should not be less than 1 pu of the short term dynamic rating of equipment, delivered when the voltage drops below 40 % of steady state value at PCC. The principle of fast acting voltage control or fast reactive current injection or absorption, as presented in the ENTSO-E draft grid code, is depicted in Figure 3.

Some new features are starting to be developed in the recent grid codes, like inertia emulation and oscillations damping in DPS [8] [11].

The **inertia emulation** is referring to capability of DG units (connected via frequency converters) to generate active power variations with respect to the derivative of frequency in the PCC or in the form of some predefined curves; reference [11] presents an example of such a curve.

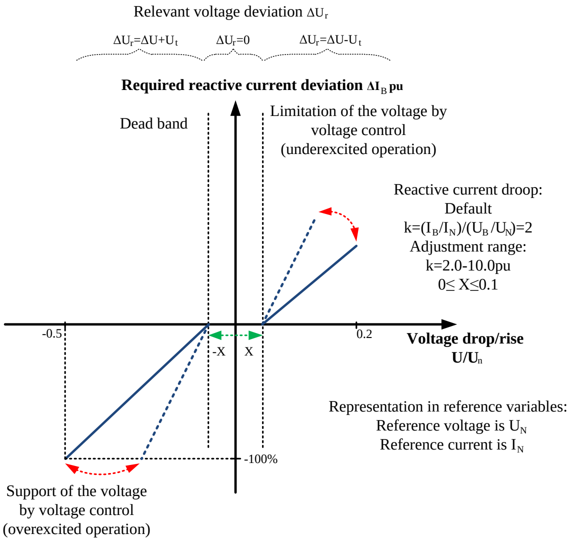

Figure 3. Voltage support principle as defined in ENTSO-E draft grid code [11]

Regarding **damping of oscillations** in DPS, some grid codes state that the DG units can be required to be equipped with power system stabilizers in order to damp power oscillations in frequency range between 0.15-2 Hz, as reference [8] requires.

5. CONCLUSIONS

In this work, an overview of different national grid codes related to the integration of DG units has been presented. The surveyed grid codes are from both transmission and distribution level of the power system, as some of the countries introduce requirements for DG connection in their national transmission grid codes.

This is mainly due the fact that DG penetration grade in their national power system is not so high and the need for a distinct distribution grid code has not been necessary. In the survey a comparison and analysis of the main steady state and transient requirements was conducted.

It should be observed that the technical connection guidelines in the presented national grid codes are varying with different countries. The principle reasons for this are the grade of DG penetration and the robustness of the national power systems. Also, it can be concluded from this overview that in latest grid codes related to DG integration, system operators are asking for more demanding capabilities during fault occurrence in the grid (fault ride through, reactive current injection or absorption). These requirements were absent in previous versions of grid codes, where a disconnection of the DG unit was permissible. It was observed that most of the grid codes (especially those issued in country with large amount of DG penetration) are making a clear distinction in the requirements between DG units which presents a power electronic interface and those based on synchronous generators. Also, the trend is to divide these requirements with respect to the specifics of the generation site where DG units are installed in: onshore and offshore requirements (offshore requirements are related to wave energy and offshore wind power plants). Some international publications (from IEEE and ENTSO-E) were also found interesting, having a regulatory harmonization approach and presenting some new features for DG connection requirements.

REFERENCES

[1] Knazkins, V.: "Stability of power systems with large amounts of distributed generation", PhD Thesis published at KTH University, Stockholm, Sweden, 2004, 1-2. ISBN 91-7283-876-0.

[2] Requirements for the Interconnection of Distributed Generation to the Hydro-Québec Medium-Voltage Distribution System, issued by Hydro-Québec Distribution, February 2009. Available online: http://www.hydroquebec.com/transenergie/fr/commerce/pdf/e1201_fev09_en.pdf

[3] Interconnection Guideline for Connecting Distributed Resources to the Manitoba Hydro Distribution System, issued by Manitoba-Hydro, January 2003. Available online: http://oasis.midwestiso.org/documents/Mheb/Interconnection%20Guideline%20for%20Connecting%20Distributed%20Resources%20to%20Manitoba%20Hydro%20Distribution%20System.pdf

[4] Technical Regulation for Thermal Power Station Units larger than 11 kW and smaller than 1.5MW, issued by Energinet.dk, October 2008. Available online: in http://www.energinet.dk/EN/El/Forskrifter/Technical-regulations/Sider/Regulations-for-grid-connection.aspx

[5] Guideline for generating plants' connection to and parallel operation with the medium-voltage network, issued by BDEW, June 2008. Available online: http://www.bdew.de/internet.nsf/id/A2A0475F2FAE8F44C12578300047C92F/$file/BDEW_RL_EA-am-MS-Netz_engl.pdf

[6] EirGrid Grid Code, issued by The EirGrid, version 3.5, March 2011. Available online: http://www.eirgrid.com/media/2011%20Mar%2008%20EirGrid%20Grid%20Code%20Clean%20Version%203.5.pdf

[7] Tekniske retningslinjer for tilknytning av produksjons-enheter, med maksimum activ effektproduksjon mindre enn 10 MW, til distribusjonsnettet; issued by SINTEF Energiforskning AS, October 2006.

[8] Technical requirements for wind power and photovoltaic installations and any generating facilities whose technology does not consist on a synchronous generator directly connected to the grid, issued by Red Electrica, October 2008, O.P. 12.2 Restricted to the technical requirements of wind power and photovoltaic facilities (draft). (translated in English by: www.aeolica.es)

[9] The Grid Code, Issue 4, revision 7, issued by National Grid Electricity Transmission plc, August 2011. Available online: http://www.nationalgrid.com/uk/Electricity/Codes/gridcode/gridcodedocs/

[10] The Distribution Code, Issue 16, by Energy Networks Association, August 2011. Available online: http://www.energynetworks.info/the-distribution-code/

[11] ENTSO-E Draft Network Code for Requirements for Grid Connection applicable to all Generators, 24 January 2012.

[12] IEEE Std. 1547/2003, Standard for Interconnecting Distributed Resources with Electric Power Systems, July 2003.

[13] Kundur, P., 1994, "Power system Stability and Control", EPRI power system engineering series. McGraw-Hill, p. 17-40, ISBN-13: 978-0-07-035958-1.