DG INTERCONNECTION STANDARDS AND TECHNICAL REQUIREMENTS: COMPARISONS AND GAPS

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ABSTRACT

The connection of distributed generation (DG) may change the operation and the topology of distribution systems. This may influence voltage control, protection regime, safety issues, etc. of the system when coupling, operating, and shutting down small generator units. Technical requirements and standards of DG interconnection are different from country to country, making international harmonization difficult. This paper aims to give an overview and to discuss those differences.

INTRODUCTION

Grid connection guidelines are still a major controversial subject with regard to distributed generation. The connection rules and technical requirements that differ from region to region make it all even more complicated. In order to allow a flexible and efficient introduction of DG, there is a need for a single document being a consensus standard on technical requirements for DG interconnection rather than having the manufacturers and the operators to conform with numerous local practices and guidelines. The standards must be transparent and nondiscriminatory for all players in the field. This contributes to the creation of competitive and environmentally minded market conditions. Standardization also helps DG technologies to become marketable by providing a foundation for certification, promoting international trade of uniform high-quality products and supporting transfer of expertise from traditional energy systems, reducing the unit cost considerably both for manufacturing and operation [1], [2].

A first attempt is the starting version of IEEE 1547 providing uniform criteria and requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the grid connection of DG. However, this guideline focuses on 60 Hz systems (American). When applying to 50 Hz systems, adaptations are necessary [3], [4].

At the international level, IEC has been developing many standards related to individual DG technologies rather than DG in general [5]. There are several guidelines for individual technologies such as wind turbines, photovoltaics and fuel cells. These guidelines can serve as input to develop a more general connecting guideline for all types of distributed generation systems and their interactions with the grid.

In Europe almost every country has its own technical requirements. There is still no general connecting guideline for all types of distributed generation systems. On the one hand, there is a very strong international transmission system connecting the continental European countries' power system, UCTE. On the other hand, the impact of DG is locally considered at distribution level. There is a critical need to have a common agreement on a single document on DG interconnection standard rather than having to conform to numerous local practices and technical guidelines. A draft version of prEN50438, concerning requirements for the connection of micro-cogenerators to public low-voltage distribution networks, is discussed by the European Committee for Electromechanical Standardization (CENELEC) [6].

This study aims to give an overview and comparison of different existing DG interconnection standards and technical guidelines. It may help to get a global view and then identify gaps that need to be filled and further investigated.

COMPARISON OF DG INTERCONNECTION STANDARDS AND TECHNICAL REQUIREMENTS

Installation

Maximum DG power installation

The capacities of transformers, cables and switchgears are used to determine the maximum power level of DG that can be installed. In Belgium, the installed capacity has to be smaller than the capacity of transformer of MV/LV or HV/MV transformer in (N-1) stage. In Italy, however, it should be smaller than 65% in medium voltage (MV) and low voltage (LV) systems while in Spain a value of 50% capacity of the substation in LV and 50% of transmission line in high voltage (HV) is used. Sometimes, depending on the thermal limit of system, an agreed apparent power is used to check whether it is acceptable or not.

Limits of short-circuit capacity are also used as a criterion.

The short-circuit power of the network with the supplementary short-circuit power added by DG must not exceed the switchgear's tripping capacity [7].

The voltage level is also used as a criterion to determine the maximum power of a DG unit allowed to be connected to a system. The connection of DG units must not lead the system voltages out of the operating limit in Belgian case.

The connection of DG may need re-enforcement of the distribution system, i.e. cables, transformers, switchgears, or other operating devices. The operators of DG units often have to pay for such reinforcement.

Voltage levels of DG connection

DG is often defined or considered to be connected to a low or medium voltage levels in the distribution system. However, no country limits the maximum voltage that DG is allowed to be connected to.

The voltage level is used to classify requirements for protection issues, maximum rated power level, synchronization, point of common coupling, etc.

In case of connection to the medium-voltage system, a transformer may be required in order to protect DG units by absorbing surges, to prevent zero-sequence current to DG units, and to reduce extra short-circuit current [7].

Power Quality

Harmonics

The level of harmonics produced by the DG should not cause any disturbances on the distribution system. As DG units are treated as loads in this respect, the total harmonic distortion (THD) in generally should be smaller than 5%. The IEEE 519-1992 requires specific values for different order harmonics and the total harmonic distortion (Table 1).

DG units using power electronic converters may inject harmonic currents in the network. The type and severity depend on the power electronic inverter technology and its connection configuration. Rotating generators can also be sources of harmonics, depending on the winding design, non-linear magnetizing (saturation), grounding, etc. They also alter the harmonic impedance of the network. In case triple harmonic currents are present, they add up in the neutral conductor of generators, when the neutral point is directly grounded.

Table 1: Harmonic current injection limits of IEEE 519-1992

< 11th	4.0 %
< 11th to < 17th	2.0 %
< 17th to < 23rd	1.5 %
< 23rd to < 35th	0.6 %
< 35th or higher	0.3 %
Total harmonic distortion	5.0 %

Flicker

Flicker can be the result of fast variations of power output of generators like wind turbines or rapid changes in load current like arc furnaces or induction motor starting leading to significant voltage changes on the feeder. In order to reduce or avoid flicker, many countries require the maximum installed power is several times smaller than the level of the short-circuit capacity at the power common coupling (PCC) point. The DG unit shall not create objectionable or observable flicker for other customers on the power system.

The IEC 61400-21 standard, applying power quality requirements for grid connected wind turbines, recommends to limit the flicker emission from a single wind turbine to P_{lt} = 0.25. The index refers to a weighted two-hour average of the flicker measured. It also recommends to limit the flicker due to the total amount of wind turbines in a medium-voltage network to P_{lt} = 0.5 at any node [5].

Power factor

Most utilities prefer DG units to operate as close to unity power factor as possible. The distribution system operator (DSO) may require the DG to install capacitors, if the technical conditions require so. The reactive power compensation is often located directly at the DG site and must not be connected to the network without the generator being active in order to prevent any over-voltage.

Technical requirements in France require large synchronous DG units to have some ability to supply and absorb reactive power proportionally to the rated active power. With induction generator based DG, self-excitation and compensation is done using capacitors.

The synchronous DG is preferred to maintain the power factor both leading and lagging in order to control the voltage at PCC. For the induction DG, the power factor should be higher than 0.86 in the Spanish case.

Direct Current

DC injection is an issue because of the economics of magnetic component design. The increased DC voltage has the potential to increase saturation of magnetic components, such as cores of distribution transformers. This saturation, in turn, causes increased power system distortion [4]. There is a concern that inverters without transformer interface may inject sufficient DC current into distribution circuits to cause distribution transformer core to saturate. Following IEEE 1547, DC currents injected by DG must be smaller than 0.5% of its rated current at the connection point. In the Belgian technical guideline, DC currents must be smaller than 1% of the rated current. If it is higher than 1%, the DG unit is tripped after 2 s.

Protection

Islanding

In almost all technical requirements and standards, unexpected islanding operation is not wanted. DG units must be disconnected as soon as possible when the main grid is not energized.

When a voltage value or frequency is out of the protection range given in Table 2, the DG unit shall cease to energize the area power system within the clearing time as indicated. The clearing time is the period elapsed between the start of the abnormal condition and the DG ceasing to energize the power system. IEEE 1547 considers small DG having less impact on system operation, but large DG (>30 kW) can have an impact on distribution system safety. This requirement is taken into account by allowing the network operator to specify the frequency setting and time delay for underfrequency trips [3], [4].

Even with voltage and frequency monitoring, unintended islanding may happen. Other methods are proposed like a third criterion that can indicate abnormal operating conditions being independent of voltage and frequency [8]. Communication is another way to send tripping signal when the area power system is not energized by the main grid.

Table 2: Protection setting for DG units

	Belgium	IEEE 1547	France
LV	**Voltage** U>1.06pu instantly, U<0.5÷0.85, delay 1.5s **Frequency** <49.5 Hz or >50.5Hz, instantly	**Voltage** U <0.5, 0.16s 0.5≤ U <0.88pu, 2s 1.1<U<1.2, 1s 1.2≤U, 0.16s **Frequency** *≤ 30 kW* > 60.5 Hz, 0.16s <59.3Hz, 0.16s *> 30 kW* > 60.5 Hz, 0.16 <{59.8Hz–57 Hz}, Adjustable 0.16-300s <57Hz, 0.16s	**Voltage** U<0.85 or U>1.15pu instantly **Frequency** f<47.5 Hz or f>51 Hz, instantly
MV	**Voltage** 0.25÷0.5pu>U or U>1.1pu instantly, U<0.5÷0.85, delay 1.5s **Frequency** <49.5 Hz or >50.5Hz, instantly		

Reclosure

Reclosure of DG units, in general, has to make sure it does not cause unintended islanding. If a fault occurs on transmission level, the DG units are recommended to remain online for a certain period in the Italian technical guideline (2 s for 150 kV, 2.6 s for 220kV, 4 s for 380 kV grids). As 70-95% of line faults are temporary if the faulted circuit is quickly disconnected, the line can be returned to service quickly. Tripping DG units in this case is unnecessary as long as it can sustain such disturbances.

Generally, a DG unit should not be damaged by auto-reclosure. The response of the DG unit must be coordinated with the reclosing strategy of the isolation devices within the power system to prevent possible damage to power system equipment and to equipment connected to the power system other than the DG unit

In the IEEE 1547 Standard, the DG unit shall cease to energize the power system circuit to which it is connected prior to reclosure by the power system. This requirement is intended to prevent out of synchronism conditions during reclosure in order to limit unnecessary actions of overcurrent protection devices or to avoid damage to transformers, motors and the DG units. If the fault is temporary in nature and the DG unit does not trip or the fault arc is not extinguished prior to the network section reclosing attempt, this attempt will be unsuccessful and the automatic restoration of that circuit may be jeopardized. Furthumore, the islanded feeder is likely to drift out of synchronism with respect to the main. It is very important to coordinate DG tripping with feeder reclosing practices to ensure that out-of-phase reclosing does not occur [4].

In Germany, DG unit protection is set shorter than the reclosure time and DG owners have to ensure that their units are not damaged by the auto-reclosure action. In Span, DG can be reconnected if the voltage at PCC point U > 0.85 pu and t > 3 min.

3. Synchronization

The connection must be done in such a way that it does not affect the network operation. In order to synchronize the DG unit with the grid voltage, the output of the DG and the input of grid must have the same voltage magnitude, frequency, phase sequence, and phase angle. If these conditions are met, the DG will synchronize with the power system with any voltage fluctuation limited to ± 5% of prevailing voltage level at the PCC.

Inverter DG

DG units connected to the grid via inverters are operated with gradual control from no up to full load.
Inverters may be line or self commutated. Synchronizing a

line commutated unit requires only voltage magnitude matching, as frequency and phase angle are established during connection. Synchronization of a self commutated inverter requires matching of voltage magnitude, frequency, and phase angle similar to any regular synchronization action [4].

Synchronous generators:

Table 3: Requirements for synchronous DG synchronization

	IEEE 1547	**Belgium**	**France**
Small DG	0 - 500 kVA ΔU = ±10% Δf = ±0.3Hz Δδ = ±20°	ΔU, Δf, Δδ must be such that they do not cause any sudden variation >6% in voltage	ΔU = ±10% Δf = ±0.1Hz Δδ= ±10°
Medium DG	>500-1500 kVA ΔU = ±5% Δf = ±0.2Hz Δδ= ±15°		
Large DG	>1500 kVA ΔU = ±3% Δf = ±0.1Hz Δδ= ±10°		

Induction generators:

An induction generator is an asynchronous machine that requires an external source to provide the magnetizing (reactive) current to establish the magnetic field across the air gap between rotor and stator. Without such a source, an induction generator cannot supply electric power, but must always operate in parallel with a power system, a synchronous machine, or a capacitor that can supply reactive power requirements of the induction generator [4].

The connection of induction generator based DG units can be performed provided that the resulting voltage drop does not surpass present limits.

Table 4: Requirements for induction DG synchronization

	IEEE 1547	**Belgium**	**France**
Voltage drop	≤ 5%	≤ 6%	≤5% for more than 0.5s

CONCLUSIONS

Different DG interconnection technical guidelines and standards are compared and discussed in the paper. The requirements are different from one to another. This makes it difficult for the international harmonization of DG interconnection hampering the deployment and increasing costs.

A common standard of DG connection is needed. It helps DG technologies to become marketable by providing a foundation for certification, promoting international trade of uniform high-quality products and supporting transfer of expertise.

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