CASE STUDY : ASSESSMENT OF POWER QUALITY IN PRACTICE

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ABSTRACT

Power quality has become an issue of interest for distribution network operators within the last years as more and more equipment connected to the network contains power electronics, and generating units based on renewable energy resources have a fluctuating power output. Those characteristics deteriorate the power quality of the network which may cause distribution network operators not to fulfil their obligations in this regard. The aim of this paper is, based on Danish experiences, to answer the question of how power quality related requirements in grid codes can be enforced, and how a tool can support the assessment of power quality, as part of the grid connection process in relation to generating units.

INTRODUCTION

Technical Reports published by IEC describes a method to assess power quality (PQ) in MV and HV networks. Together with the international standards these reports serve as the basis for setting up requirements for generating units in various grid codes, including the Danish grid codes, used in this case study.

Requirements related to PQ e.g. flicker and harmonics have been part of grid codes for wind farms and other generating plants, based on renewable energy resources, for some years. Except for very large power plants, the requirements in general have not been enforced.

In this study, the assessment process has been clarified as well as the needed tasks to be performed by each stakeholder. Additional gaps in knowledge or information to perform the individual tasks have been identified.

The outcome of the analysis has been used to set up specifications for a tool to support the assessment process and recommendations to improve the grid code in order to make the responsibility of each stakeholder clearer. A simple EXCEL application to be used for the assessment of PQ as part of the grid connection process has been developed.

Experiences with the tool show clear improvements in enforcing the requirements in the grid code. The most important advantage is that PQ issues are considered early in the grid connection process. Secondly, the focus on PQ generates ideas to improve PQ models as well as mitigation measures to avoid disturbances.

FRAMEWORK OF ASSESSMENT

The Transmission System Operator (TSO) in Denmark is legally responsible for composing Grid Codes for generating plants, connected to either distribution or transmission network. Those grid codes specify PQ requirements to be fulfilled by generating plants. For generating plants connected to the distribution network, the Distribution System Operator (DSO) administrates the grid codes, e.g. ensure that the requirements in the grid codes are fulfilled. This case study is based on the Danish grid code for wind power plants greater than 11 kW, TF 3.2.5[1].

To perform the assessment of PQ, the stakeholders in figure 1 has been identified:

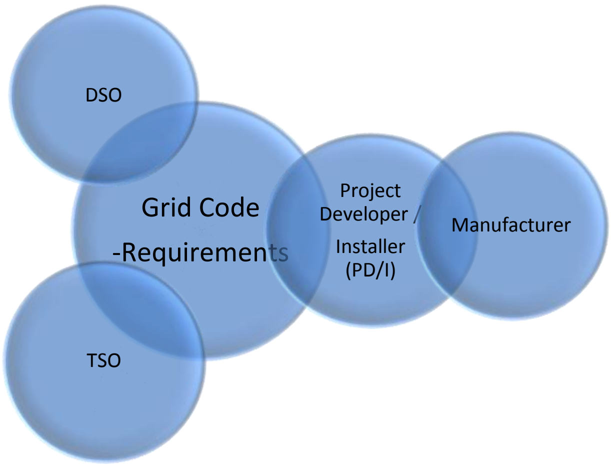

Figure 1: Stakeholders involved in the assessment

Transmission System Operator (TSO)

The TSO is responsible for the PQ in the transmission system. The TSO administrates the Grid Codes for generating plants connected to the transmission system.

Distribution System Operator (DSO)

The DSO is responsible for ensuring a PQ level according to EN50160 [2] in the distribution system. The DSO administrates the grid codes for generating plants connected to the distribution network.

According to TF 3.2.5[1], the DSO/TSO must deliver the required information about the distribution and transmission system to make the required assessment of PQ, e.g. short circuit levels and network impedance in the assessed frequency range.

Project Developer / Installer (PD/I)

Contractually, the plant owner is responsible for fulfilling the requirements stated in the Grid codes. However, it cannot be expected that the plant owner possesses sufficient know how to do the assessment of PQ related issues. Thus, the PD/I are expected to have this role on behalf of the plant owner.

According to TF 3.2.5[1], the plant shall be constructed and designed in such a way that no reinforcement of the network is required, other than reinforcement required to ensure sufficient capacity of the network with respect to the fundamental frequency. Furthermore, the PD/I shall carry out the needed assessment to verify that the requirements within the Grid code are fulfilled.

Manufacturer

The Manufacturer develops and produces the generating unit and is the only one who can provide the required data of the generating unit.

According to TF 3.2.5[1] the assessment shall be done on the basis of the PQ characteristic of the generating unit(s). For Wind Turbines, this shall be done according to IEC 61400-21[3].

METHODOLOGY OF ASSESSMENT

PQ assessment in this regard is characterized by following PQ parameters:

- Rapid Voltage Changes
- Flicker
- Harmonic disturbances (Harmonics, Inter Harmonics and disturbances in the range of 2-9 kHz)

The methodology used in TF 3.2.5[1] is based on technical reports published by IEC, IEC/TR61000-3-6[4] and IEC/TR61000-3-7[5] which describes methods to assess PQ in MV and HV networks. Together with the international standards IEC 61000-3-12[6], IEC 61000-3-11[7] and IEC 61400-21[3], these reports serve as the basis for setting up requirements and to do the assessment of PQ when connecting generating plants to the electricity network.

Three different approaches of assessment are applied:

- No assessment
- Generic approach
- Specific approach

No assessment

Apply to all types of disturbances for generating plants ≤ 11 kW. Generating plants ≤ 11 kW are, however, not covered by TF 3.2.5[1]. The generating unit(s) shall comply with all relevant standards, e.g. IEC 61000-3-2[8] and IEC 61000-3-3[9].

No further assessment is to be done.

Generic approach

Apply to harmonic disturbances for generating plants > 11 kW and ≤ 1.5 MW. Generic current emission limits appear from TF 3.2.5[1] and are calculated according to RA 557 [10].

The assessment is done, applying the method described in IEC/TR 61000-3-6[4] based on the PQ characteristic of the generating unit(s). No information about the grid is required.

Specific approach

Apply to rapid voltage changes and flicker for generating plants > 11 kW and harmonic disturbances for generating plants > 1.5 MW. Generic limits for rapid voltage changes and flicker appear from TF 3.2.5[1]. Specific voltage emission limits for harmonic disturbances are calculated by the TSO/DSO based on the method in IEC/TR 61000-3-6[4].

The assessment is done, applying the method described in IEC 61400-21[3] and IEC/TR 61000-3-6[4] based on the PQ characteristic of the generating unit(s). The TSO/DSO shall provide information on short circuit levels in order to calculate the emission of all types of disturbances. Additionally, the TSO/DSO shall provide information on network impedance in the assessed frequency range in order to calculate voltage emissions.

IDENTIFIED GAPS

Generally seen, it is clear how to do the assessment, and thus how to enforce the requirement in the TF 3.2.5[1]. In cooperation with the identified stakeholders in figure 1, the possible causes for not enforcing the requirements were analysed. The following gaps were identified:

TSO
- A short circuit level, which is expected more than 95% or 99% of the time, should be provided. Applying $S_{k,min}$ will lead to very conservative results.
DSO
- The approached network impedance in IEC/TR 61000-3-6 is too conservative at higher frequencies. - The DSOs Grid models do not include capacitances, which mean that the network impedance in the complete frequency range cannot be calculated. - General lack of know how. The issue has not so far been considered.
Grid Code
- Too academic written. The Grid code is hard to understand.
PD/I
- Relatively high costs to perform the assessment, especially for smaller generating plants. - General lack of know how. The issue has not so far been considered.
Manufacturer
- A standard to the provide PQ characteristic only exists for Wind Turbines.

Table 1: Identified gaps

The conclusion of the analysis was to develop a tool to support the assessment and to setup training courses for DSOs and PD/Is. The tool shall be available for both DSOs and PD/Is.

DESCRIPTION OF THE TOOL

The tool consists of two EXCEL applications. The first application is applicable to one generating unit or more generating units of the same type. The second application is applicable to generating plants consisting of 2 to 4 different types of generating units. The tool is applying standard EXCEL function and VBA code.

Overall specifications:

- Assessment of wind power plants and PV power plants of all sizes connected to LV and MV network.
- Assessment of 4 different types of generating units in one generating plant.
- Assessment of rapid voltage changes, flicker, harmonics, inter harmonics and disturbances in the range of 2-9 kHz.

Functional specifications:

- Calculation of specific voltage emission limits for generating plants > 1.5 MW.
- Calculation of total emission from power plants consisting of more generating units of same type.
- Calculation of total emission from power plants consisting of 4 different types of generating units.
- Generation of report with emissions limits.
- Evaluate emissions up against the requirements in Grid codes for wind power plants and PV power plants.
- Generation of assessment report contenting overall and detailed results.

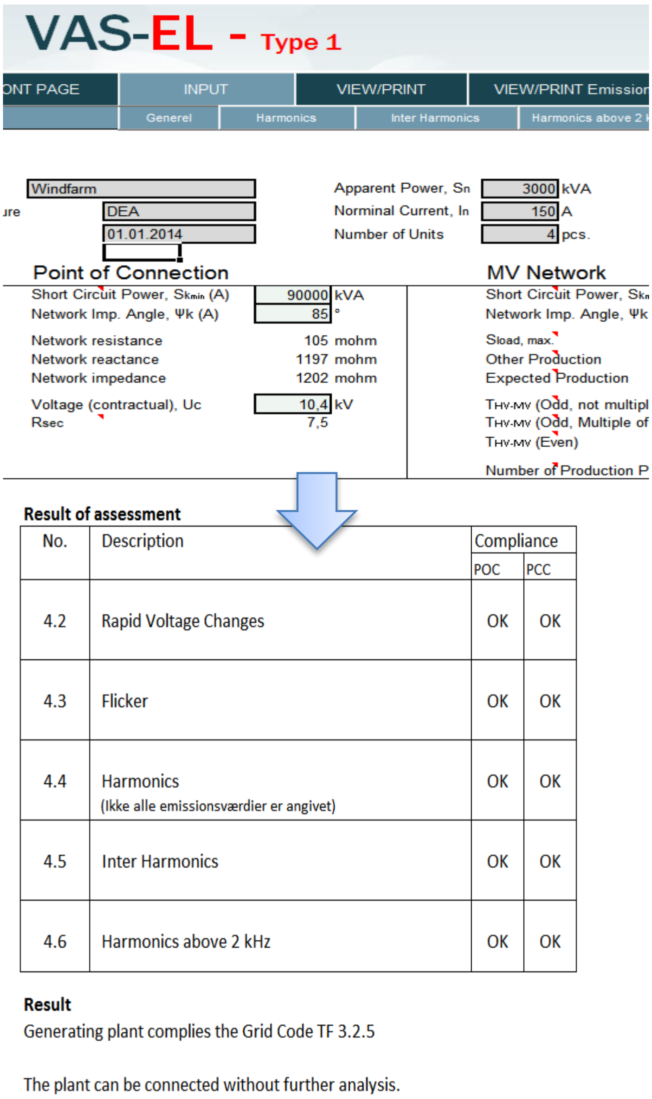

Figure 2: General input screen (upper), Overall assessment results (lower)

Approached network impedance

As stated in table 1, the DSO in general cannot provide an exact network impedance as a function of the frequency, as the models in the simulation tools do not include capacitances. Thus, an approached network impedanse model has been apllied to the tool.

The maximum impedance curve from annex A in IEC/TR 61000-3-7[4] is shown in figure 3:

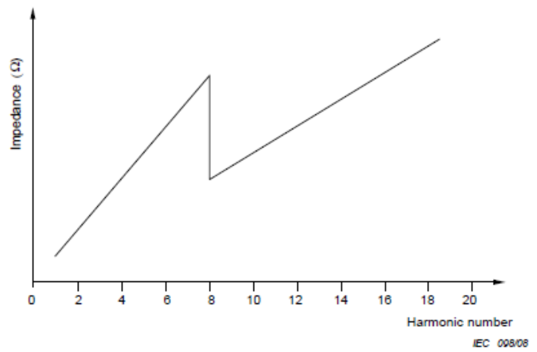

Figure A.1 – Example of maximum impedance curve for a 11 kV system

Figure 3: Maximum network impedance curve from IEC

The curve is very conservative, especially at higher frequencies. Taking into account that most of the MV and LV networks in Denmark consist of cables, simulations show that the approached network impedance curve in figure 4 is more applicable to PQ assessment.

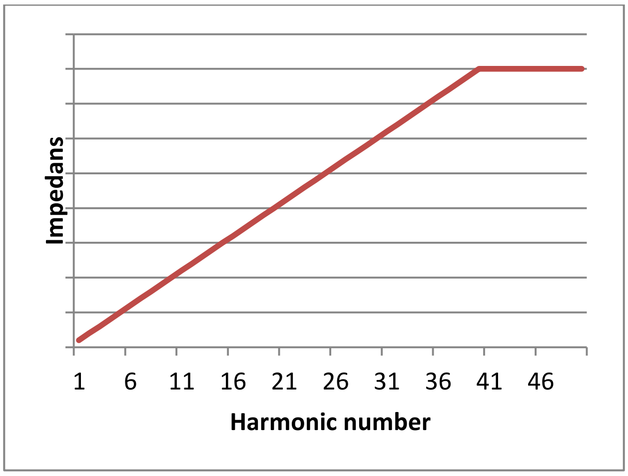

Figure 4: Approach network impedance

The approached network impedance is proportional to the fundamental impedance up to 40th harmonic number. Above the 40th harmonic order, the impedance is constant and equal to the impedance at the 40th harmonic number.

PERSPECTIVE

The tool is given away for free after participating in relevant training courses, and has been available for approx. 2 years and is well known in the business, especially in the area of medium size power plants. Few manufacturers have startet to develop own assessment applications.

A future improvement of the tool is to enable import of customized network impedance curves to enable assessment on higher voltage levels.

The gratest advantage of the tool is that the assessment is performed at an early stage of the project, which leaves room to make specific agreements on required measurements or metigation meassures, if not compliant.

The assessment in general could be improved by following activities:

- Disseminate know how ragarding assessment of PQ to PD/Is and DSOs.
- Be aware of the target group when writing the Grid code.
- Fix a short circuit level applied to PQ assessments. Applying minimum short circuit levels leads to very conservative results.
- Preparation of an international standard covering PQ characteristic for all types of generators. For PV power plants the PQ characteristic is perform, only due to the requirements in VDE-AR-N-4105[11]
- Improvement of assessment methods for a higher adequacy of the assessment.
- Improvement of network models to include capacitances

CONCLUSION

The case study shows that enforcement of PQ requirements is possible if the issue is adressed and the right prerequisites are present. At this stage of maturity, a tool to support the assessment, showed its worth. Considering PQ aspects as part of the grid connection process is an evolution, which first of all needs the issue to be addressed. Secondly, dissemination of know how related to PQ aspects, supported by the right tools, is important. Furthermore, the evolution should be supported by improvements of methods and models.

REFERENCES

[1] Energinet.dk, 2010 “Technical regulation 3.2.5 for wind power plants with a power output greater than 11 kW,” rev 4.1

[2] CENELEC, EN 50160, 2010 “Voltage Characteristics of electricity supplied by public electricity networks”

[3] IEC, IEC 61400-21, 2008 “Measurement and assessment of PQ characteristics of grid connected wind turbines”

[4] IEC, IEC/TR 61000-3-6, 2008 “Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems”

[5] IEC, IEC/TR 61000-3-7, 2008 “Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems”

[6] IEC, IEC 61000-3-12, 2011 “Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current > 16 A and ≤ 75 A per phase”

[7] IEC, IEC 61000-3-11, 2000 “Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75A and subject to conditional connection”

[8] IEC, IEC 61000-3-2, 2008 “Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)”

[9] IEC, IEC 61000-3-3, 2008 “Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection”

[10] Dansk Energi, RA 557, 2010 “Maksimal emission af spændingsforstyrrelser fra vindkraftanlæg større end 11kW”

[11] VDE(FNN), VDE-AR-N-4105, 2011 “Power generation systems connected to the low-voltage distribution network”