EU Grid Code Compliance

Different Ways and Levels of Network Code Verification

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***Abstract* — The EU-Regulation for NC RfG calls for independent verification. Such will be important for the years to come. The corresponding procedures are described in this paper, including testing to receive equipment certificates already by now.**

Equipment Certificates or other parts of the 'power generating module document' (PGMD) helps the relevant network operator to accept grid connection for the power generating module as compliance with the technical criteria has been demonstrated. Certificates provide the necessary data and statements, including a statement of compliance.

Keywords - certification; grid code compliance; GCC; verification; validation; Equipment Certificate

I. Introduction

As harmonization of grid code requirements is especially important in cross-border exchange areas of Europe, Entso.E has been asked to draft a set of Pan-European grid codes called "Network Codes" to be used as an EU-Regulation. Rule makers [1] all over Europe are now making use of this English Document [2] to have it translated and nationally embedded to corresponding local or national grid codes, laws and procedures [3].

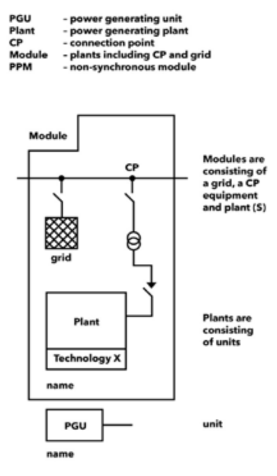

Figure 1: Nomenclature

In this Introduction power generating infrastructure and corresponding terms and definitions are explained. Short terms for easy use are defined: Unit, plant, module and facility.

The second part gives the principles for verification DNV GL has developed and recently published, which perfectly can be used for verification according to the new European Commission Regulation establishing a network code on requirements for grid connection of generators (RfG) [2].

In a third part Examples are described, how to apply this in a way, that synergies help reducing the effort of verification.

A. Facility

On a TSO level the infrastructures for distributed generation can be called a power generating facility, see below Figure 2. A facility is connected to one single grid but

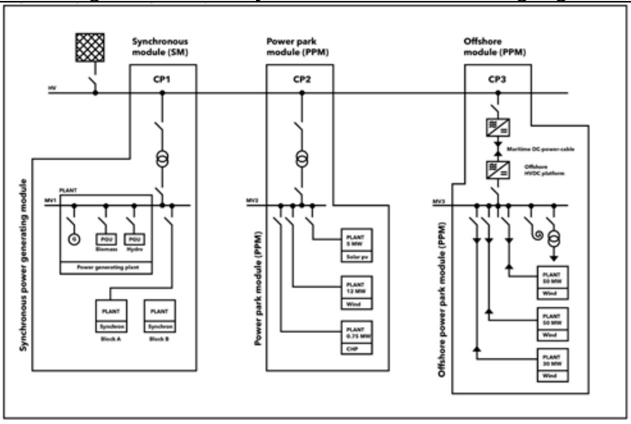

Figure 2: Example of a power generating facility

by several connection points. Facilities include several modules, each with its connection point (CP).

B. Modules

Modules (Power generating modules) are power plants or clusters of power plants. There are different categories of modules (see Figure 2). All modules are connected by one single CP to one single grid.

Wind and solar power plants are mainly of the non-synchronous type, called "Power Park Modules" (PPM), see Figure 3.

Other modules are synchronously connected to the grid, i. e. the rotating electrical machine is not from an induction

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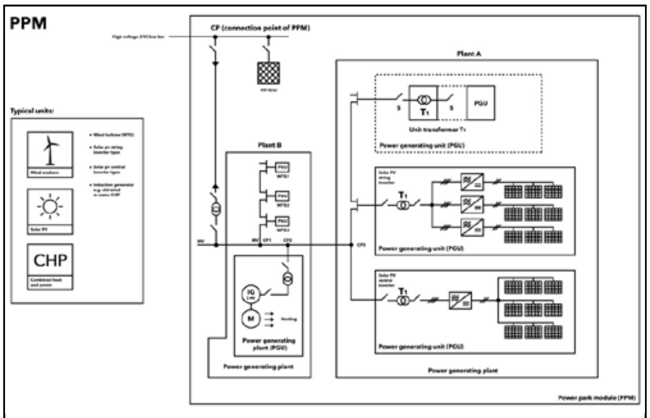


Figure 3: Power Park Module (PPM)

machine type and not connected via electronic frequency converter systems, but directly connected to the grid, rotating synchronously with the system frequency. These

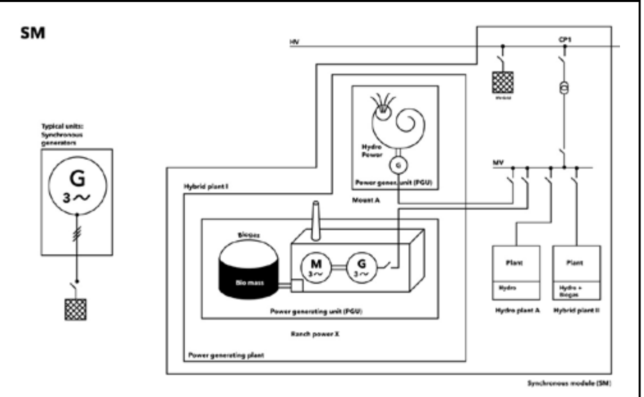


Figure 4: Synchronous Modules (SM)

kinds of modules are called "synchronous modules", covering most hydro power, bio gas, CHP and conventional power generating plants (see Figure 4).

C. Plants

Modules are made from plants, which is the short name for power generating plants. Conventional power plants usually are in the category of synchronous modules. In some cases plant can be the same like module, see I.E below.

D. Units

Power generating units may be wind turbines, PV inverters or other equipment intended for the distributed generation of electrical power. Figure 3 shows typical units.

E. Terminology

The new terminology covers both, distributed as well as centralized power generation. While Centralized power plants are covered as "synchronous modules", decentralized types are called "power park modules" being non-synchronously connected to the grid, e.g. by means of converters respectively inverters.

Historically distributed generating infrastructures exist which have more than one wind power plant or PV power plant connected to the same connection point as defined by the relevant system operator (RNO). Therefore the term "plant" is needed additionally to the term "module". However, in most cases a plant can also be regarded as a module, as far as the corresponding upstream substation is simplified as a grid. Several plants can then be also regarded as a facility with several modules in the meaning of a module being just one plant.

II. Verification Principle

As internationally applicable verification procedures based on national or regional grid code requirements do not yet exist, DNV GL issued in 2015 its Service Specification GCC [4].

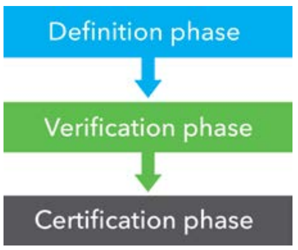


Figure 5: Verification principle

The three phases of this verification principle have to be run through (see Figure 5); the next phase can only start after the previous has been finalized.

The new verification principle is furthermore depending on the following items, as threshold values and requirements do not come from the verification principle itself, but from the grid codes, as defined during definition phase:

- Kind of equipment under assessment (facility, module, plant, unit or component)
- grid code requirements applied (grid code)
- GCC class chosen (verification level)

A. Verification Level

The scope of verification can be set differently during the definition phase of the verification process by allocating a GCC class to the verification performed. Three verification levels are possible, corresponding GCC classes are shown in Table I.

TABLE I. GCC Classes and Examples

Equipment	**GCC Class [a]**		
	I	***II***	***Without GCC class***
	approved verification level	***standard verification level***	***supplier defined verification level***
Unit	TC_{I}	TC_{II}	EC or CC
Example Text	The wind turbine type "Stream 120" is finally approved by system operator to be used in his grid.	The solar inverter "ConVer 12k" has been evaluated according to DNV GL's Service Specification and Standard and was found to fulfil the grid code requirements of …	The wind turbine converter "ACDC" was tested according to the maximum capability approach, reaching the values as listed and shown in the graphs of the certificate
Plant or Module	PC_{I}	PC_{II}	EC or CC
Example Text	The wind power plant "windy island" has absolved all commissioning tests required and is approved by the system operator for generating, e.g. by FON (final operation note).	The solar PV farm "sunny site" has been evaluated according to DNV GL's Service Specification and Standard and was found to fulfil the local grid code requirements valid at this site.	The wind power plant "stormfront" has been evaluated against the supplier defined list of requirements (GCC-features). The values are listed and shown in the graphs in the certificate. In this area there is no grid code available.

a: GCC class means verification level according to Service Specification [4]

B. How verification level changes Grid Code requirements

In general grid code requirements are coming from the corresponding grid code, relevant for the installation site of the equipment to be verified. But often the level of verification is important.

For verification levels in GCC class II the requirements from the grid codes are only assessed, if Service Specification [4] and Standard [5] list it. Vice versa only those requirements from the Service Specification [4] and from the Standard [5] will be assessed, which are mentioned in the grid code. In other words: Class II verification is taking into consideration the intersecting requirements from the DNV GL rules and from the grid code requirements applied. As an example the Standard requires assessing GCC-feature D11 to the level of D11E, F, I and U (all voltage control, see Table II). If the grid code does not require voltage control, none of them has to be assessed. If the grid code gives no values for D11U (maximum steady state voltage control error: maximum allowable steady state voltage error) this issue cannot be assessed either.

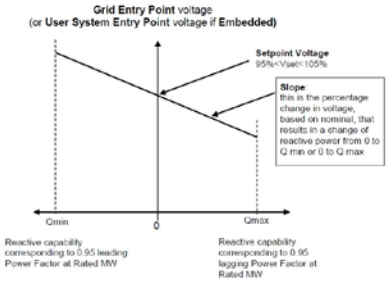
If no GCC class is assigned the verification is performed with supplier defined verification level, i.e. the individual listing of GCC-features to be applied together with the threshold values associated with each GCC-feature.

GCC-features are e. g. voltage control, as specified under D11 in the Appendix to the Standard and given below as an example only. Supplier defined means that the supplier of the equipment can define less lines in Table II compared to GCC class II assessment, but he also could define to assess more lines than required for GCC class II.

If GCC class I shall be assessed the relevant network operator (RNO) will be asked for the scope of assessment in any case.

TABLE II. TABLE TYPE STYLES

No.[a]	**GCC-feature**[a] **voltage control mode**		
	Mode	***description of voltage control mode***	***units***
D11	A	voltage control requirement limit (voltage level, MW level): minimum voltage and/or a MW limit from which voltage control has to be available.	V or W
D11	…	…	…
D11	E	voltage measurement accuracy The signal might be provided by a second or third party.	%
D11	F	voltage reference set-point range typically +/- 5% or +/- 10 %.	%
D11	G	voltage reference resolution	%
D11	H	voltage reference update rate (received from outside).	Hz
D11	I	slope reference set-point range This parameter specifies the slope set-point range, typically 1-10 %. An exact definition of the slope should be given, for example in a figure. The figure below from the UK grid code is given as an example only.	%



No.[a]	**GCC-feature**[a] **voltage control mode**		
	Mode	***description of voltage control mode***	***units***
D11	…T	…	…
D11	U	maximum steady state voltage control error: maximum allowable steady state voltage error.	%
D11	…Z	….	….

a. according to the Appendix to the Standard [5] based on the EWEA Grid Code Requirements TF

C. *Equipment to be verified*

Equipment which could be verified is of a big variety. The main difference is the distinction between

- units / components and
- modules / plants

Plant equipment is influencing directly the connection point and can achieve project certificates (PC) and equipment certificates (EC). Plant equipment can be facilities, modules, plants, transformers, cables or plant control functionalities. Usually simulation with validated software models is required.

Component equipment and such, being installed in bigger numbers within each plant, module or facility can achieve type certificates (TC), equipment certificates (EC) or component certificates (CC). Such equipment may be wind turbines, frequency converters, solar PV inverters, cables & lines, secondary components and complete power generating units.

Furthermore statement of compliances can be issued as well as certification reports (see [4]), all can be based exclusively on the requirements from Network Code RfG.

This is a complex system of possibilities, which can help to facilitate the overall compliance monitoring tasks. Some examples are given in the next section which shall make clear, which possibilities exist.

III. EXAMPLES

Using the flexible verification procedures in the best possible way, will make it possible, to:

- Use verification efforts made once again and again
- Proof of evidence for different sites can be performed, based on the same Equipment Certificates (EC)
- By choosing GCC class I for verification, the acceptance of the relevant network operator can be achieved
- Show compliance of products with the Network Code RfG
- certify a very specific part of the Network Code RfG [2], by choosing the verification level without GCC class

Different EU Member states will implement the European Commission Regulation NC RfG in different ways.

A. *Use of existing Certificates*

Germany and Spain have required certificates for grid code compliance for some years already. Many of those certificates will, to some extent, be usable for verification according to NC RfG [2].

Certificates according to German SDLWindV require the validation of simulation models for wind turbines, they can be used as well, provided they are used properly.

B. *Example The Netherlands*

The Dutch Transmission System (110 – 380 kV) is operated by TenneT TSO. TenneT developed Wind Farm Connection Requirements [6], stating the technical performance requirements for wind farms to be connected to the TenneT system (Project Certificate, GCC class I: PC_I). Such certification assessment includes requirements from the following areas:

- Frequency and Voltage variations
- Reactive power capability
- Reactive power / Voltage control
- Voltage stability
- Fault Ride Through Capability
- Active Power Control
- Active Power Frequency response
- Power Quality

Next to the Requirements, TenneT drafted, in consultation with DNV GL, a Compliance Activities document [7], describing the process and activities for the wind farm owner to demonstrate that the wind farm is compliant. For these activities test procedures, test reports and model simulation reports have to be submitted for review and acceptance. This is a typical example of a certification according to GCC class I, as assessment will be made in accordance with the relevant network operator, in this case TenneT Netherlands (provided all certification rules are fulfilled, too, e. g. a validation of the unit software simulation models against FRT testing results have been performed).

A number of wind farms (plants) are currently under construction. TenneT ordered DNV GL to review the Compliance documentation to be submitted by the Wind Farm owner and to witness the Compliance on-site tests at completion of the wind farm (acceptance process of GCC class I assessment).

The reviews within acceptance process include:

a) **Approval of the Type Certification** of the unit type, in this case a wind turbine based on TenneT test reports proofing the capability of the individual wind turbine to comply with the TenneT requirements. Since TenneT requirements are referring to the module performance at the connection point (110-380kV), the influence of the wind plants internal grid (cables, transformers, reactive compensation etc.) and the plant controller on the required performance of the individual units has to be taken into account.

b) **Load flow calculations** to proof compliance with the reactive power requirements at the connection point. This is actually a typical part of any project certification for plants, modules or facilities. Reactive power consumption and generation by the internal grid of the module or plant (transformers, cables and compensation equipment) has to be taken into account. The calculations shall show that units (individual wind turbines) will operate within their power and voltage capability limits at maximum required reactive power exchange with the transmission system for several cases of grid voltages and active power generation (see Figure 6 and Figure 7).

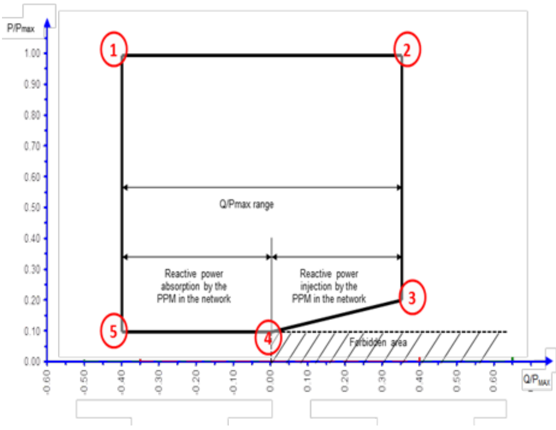


Figure 6 Load flow simulation cases Q-P

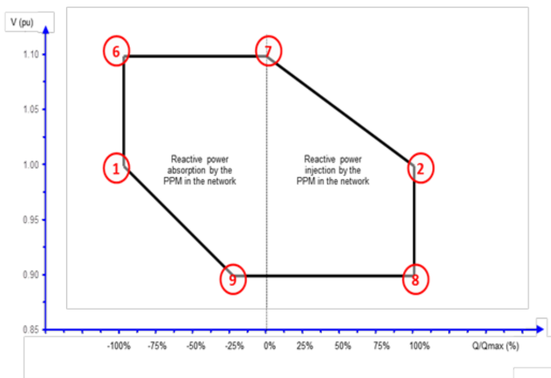


Figure 7 Load flow simulation cases Q – V.

c) **Dynamic model simulations** to proof:

   a. Voltage stability (injecting additional reactive current when grid voltage drops below 90%).

   b. Fault-Ride-Through capability (ride through during grid faults and fault recovery).

   Simulations include a grid fault with defined grid voltage drops or profile at normal operation of the plant or module. The results of the simulation shall show that the requirements for additional reactive current (response time and value) are met at the connection point and that the units, plants and modules recover after fault clearance.

d) **On-site tests** are part of the project certification acceptance process to show compliance with requirements for:

   a. Reactive power capability and control modes (voltage control, reactive power control, power factor control) and capability. All three control modes are tested by set point changes. Also tests at maximum required reactive power exchange are performed. Measured accuracy and range of controls, droop, dead band and response time are reviewed.

   b. Active power control (adjusting / curtailing active power output). Tests are performed by changing the set point of the plant controller. Measured response and accuracy of control are reviewed.

   c. Reduction of active power output at over frequency is checked by injecting a frequency deviation signal into controller. Response and droop are checked against the requirements.

e) **Power quality calculations and measurements** are done, assessing:

   a. The voltage dip when energizing the wind farm step-up transformer and switching of unit transformers is calculated by model simulations. Saturation and point-on-wave case switching shall be taken into account. At first energizing the inrush current and voltage dip at the connection point are measured. The calculated / measured voltage dip (½ cycle rms) is checked against the requirements.

   b. Harmonic voltages and currents at the connection point. Power quality measurements are carried out before the wind farm is connected (reference) and when the wind farm is in full operation.

A summary of the compliance process is shown in Table III . It covers three phases: design phase, construction phase and full trial operation.

TABLE III. PLANT / MODULE COMPLIANCE PROCEDURE OVERVIEW

Design phase	- Technical data wind turbines and wind farm - Load flow study and dynamic study - Power / Voltage Quality simulations - Interim statement of compliance 1 - Interim Operational Notification 1 (ION)
Construction phase	- Initial power quality measurement - Above 60 MW installed: Interim on site tests if required - Above 60 MW installed: interim power quality measurements, if required - Interim statement of compliance 2, - Interim Operational Notification 2
Full trial operation	- On site tests - Final power quality measurement - Statement of compliance - Final Operational Notification

In the **design phase** the wind farm owner submits an Interim Statement of Compliance and includes simulation studies and technical data of wind turbines and wind farm. DNV GL reviews these documents on content (is technical compliance demonstrated) and completeness (are all items addressed in a proper way). If not completely satisfied, DNV GL will ask for clarifications and/or updates/additions. DNV GL informs TenneT and the wind farm owner on their findings. TenneT will submit an Interim Operational Notification to the wind farm owner when Compliance is demonstrated.

During the **construction phase**, the step-up transformer will be energized and wind turbines will be commissioned. The power quality of the grid voltage at the Connection point is measured as a reference. The voltage dip when switching on the step-up transformer is measured and checked for compliance. Wind farms are typically 100-300MW and construction will take many months or even years. Wind turbines are commissioned sequentially. The wind farm owner prefers to continue operation of individual wind turbines after commissioning, although no on-site Compliance tests are performed at that moment. When the installed wind turbine capacity reaches 60 MW, TenneT may require interim on-site tests to be carried out. Typically a reactive power control test shall demonstrate that the wind turbines provide grid voltage support. DNV GL reviews the test procedure and the test results.

At completion of the wind farm, after commissioning of all wind turbines and wind farm controller(s), the on-site Compliance tests will be carried out by the wind farm owner and tests will be witnessed by DNV GL. Test procedures have been reviewed in advance by DNV GL. Test results will be assessed and when successful, DNV GL will advise TenneT accordingly.

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