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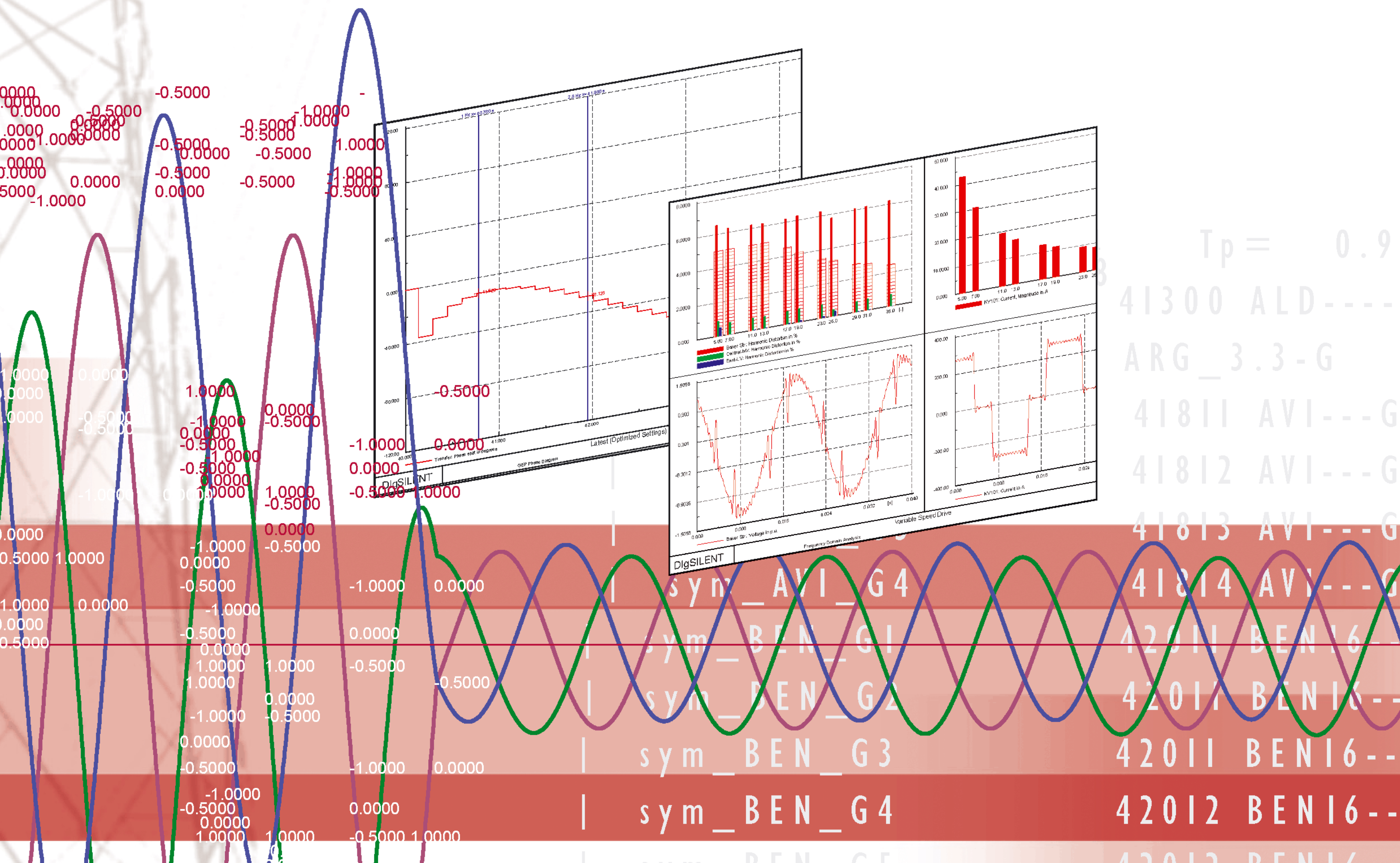
Assist in the development of standard rules and procedures for the interconnection of renewable and cogeneration plants to the national interconnected system

Deliverable 1: Status quo analysis and proposal for Mexico from an international perspective

prepared for

GTZ/CRE



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1 Introduction

The purpose of this report is to provide an overview with regard to the international practice related to technical guidelines for the connection of renewable energy power plants and co-generation plants and to describe and analyse the status quo in Mexico.

Besides this, the related administrative procedures shall be analyzed and potential improvements proposed.

Chapter 1 of this report is dedicated to the international practice. A detailed overview about the connection rules and guidelines in Germany is given including a description of the administrative procedures. The situation in the United Kingdom and Spain is then described at a higher level.

Chapter 2 describes and analyzes the status quo for the connection of renewable energy power plants and co-generation plants in Mexico. This section makes extensive reference to the "Preliminary Analysis of the official documents for the development of the study" [1] that has been carried out by Mexican consultant.

Chapter 3 provides some comments on the proposed connection conditions for renewable energy power plants and co-generation plants [18] and [19].

Chapter 4 summarizes a few "lessons learned" from the development of renewable generation in Germany and Spain.

At the end, this report presents conclusions and recommendations.

2 International Practice for the Grid Connection of Renewable and Co-Generation Plants

2.1 Germany

2.1.1 Overall Framework

The grid connection of renewable generation in Germany is mainly defined by the Renewable Energy Act (Erneuerbare Energien Gesetz, EEG), which states that every renewable generator gets:

- Prioritized grid access
- Remuneration for every produced kWh of energy (Feed-in tariff)

These two aspects guarantee highest possible security for investors, which is the main reason for the very wide usage of renewable generation in Germany.

For the connection of co-generation plants (fuelled by non-renewable fuel), the Co-Generation Plant Act (KWK-Gesetz) applies, which also defines a prioritized grid access for all co-generation plants, at the same level as for renewable generation. However, remuneration is not according to a feed-in tariff scheme in place for co-generation plants but only a general framework for the determination of prices for electricity produced by co-generation plants.

As part of the renewable energy act and the co-generation act, the following guidelines for the connection of those power plants are given:

- The network operator whose grid suited with regard to the voltage level and whose grid is next to the power plant is obliged to connect it to his grid.
- In the case that the connection to a more remote grid has techno-economic advantages, the network operator can connect the power plant to an alternative connection point.
- The obligation persists, even if grid reinforcements or extensions are required.

With regard to the technical requirements, the acts refer to the technical requirements of the system operators and general safety requirements.

However, since the renewal of the renewable energy act in 2009, the following two technical details have been incorporated into the renewable energy act:

- In case of plants with an installed capacity >100kW, there must be an interface allowing the system operator to monitor the currently fed-in power and to limit it in case of grid congestions.
- Wind farms must comply with technical connection conditions, as detailed in Annex 7 of the renewable energy act.

This annex 7 however, refers again to general grid codes and connection conditions of the German system operations, together with some additional guidelines for clarification and interpretation.

This means in other words, that (only) for wind generation, the connection conditions with the interpretation according to SDLWindV are part of the renewable energy act since beginning of 2009.

2.1.2 Connection Conditions for Generators

Every operator of an electricity network has to define a set of minimum requirements for the connection of generators and to publish those in the internet. This means that each of the four German transmission system operators and each of the several hundreds of distribution network operators in Germany defines connection conditions for the connection of consumers or generators to his grid.

For simplifying the process the BDEW, which is the organisation of all German network operators, provides guidelines for the connection of generators to high-, medium and low voltage networks.

With the exception of some specific clauses, these connection conditions are not specific to renewable energy generation or co-generation plants but generally define a common set of connection conditions for all types of power plants.

The relevant codes for the connection of generators to German grids are the following:

- Voltage level <1kV (LV networks): VDEW Richtlinie für den Netzanschluss und Parallelbetrieb von Erzeugungsanlagen am Niederspannungsnetz

- Voltage level >1kV and <110kV (MV-networks): Generating Plants Connected to the Medium Voltage Network

- Voltage level >=110kV: Transmission Code 2007: Network and System Rules of the German Transmission System Operators

For onshore wind generation, the so-called SDLWindV, which is part of the renewable energy act, contains a set of clarifications and additional explanations, which complement the Transmission code and the MV connection conditions.

2.1.3 LV Connection Conditions – Overview

2.1.3.1 Scope of Application

For generating plants that are connected to voltage levels below 1kV (LV levels), the VDEW guideline "Eigenerzeugungsanlagen am Niederspannungsnetz [2] from 2001 is still relevant. At present, new guidelines for the connection of generators to LV voltage levels are being written and most likely, the new guidelines will adopt some of the concepts of the MV-guidelines.

2.1.3.2 Overview

The LV guidelines cover the following aspects:

- Plant design (including primary equipment and secondary equipment/protection aspects)

- Network connection, including power quality aspects

- Power plant operation

The technical requirements for power plants connected at LV levels according to the LV-guidelines from 2001 are still relatively basic and mainly focussed on protection and power quality aspects.

There is no clear voltage or frequency ranges of operation given, neither during normal operation nor during grid disturbance. All aspects related to frequency or voltage ranges are defined in the context of protection requirements, meaning that LV power plants are still requested to disconnect in case of voltage or frequency disturbances.

2.1.4 MV Connection Conditions – Overview

2.1.4.1 Scope of Application

For generating plants that are connected to MV levels, the BDEW-guideline "Generating plants connected to the medium-voltage network", applies.

It applies to all kinds of energy conversion technologies, such as wind, hydro, cogeneration, photovoltaic etc. and all kinds of generator technologies such as synchronous generators or induction generators with or without power electronics converters.

2.1.4.2 General Provisions and Regulations

For the construction and operation of electric facilities, all relevant standards that apply in Germany also apply to generation plants connected to MV networks. A list of those standards is given in the MV connection conditions and it is explicitly stated that this list isn't complete but that other relevant German (e.g. DIN or VDE) or IEC standards apply as well where applicable.

2.1.4.3 Application

Before an application for the connection of a generating plant can be submitted to the network operator, a basic design of the plant, including protection schemes and switching schemes has to be carried out.

In particular, the application for the connection of a generating plant to an MV network must contain the following set of information:

- Site plan showing the location and streets, the designation and borderlines of the site as well as the place where the connection facility and the generating units are to be installed (preferably on the scale of 1:10,000, inside built-up areas 1:1,000).

- Data sheet with the technical specifications of the generating plant, and relevant certificates.

- Basic circuit diagram of the entire electrical installation with the data of the equipment used (a single-pole representation is sufficient), information about the customer's own medium-voltage lines, cable lengths and switchgear, basic diagram of the generating

- plant's protection equipment with settings; diagram showing where measured variables are registered and on which switching appliances the protection equipment is acting on,

- Information about the short-circuit current capability of equipment in the connection facility,

- Electric data of the customer transformer(s) used for network connection, i.e. rated capacity, transformation ratio, relative impedance voltage, connection symbol,
- Short-circuit current of the generating plant (incl. time-dependent evolution) at the point of transfer to the system operator's network,
- Description of the type and operation mode of the main engine, the generator and, where applicable, the converter and the kind of connection with the network by means of data sheets or inspection records,
- Verification of the electric characteristics (Unit certificates).

In Annex of the MV-connection conditions, there exist templates of forms that have to be filled in for the submission of a connection application.

2.1.4.4 General Network Requirements

Based on the information that has been submitted together with an application, the network operator has to identify a suitable point of connection.

In case of a renewable power plant, the Renewable Energy Act applies. In this case, there is an obligation to connect it to the next suitable connection point, whereas suitability is just defined in terms of registered capacity and voltage level. In the case that the network has to be reinforced for connecting the planned renewable power plant, the network operator has to carry out the required network reinforcements. Only in situations, in which the required network reinforcements would be economically unreasonable, the network operator can propose an alternative connection point.

In case of a generating plant that is not supported by the Renewable Energy Act

The general network requirements that will be verified are:

- Dimensioning of network equipment
- Admissible voltage changes
- Network disturbances (Power Quality Aspects)
- Maximum admissible short circuit currents

In terms of studies that the system operator has to carry out for evaluating the suitability of a connection point, there are:

- Load flow studies (dimensioning of network equipment, admissible voltage changes)
- Short circuit studies (Maximum admissible short circuit currents)
- Harmonics and flicker assessment studies

As soon as a suitable connection point has been identified, the network operator hands over the minimum fault level and the network impedance angle at the connection point to the applicant.

2.1.4.5 Connection Conditions

Based on the minimum fault level at the grid connection point and the impedance angle (or range of impedance angles), the connection owner has to make a detailed design of the power plant and a compliance certificate has to be prepared by an authorized certification organization showing the compliance of the concept with all relevant clauses of the connection conditions.

Power plants with a rated power of less than 1MVA and a connection line between the connection point and the generating unit(s) of less than 2 km don't require a formal certificate.

The relevant clauses, which are subject to certification, are:

- Dimensioning of network equipment
- Admissible voltage changes
- Network disturbances (Power Quality Aspects)
- Maximum admissible short circuit currents
- Reactive power control/voltage control
- Fault ride through capability and dynamic voltage support during grid disturbances
- Calculation of maximum fault current contribution
- Automatic reduction of active power in case of overfrequencies (>200mHz)
- Plant design/primary equipment:
    - Transfer switches
    - Coupling switches
    - Consideration of general guidelines for the installation of MV plants and equipment
    - Remote control possibilities (if required by the system operator)
    - Auxiliary energy supply
- Plant design/secondary equipment:
    - Undervoltage protection U< and U>
    - Overvoltage protection U> and U>>
    - Underfrequency protection f<
    - Overfrequency protection f>

- Reactive power – undervoltage protection

- Short circuit protection (overcurrent I> and I>> or distance protection or on-load fuses)

Figure 1 shows a typical protection scheme for the connection of a MV power plant according to the German guidelines for MV connections.

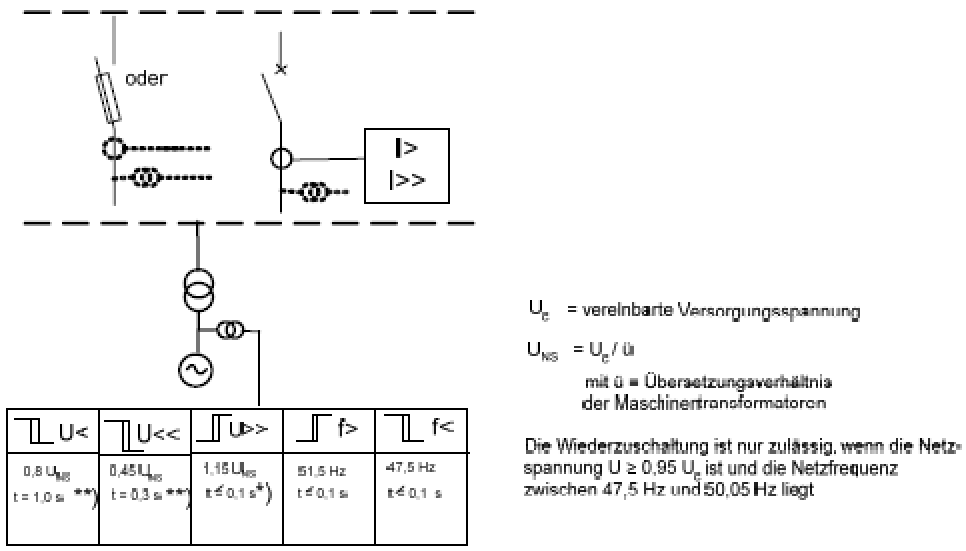


Figure 3.2.3.4-1 Protection scheme for the connection of generating plants to the medium-voltage network

Figure 1: Typical protection scheme for the connection of MV power plants (according to German MV guideline)

2.1.4.6 Validation and Certification

For supporting the validation and certification process according to the German Guidelines for MV connections and the SDLWindV (Renewable Energy Act), a set of measurement, modelling and certification guidelines has been worked out by the FGW (Fördergesellschaft Wind e.V., Association for the support of wind generation). The relevant series of guidelines is:

- FGW TR-3: Guideline for the measurement of power quality indices according to IEC 61400-21 and FRT-capability

- FGW TR-4: Guideline for the modelling of renewable energy plants

- FGW TR-8: Certification guideline for grid code compliance certificates based on measurements and simulation studies.

The FGW-series of guidelines requires:

- FRT-tests for every renewable energy unit (individual wind generator or solar panel)

- Implementation of a validated model for carrying out simulation studies (steady state and dynamic/FRT-studies)

- Simulation studies for verifying grid code compliance of each individual renewable energy plant (>100kW), based on validated models.

2.1.4.7 German MV Connection Guideline – Experience and Comments

The new German MW Connection Guidelines represent a very well elaborated document, which has been set up in a very conclusive way, supported by numerous examples etc. It can therefore be recommended to study these guidelines as a good example for the definition of connection conditions.

However, with regard to the actual technical requirements, some of the new requirements seem to be exaggerated and even cause problems to distribution network operators or generators.

Based on the consultant's experience with the new rules, the following recommendations can be given:

- **FRT-capability** is a definitive requirement for all power plants and definitely required for systems with a considerable share of distributed generation. With the introduction of FRT-requirements to MV connections, it could be observed that wind generator manufacturers were well prepared. For photovoltaic systems, FRT is relatively easy to realize and doesn't cause any substantial problems. However, it has also been observed that gas or fuel-fired engines that drive either conventional induction generators or synchronous generators heavily struggle with these new requirements and were not well prepared. For this reason, FRT for non-wind generation plants has been postponed until mid 2010.

- **Dynamic voltage support** during grid disturbances, meaning that power plants are asked to inject reactive current into the grid causes numerous problems to system operators because those generators interfere with classically applied protection concepts because they continue contributing to an arc, even when the main feeder protection relay has already cleared the fault. Many distribution network operators are therefore of the opinion that dynamic voltage support should better not be required for generators connected to MV levels and that FRT-capability alone would be sufficient.

- The **Q/ u< protection** device has been introduced for avoiding that induction generators that ride through faults drive the system into a dynamic voltage stability problem. However, this device represents a new type of protection device and is therefore not correctly understood. Further, it is unclear, in which way the settings of such a protection device shall be worked out. Because the risk for dynamic voltage collapse only depends on the generator technology and doesn't exist in case of inverter driven generators (including DFIG), it is recommended to ensure that the generating plant doesn't absorbs large amounts of reactive power during voltage recovery and to validate this based on simulation studies. It is definitely not recommended to introduce Q</u< protection devices.

- The MV guidelines ask for a **power factor range of cos(phi)=0,95** in the over-/and underexcited quadrant. They further allow reducing active power to the benefit of supplying/absorbing reactive power if the required power factor range cannot be covered under full load conditions.
  From the consultant's point of view, there are two comments:
  - It is recommended to ask for the full power factory range, also under full load conditions. From a distribution network point of view, this might not be necessary. From a global system point of view, it is however advisable to decouple active and reactive power supply for ensuring a reliable active power

delivery.
- In distribution networks, there is typically a high voltage problem in case of high infeeds of distributed generators. It is therefore unclear if it is really required to ask for a power factory of 0,95, also in the overexcited (voltage supporting quadrant). Many distribution network operators in Germany have started to require a power factory range between 0,95/underexcited and 1 and the MV connection point.

- With regard to the required **certification** of grid code compliance of every wind farm, a bottleneck with regard to the certified consulting organisations that are technically able to provide those services can be observed. Until now, only 7 consulting companies have obtained a preliminary registration. This won't be enough for working through the more than one hundred wind farm projects per year, which require certification plus numerous other distributed power plant projects. It is essential to put a system in place for grid code validation that can be supported by the industry. Otherwise, many projects will be pending just because of resource constraints for grid code validation studies.

- With regard to the implementation of **validated and certified models**, the process of FRT testing and modelling has started. However, until today, there only exist certified models of ENERCON wind turbines. The certification of other turbines is still under progress.

2.1.5 Transmission Code – Overview

2.1.5.1 Scope of Application

For generating plants that are connected to HV levels (>=110kV), the "Transmission Code 2007 - Network and System Rules of the German Transmission System Operators"applies.

The Transmission Code applies to all kinds of power plants, including large coal or gas fired power stations, wind farms etc.

The Connection Conditions only form a relatively small part of the overall transmission code. Other aspects of it cover operational rules, ancillary services (system services), network development and operational planning.

In Germany, there are four transmission system operators, each of them owning and operating a part of the German power transmission network. The Transmission Code forms a common basis for all of them but because the safe and secure network operation is exclusively in the responsibility of the system operator, each system operator has the right to define his own set of connection conditions. The current practice of the German system operators is the following:

- RWE Transportnetze Strom: Transmission Code directly applies

- 50Hz Stromübertragungs GmbH (former Vattenfall Transmission): using their own connection conditions

- Transpower Stromübertragungs GmbH (former E.ON. Netz): using their own connection conditions

- EnBW Transportnetze AG: Refers directly to Transmission Code

This means that only in the area of two of the four system operators the Transmission Code 2007 directly applies. Transpower and 50-Hz specify their own set of rules, which is very close to the Transmission Code.

Besides this, there is an obligation to fulfill technical requirements according to the Renewable Energy Act, the SDLWindV. which only applies to wind generation. The SDLWindV makes reference to the Transmission Code but because of the relatively poor consistency and clarity of the German Transmission Code, there are numerous amendments and additional explanations and interpretations given by the SDLWindV.

2.1.5.2 Application

The connection owner (power plant operator) submits an application to the network operator with the aim of agreeing on a connection agreement.

During this process, a set of relevant data has to be agreed between the TSO and the connection owner, such as:

- grid connection capacity
- maximum and minimum continuous operating voltage, as well as duration and level of the short-time violations of the maximum and minimum limits
- nature and volume of the reactive power interchange
- maximum and minimum *network short-circuit power*
- breaking capacity
- method of neutral point connection
- electric protection scheme
- automatic synchronising conditions
- harmonic component and flicker component
- inclusion into the voltage control scheme (reference voltage, accuracy, velocity, fault-mode operation)
- behavior under *large-scale failure* conditions
- involvement in *ancillary services* required for the provision of *system services*
- measuring, metering and information technology
- Insulation coordination.

During this process, the system operator typically carries out load flow and short circuit studies for analyzing the feasibility of the planned connection and for determining maximum and minimum fault levels, which are handed over to the connection owner.

The connection owner has to carry out a set of studies demonstrating the compliance of the planned connection with the connection conditions of the Transmission Code.

In case of a renewable energy plant, the application process is similar to the one described for the connection to MV-networks. Particularly, the obligation of the system operator to connect the renewable energy plant and the obligation to reinforce the grid if necessary is of particular importance.

2.1.5.3 Connection Conditions

The Transmission Code lists a set of minimum technical requirements that must be fulfilled by the connection owner in order to obtain a connection agreement.

This list covers aspects related to

- Protection
- Control and communication
- Active power vs. frequency criteria
- Frequency control
- Reactive power supply
- Stability aspects (transient and "static" stability)

All these aspects relate to all types of power plants. For power plants based on renewable energies a special section defines exceptions and additional rules, which are additional to the general section of the Transmission Code.

These rules relate to:

- Controllable active power output (possibility to limit the active power output)
- Generally no contribution to primary or secondary frequency control required.
- Automatic reduction of active power output in case of high frequencies (frequencies >50,2 Hz)
- Reactive power control (dynamic requirements, asking for "slow" reactive power/voltage control, in the time frame of minutes.
- FRT-capability
- Dynamic voltage support during grid disturbances (injection of reactive current during low voltages

2.1.5.4 Validation and Certification

The German Transmission Code doesn't provide any detail with regard to the validation of grid code compliance. It is typically up to the system operator to define the type of studies that need to be carried out and submitted for obtaining a connection agreement.

In case of wind farms, the validation and certification procedure described in the guidelines for MV connections is also applied to connection applications for wind farms with a HV connection point. As in case of MV connections, formal certificates are required for getting prioritized grid access according to the Renewable Energy Act.

2.1.5.5 German Transmission Code – Experience and Comments

The quality of the German Transmission Code is not nearly as good as the MV connection guidelines. Many aspects are unclear or contradictory and for this reason, a large number of additional explanations and amendments were required in the process of formulating standard connection conditions, as part of the Renewable Energy Act.

In terms of the actual technical requirements, it corresponds to nowadays generally accepted standards, particularly for wind generation.

2.2 National Grid (United Kingdom)

The National Grid being the sole transmission system operator of England, Wales and Scotland has established a very well defined Grid Code to which every connection has to comply with.

The Grid Code contains:

- Planning Code (PC)
- Connection Conditions (CC)
- Operating Codes (OC)
- Balancing Code (BC)
- Data Registration Code (DRC)

All connection to the national electricity system, including embedded generators, which are connected to a distribution network have to comply with the Connection Conditions of The Grid Code.

Wind farms and other generating plants consisting of several generating units are generally referred as Power Park Modules, for which some special conditions apply.

For supporting applicants in the execution of studies and tests and for clarifying some of the requirements, National Grid offers a document named "Guidance Notes for Power Park Developers". This document does not represent any standard but it clarifies many aspects of the requirements and provides comprehensive guidelines for the connection of Power Park Modules according to The Grid Code.

2.2.1 Applications

The procedure for a connection application of embedded generators, including relevant time scales are described in the CUSC-documents (Connection and Use of System Code).

According to these time scales National Grid provides an offer for the connection of an embedded generator or a large power station within:

- 28 days if no works are required
- 3 months if works is required.

There are predefined form sheets, which have to be completed by the applicant before submitting the application.

National Grid's costs for working out a proposal are covered by an application fee, which the applicant has to pay. The applicant has the choice whether to pay a fix fee, which is worked out based on historical data, or to pay the actual costs incurred (variable price application fee).

2.2.2 Connection Conditions

The Connection Conditions (CC) of National Grid, which are part of The Grid Code, are representing one consistent document for all types of power plants.

Most renewable generation technologies are covered by the clauses related to Power Park Modules.

The Connection Conditions cover the usual aspects, particularly:

- Power Quality Aspects (Harmonics, Flicker, Referencing to the relevant BE standards)
- Voltage range of operation.
- Reactive Power Capability at the Connection Point.
- Dynamic performance requirements for reactive power compensation at the Connection Point.
- Frequency range of operation.
- Performance requirements for primary and secondary frequency control.
- Fault ride through requirements.
- Studies and Tests for showing grid code compliance.

Compared with other European connection conditions, most requirements defined by National Grid are particularly challenging because the U.K. transmission system represents an island grid having a much smaller inertia compared to the continental European system.

Particularly reactive power control requirements and frequency control requirements are very challenging:

- National Grid asks for fast voltage control at the grid connection point. With regard to the voltage control characteristic, a voltage-reactive power droop characteristic is part of the grid code. The fully reactive power range must be covered within 1s. This means that in most cases, a dynamic reactive power compensation device (STATCOM, SVC) will be required at the connection point.
- In contrast to continental Europeans connection conditions, all Power Park Modules having a rating >50MW must have the technical capability to participate in primary and secondary frequency control. Power Park Modules must comply with the same dynamic performance requirements as other power plants.

For showing compliance with the Grid Code, National Grid asks for a series of standardized Grid Code compliance studies and tests during commissioning of the plant. These studies and tests are very well described in the Guidance Notes for Power Park Developers.

2.3 Red Espania Electrica (Spain)

Implementation of specific Grid Codes or Connection Conditions for wind turbines / wind parks started slowly and was predominantly initiated by numerous negative effects during grid upset situations. Latest quite critical observation on the behaviour of wind generation was made during the UCTE brown-out in November 4, 2006 where a total of 2,800 MW wind power tripped. Starting in 2006, a number of steps have been undertaken to impose more adopted connection conditions to wind power in Spain.

The majority of the transmission system in Spain is operated by Red Eléctrica de Espana (REE). Issued in 2003, basic Connection Conditions named "Instalaciones conectadas a la red de transporte: requisitos mínimos de diseno y equipamiento" for installations connected to the transmission system are defining the technical key requirements. In section 12.3.2, REE is stating their right to impose restrictions on the dispatch of wind power plants in that sense that the maximum increase of generation / minute (by plant connection) is limited. Other definitions for wind generation had not been established.

In October 2006, the "Ministerio de Industria, Turismo y Comercio" issued the resolution 18485 defining PO 12.3 which is now imposing additional requirements on the behaviour of wind generation units in case of voltage sags. The complete technical definition is found in Annex PO123_A37017-370191.pdf where basically the below voltage sag curve is further explained.

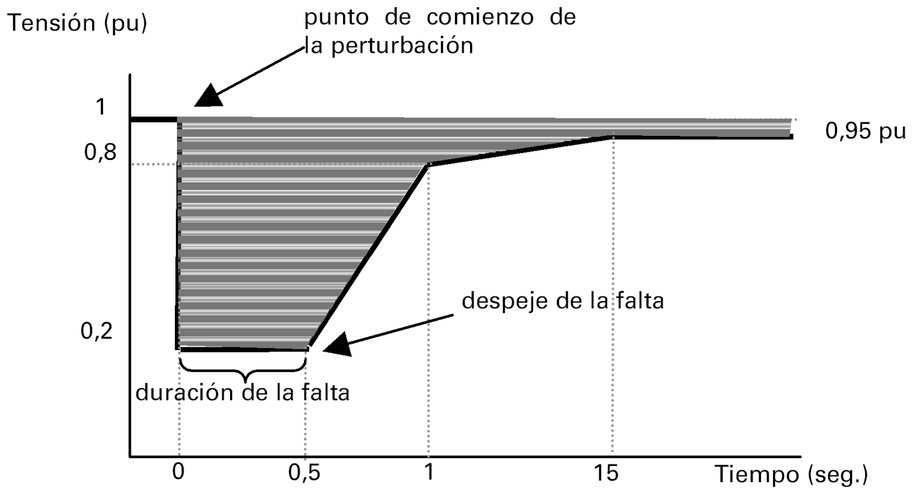


Figure 2: Voltage Profile for FRT Capability

Along with the publication of the resolution 18485, in February 2007 the "Procedures for verification validation and certification of the requirements of the PO 12.3 on the response of wind farms in the event of voltage dips" has been released. This document covers in general:

- The testing and measurement procedure for the individual response of wind turbines or FACTS devices in the event of voltage dips;
- The validation procedure for computer models of wind turbines or FACTS devices based on measurements recorded in the field tests;
- The procedure to check compliance of wind farms with the response requirements in OP 12.3.

The overall validation process described in the below flow chart show the different stages of the validation process.

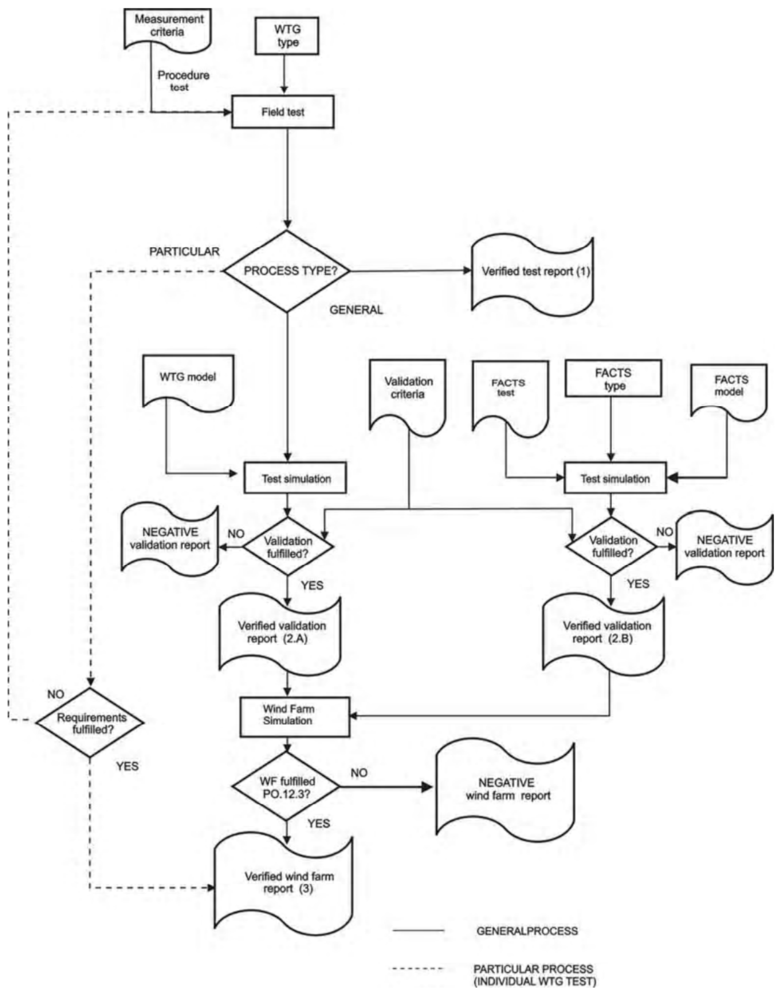


Figure 3: PO 12.3 stages of the validation process

Critical issue of the PO 12.3 process is that verification of the wind turbine behaviour, respective the behaviour of a complete wind farm which is base on a simplified benchmark system with typical data and short circuit level at the equivalent electrical grid as per below test environment (see also Fig. 4).

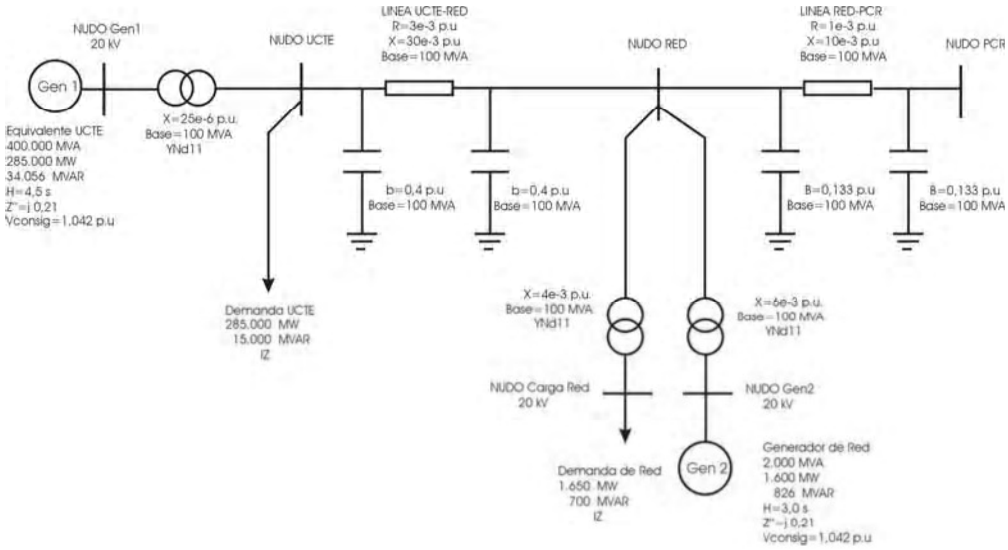


Figure 4. Model of the equivalent electrical grid (single-line scheme).

3 Grid Connection of Renewable and Co-Generation Plants in Mexico

3.1 Administrative Procedures

According to the publication "Guide to the implementation of generating plants based on renewable energies" that has been published by SENER, the Mexican Ministry of Energy, the main steps for the implementation of a generation project are according to the flowchart of Figure 4.

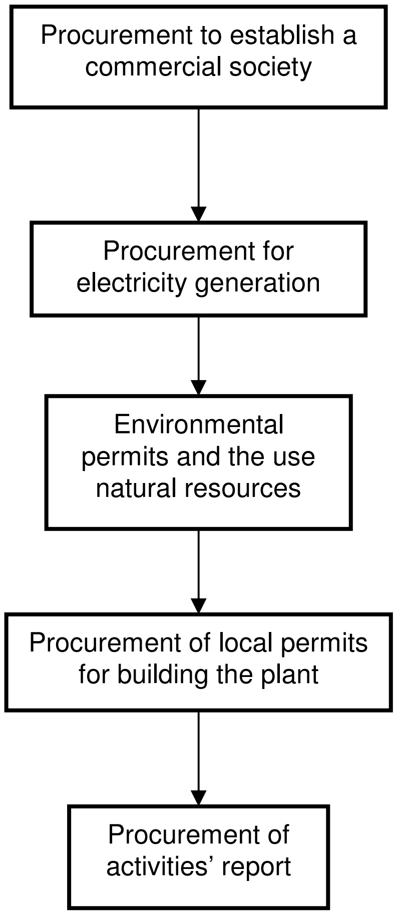


Figure 4: Main Steps to develop a generation project

The second step "Procurement for electricity generation" is further detailed in Figure 5. This procedure mainly requires the submission of general information required by CRE and it requires CFE to carry out feasibility studies about the new power plant.

As shown in Figure 5, there are clearly defined time frames for each step of the procedure.

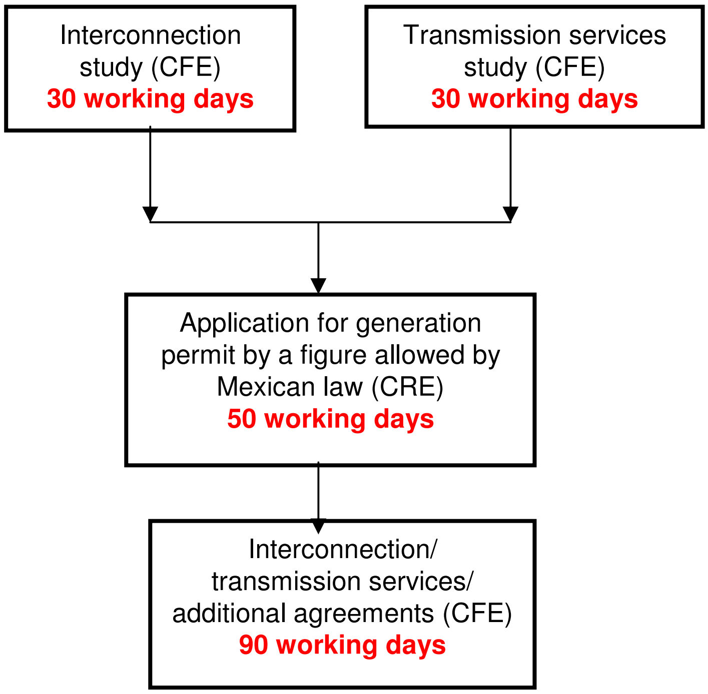


Figure 5: Procurement for electricity generation

When connecting a power plant to the Mexican grid, there are three different modes of operation of the power plant. These modes of operation are defined by the "law for the public service of electric energy" (LSPEE), which are:

- For Self Supplying (*Auto abastecimiento* - using the supplier network)
- For Cogeneration (*cogeneración*)
- For Small production (*pequeña producción*)

Following the permit to generate electricity, an interconnection agreement, and if the applicant intends to offer additional service, additional agreements have to be signed between the parties (see Figure 6).

There are three relevant types of interconnection agreements for the production from co-generation or renewable energies, which are:

- Interconnection agreement for sources based on non-renewable energy (applies to co-generation of any scale)
- Interconnection agreement for sources based on renewable energy (applies to renewable energy plants of any scale)
- Interconnection agreement for the use of solar power at small scale (applies to solar power plant with a maximum capacity of up to 10kW for residential users and up to 30kW for general use and connection to the LV network).

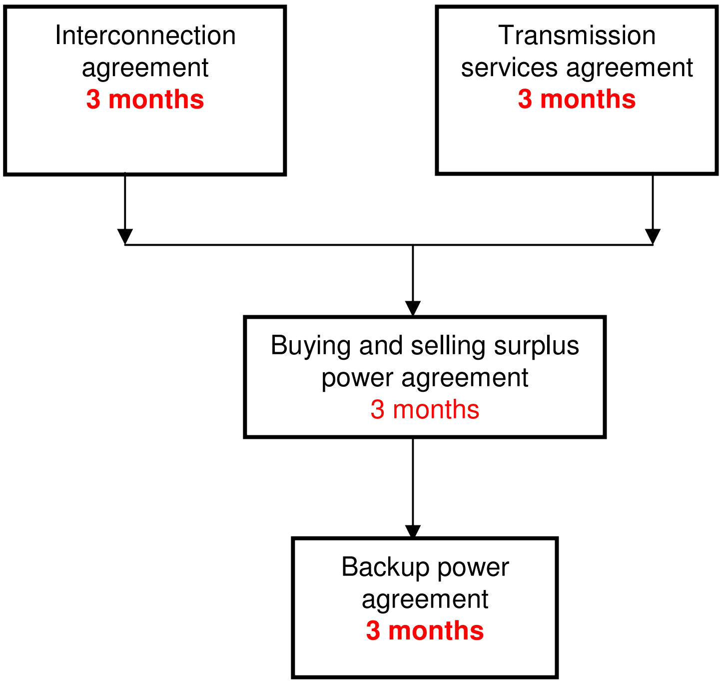


Figure 6: Procurement of Agreements

The purpose of these agreements is to establish the conditions of an interconnection between the source of energy and the network of the system operator. They contain the technical, commercial conditions for managing such connection and the legal acts related to such connection.

With regard to the timescales for the different agreements, there are maximum periods of 3 months for each agreement defined. In the case that the applicant doesn't get notice from CFE within this period, he shall assume that the answer is negative.

There is no indication that CFE would have to provide reasons for the rejection of an agreement.

3.2 Technical Specifications

With regard to the technical requirements for the connection of renewable energy plants or co-generation plants, there exist two generally applicable documents, defining connection conditions for:

- Wind generation for wind farm connections at high voltage (>115kV)
- Photovoltaic systems of up to 30kW

At present, there don't exist any generally available documents related to connection conditions of co-generation plants.

More importantly, there is no generally applicable grid code in place that would define minimum requirements for all types of power plants, including CFE's own power plants. For this reason, it is difficult to evaluate if the connection conditions for wind generation and PV are consistent with the general characteristics or CFE's power system, e.g. with regard to voltage or frequency ranges, which is a very important aspect for assessing the interoperability of the various generation technologies of the system.

3.2.1 Requirements for the Interconnection of Wind Generators to the Electrical System in Mexico

The existing "Grid Code for Wind Generators" named "Requerimientos para Interconexion de Aerogeneradores al Sistema Eléctrico Mexicano" is covering the following sections:

1. Introduction (validity, definition of voltage levels and glossary)
2. Operational range regarding system frequency
3. Acceptable harmonic current levels
4. Reactive power control range requirements, operational voltages and flicker
5. Plant and substation Protection; definition of disconnection conditions
6. Communication and control
7. Tests
8. Studies

The connection conditions define technical properties, tests and studies.

3.2.1.1 Technical Requirements

The technical requirements are mainly inline with international standards, such as IEC 61400-21 for power quality aspects.

Definitions for frequency ranges of operation, voltage ranges of operation, power quality requirements and the required reactive power range at the connection point are given. However, as mentioned earlier, it is not possible to assess, if these requirements are inline with corresponding requirements or characteristics of CFE's thermal and hydro power plants.

The connection conditions require fault ride-through capability of wind generators in case of three-phase, two-phase and single-phase faults. Additionally, a LVRT-characteristic is given, which is in-line with international standards.

There is no requirement for reactive current contribution (dynamic voltage support) during the fault and the connection conditions don't make any statement related to the recovery of active and reactive power subsequently to a fault or voltage dip.

3.2.1.2 Tests

The compliance of wind farms with the connection conditions has to be demonstrated by a series of tests, such as:

- Protection tests
- Communication and monitoring equipment
- Harmonic levels

- FRT capability using field tests.

It should be stated that FRT-tests can only be carried out for individual wind generators, not for an entire wind farm (at the grid connection point). For this reason, the German connection conditions ask for FRT-tests only of individual wind generator types (can be carried out by the manufacturer). The validation of FRT-requirements for a complete wind farm is then based on simulation studies using validated models.

3.2.1.3 Studies

The connection conditions for wind generation list a number of studies that CFE will carry out for analysing the grid impact of new wind generation projects. These studies cover:

- Short circuit studies
- Load flow studies
- Contingency analysis
- Transient and dynamic stability
- Voltage stability
- Power quality studies
- Protection coordination studies

The applicant has to support the execution of those studies by delivering information related to the planned wind farm so that appropriate models can be implemented.

3.2.1.4 General Comments related to the Connection Conditions for Wind Generation

The connection conditions for wind generation define a comprehensive series of technical requirements for the connection of wind farms to high voltage networks (above 115kV).

Most of the technical requirements are according to international practice. It can therefore be assumed that standard wind generators of major manufacturers are able to comply with these rules.

However, there are some aspects, which are not properly defined, such as the applicability of some of the requirements or tests (connection point or individual wind generator).

The list of studies that CFE will carry out every wind farm project is very complete but it has to be supported by appropriate models.

3.2.2 Connection of Photovoltaic Systems with a Capacity up to 30kW to the Electrical Low Voltage System

For photovoltaic systems with a rated capacity of up to 30kW, CFE has defined technical requirements for the design, installation, inspection, authorization and operation of PV systems.

3.2.2.1 Overview

With regard to terms and definitions, the document is much more detailed than the connection conditions for wind generation.

The standards address all relevant aspects, including:

- Installation options
- Safety rules
- Power Quality Aspects
- Frequency and voltage ranges of operation
- Reactive power range requirements
- Protection
- Verification procedures

3.2.2.2 Preliminary Comments

With regard to the actual technical requirements, a detailed analysis of the required level of power quality requirements still has to be carried out. During an initial review, no references to typically applied IEC or IEEE standards for harmonics and flicker levels could be identified.

The required power factor range of 0,9 inductive/capacitive appears to be excessive, particularly in the overexcited (voltage supporting) range and requires further justification because of the related implications to the rating of inverters.

4 Comments on Newly Proposed Mexican Connection Conditions for Renewable Energy Sources and Cogeneration

4.1 Introduction

In December 2009, CFE proposed new connection conditions for renewable energy sources and cogeneration plants (see [18], [19]):

- at distribution level: "Reglas Generales de Interconexión al Sistema Eléctrico Nacional parte I: Interconexión de fuentes renovables y cogeneración en baja y media tensión" [18]

- at transmission level: "Reglas Generales de Interconexión al Sistema Eléctrico Nacional parte II: Interconexión de fuentes renovables y cogeneración en alta tensión" [19]

In these documents, "Low voltage" defines networks or equipment operating at voltages below 1kV, "Medium voltage" networks operating at 4.16, 13.8, 23 and 34.5kV and "Transmission" levels are voltages of 115, 230 and 400kV.

According to these documents, power plants with active power output > 20MW are considered to be connected to the transmission system.

The rules for power plants connected at distribution level, only apply for power plants with active power output <20MW.

It is generally unclear what rules shall be applied for power plants <20MW which will be connected to transmission levels.

The Federal Electricity Commission (CFE) considers as renewable energies and cogeneration the following technologies that are listed in the grid code:

- wind turbines and wind farms

- hydraulic power plant

- solar photovoltaic plant

- Cogeneration (biomass, gas, etc.)

With regard to the application of connection conditions one can not that it is general international practice to define connection conditions for all kinds of power plants, including thermal power plants, large hydro power plants, all kinds of renewable energy generators and co-generation plants. Distinctions, if required, are only made based on the way power units are connected to the grid, e.g. by power electronics converters or directly by synchronous generators and not based on the type of primary energy source.

This format allows easily to verify the consistence of requirements relating to the entire network and to integrate new generation technologies without having to re-write interconnection rules.

4.2 Reglas Generales de Interconexión al SEN parte I

4.2.1 Comments on the Introduction

In the introduction of the document, it is stated that small scale power units ("generación de pequeña escala") are included in these documents; but no limits nor rated power output values figure in the document to define exactly what "pequeña escala" means. From the rest of the document, one can guess that "pequeña escala" refers to generation connected to LV networks and/or generation <1MW. A definition of "pequeña producción" can be found in chapter 12, where the active power produced by a small size unit is set to 30kW in MV. It is also unclear the fact that small scale generators are part of this document but at the same time, it is clearly mentioned that no formal rules apply to them.

To avoid confusion, it should be clearly stated which rules apply to small scale generators and if none, the reference to this type of generation can be removed from the document.

4.2.2 Comments on Chapter 2 "Especificaciones y Requerimientos de Operación y Control"

The definition of registered capacity ("capacidad registrada") can be added to the definitions chapter.

The definition of declared net capacity ("capacidad neta declarada") can be sent to the definitions at the end of the document. There is no reference to this capacity in this section.

It is not clear if the requirements are given according to the registered or declared power. In general, in the grid codes, the requirements are given according to the name plate and the rated powers of the generator.

4.2.2.1 Comments on 2.1 "Regulación de Tensión"

The condition to connect power plants to the distribution network in Mexico, if no voltage control is available at the substation or in the generator itself, is that the short-circuit power at the point of common coupling must be at least 25 times the rated power of the generator to be connected.

Spain has a similar requirement, but only for the connection of generators to transmission levels: rated output power of wind farms connected to transmission levels can not exceed 20 times the short-circuit power. In other countries, this requirement is mostly expressed in maximum power quality disturbances for the neighboring loads.

One can note that this section actually does not focus on voltage control. It gives the maximum permissible voltage change and maximum voltage step which are mostly power quality features as it affects neighboring customers.

Nevertheless, voltage control is an important feature, especially in areas where the percentage of distributed generation is high.

It is not clear if "En el evento de desconexión de una planta o de varias plantas simultáneamente en un punto de conexión a la red, el cambio de tensión en cualquier punto de la red se limita a 5 %, calculando el cambio como la diferencia entre tensiones con y sin las inyecciones de las plantas" refers to low voltage or to medium voltage level, or both.

For a better understanding of the connection conditions, the various limits of voltage changes could be expressed as in other grid codes:

- Normal operating voltage range: -10% → +5% around the nominal voltage.

- The operation of the power plant cannot cause voltage deviation > 4% (relative to the situation where the power plant is not connected);

- Switching operations of the power plant (connection or disconnection) can not cause voltage step > 5%.

Most of the grid codes do not state a MW limit per feeder as long as the power quality requirements are met. If limits in size of the installation are given, they should be given for all levels of voltage and not only 13.8kV and 23kV. The MW limits must be defined on a project basis, assuring the compliance with requirements relating to voltage limits or minimum short circuit level to avoid conflicts.

In 2.1.2, in the sentence: "En relación con el tercer punto el soporte de reactivos durante una falla es permisible para fallas asimétricas, para fallas simétricas la corriente reactiva inyectada a la red puede incrementar el tensión de las fases no falladas por arriba de 1.1 veces el valor nominal en el punto de conexión", the words "simétricas" and "asimétricas" have most likely been inverted.

Regarding wind turbines equipped with power electronic converters, even in the case of asymmetrical fault, most modern controllers are able to control the reactive current injection in order to prevent overvoltage on unaffected phases. Therefore, it may be sufficient adding the maximum permitted voltage in case of voltage sags.

In this section, if voltage support is required during faults, a range or a ramp of reactive current in function of the voltage drop should be given, similar to the definitions of the German Grid Codes (see [3], [4]).

4.2.2.2 Comments on 2.2 "Potencia Reactiva"

The power factor range between 0.95 lagging to 0.95 leading is a quite common requirement of connection conditions for the connection of generators to MV and LV grids. For being more precise, it should additionally be specified that this power factor should be met for the whole range of normal voltages and for the whole range of active power outputs.

It is unlikely that new wind farms will be built on asynchronous technology, they will probably be based on DFIG, or full converter technologies. The paragraph on the capacitor bank connection is maybe not useful and is redundant with the requirements of 2.1 where it is stated that connection and disconnection of the power plant should not cause voltage change above 4 or 5%.

The plant should be able to control reactive power according to 4 different modes:

a) fixed PF

b) fixed Q

c) PF(P)

d) Q(V)

Response times are 10s for c, and adjustable between 10s and 1min for d.

This means that the power plant is not controlling the voltage at its terminals when running in mode a, b or c. It can be contradictory with 2.1 and 4 "monitoreo and control" where a requirement is that the operator would be able to send set points to the plant to control the voltage.

Characteristics are mentioned for c and d but are not explicitly provided in the document

The paragraph on harmonics should not be part of this section but should be shifted of the chapter on power quality requirements.

4.2.2.3 Comments on 2.3 "Control de frecuencia"

Actually this section, does not describe requirements on frequency control but the frequency range of normal operation. Comparing the required frequency range of operation with other relevant connection conditions in Mexico it becomes should be noted that the required frequency range of operation of the existing grid code for wind generation [16] is actually wider.

Because frequency is a very global variable in a power system, the same frequency ranges of operation for generators connected to transmission and distribution levels should be applied. Of course, while the overall amount of distributed generation is still very low, this aspect is not very important. But with growing penetration of distributed and embedded generation the potential loss of generation because of low frequency could grow rapidly.

4.2.2.4 Comments on 2.4 "Control de Potencia Real"

This section describes a requirement for an interface of units >1MW, which allows the grid operator to limit the generator power.

This is necessary if renewable generators or co-generation plants can possibly cause grid congestions, in which case the system operator could intervene and curtail the generated power.

A similar requirement has recently added to the German connection conditions for ensuring system security.

4.2.2.5 Comments on 2.6 "Sincronización"

The proposed connection rules describe synchronisation of various generation technologies in very detail.

The common international practice for limiting grid disturbance in case of switching actions however is to cover this aspect by the generally accepted flicker standards, which limit the voltage step in case of a single switching operation and consider additionally the frequency of occurrence of such switching actions.

It is then up to the power plant operator to put appropriate synchronisation mechanisms in place in order to comply with these requirements.

In countries with feed-in tariff remuneration schemes, renewable generators and co-generation plants typically resynchronize automatically if the grid voltage is sufficiently high. Experience has shown, that this automatic resynchronisation can cause problems to the system operator during system restoration after black out, when renewable power plants and co-generation plants reconnect to the system in an uncoordinated way. It is therefore recommended to ask for a communication interface that allows the system operator to disable the auto-resynchronisation feature in case of black-out scenarios, as it is common practice in Germany since the beginning of 2009.

4.2.3 Comments on Chapter 4 "Monitoreo y Control"

For power plants < 500kW, it is not specified at what frequency the generation data have to be provided to the operator (every day, every 10 min, every month, etc.); it is said that this information should be provided on the internet. The operator should describe the interface or the file format for the data.

Big wind farm developers and manufacturers have their own central control room, in many cases they monitor and control their power plants all over the world from there. For smaller players, there are companies offering the services of a control room; they connect wind farms of different owners. Set points are sent to the generator dispatching centers and this central dispatching act as an interface between the operator and the plant. It also simplifies the management for the system operator; the operator does not have to take care of the connection to the dispatching of every single units and many different communication protocol.

The rate for sending data is not mentioned in this section.

4.2.4 Comments on Chapter 7 "Condiciones de disturbio"

4.2.4.1 Comments on 7.1 "Fallas"

The section relating to the behaviour of renewable energy plant and co-generation plants during grid faults describes in relatively high detail the behaviour of various generation technologies in case of grid faults. These are very important aspects for system operators in order to identify of impact of distributed generation on fault currents, protection selectivity and security.

However, the document does not clear describe what the required behaviour of distributed generation plants will be, e.g. details about fault type and duration for which no disconnection is allowed are given. It is advisable to include a FRT curve, similar to the curve of other grid codes or the corresponding code relating to transmission levels for obtaining clarity to wind generator manufacturers.

4.2.4.2 Comments on 7.2 "Reconexión"

According to this section, it is mandatory to include a delay of 5min after frequency and voltage are back into their normal range before reconnecting the unit while in section 2.6 (sincronización) it is only recommendation to add a delay when a protection causes the disconnection of the plant.

It is recommended to coordinate both sections e.g. by including references in order to avoid misinterpretations.

4.2.4.3 Comments on 7.5 "Desbalances de tension"

Because voltage unbalance is a power quality aspect, it is recommended to include this section into section 8 "Calidad de la energía".

4.2.5 Comparison with Annexo E-RDT of the Interconnection Contract for Small Scale Renewable Generators and Co-generation plants

Annex E-RDT of the Interconnection Contract for Small Scale Renewable Generators and Co-generation plants [21] provides a set of technical requirements for the interconnection of small scale power plants. The range of application is overlapping with the proposed CFE-document [18].

Because these two documents will be used simultaneously, there is a considerable risk for contradicting requirements. For this reason, a comparison between both documents is carried out in this section.

This comparison can be summarized as follows:

No real incompatibilities in the described rules or requirements have been detected between the studied documents.

"REGLAS GENERALES DE INTERCONEXION AL SISTEMA ELECTRICO NACIONAL PARTE I" [18] addresses generators connected from 34.5kV to voltage levels < 1kV and makes distinction between power ranges (up to 20MW, over 1MW, over 500kW, above 30kW and below 30kW) while the technical rules of the interconnection contract [21] only distinguishes between generators above and below 30kW.

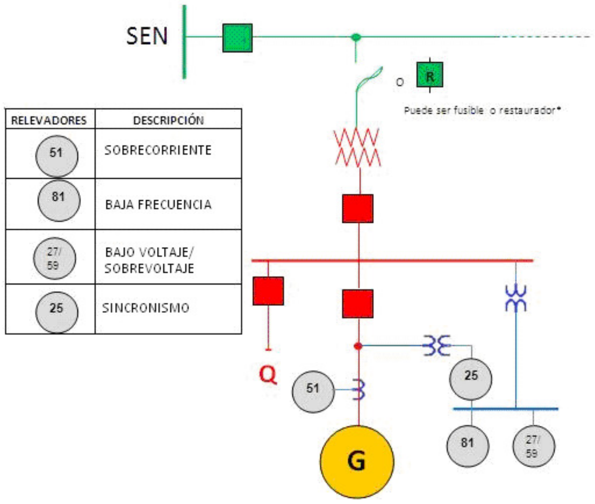
No control aspects (voltage, power factor, active power) are considered in the technical requirements of the interconnection contract [21]. Overall frequency and voltage ranges are identical between both documents but the interconnection contract [21] does not consider the power quality aspects (harmonics, flicker, voltage imbalance, etc.) presented in [18].

Definitions of protection systems are not incompatible but the connection rules [18] defines protection requirements more precisely (<500kW, protection can be included in the control system, >500kW protection must be implemented by external devices). Frequency settings given in the tables are slightly different between the documents (see Table 1 - Frequency range / frequency protection).

"REGLAS GENERALES DE INTERCONEXION AL SISTEMA ELECTRICO NACIONAL PARTE I" [18] gives an additional condition for connecting generators: the apparent rated power of the generator must be smaller than 0.04 x the short-circuit power at the point of connection, or it must be able to control the voltage. Such a rule is missing in the interconnection agreement.

Table 1: Comparison of technical rules according to the interconnection contract and the general CFE rules

<table>
<tr><th>Interconnection contract</th><th>REGLAS GENERALES DE INTERCONEXION AL SISTEMA ELECTRICO NACIONAL
PARTE I</th></tr>
<tr><td colspan="2">Defined power ranges</td></tr>
<tr><td>Small scale
➢ residential use<10kW
➢ general use at low voltage <30kW
Medium scale: <500kW</td><td>➢ Up to 20MW
➢ Above 1MW
➢ Above 500kW
➢ Above and below 30kW</td></tr>
<tr><td colspan="2">Considered voltage levels</td></tr>
<tr><td>Not defined</td><td>34.5kV to LV (<1kV)</td></tr>
<tr><td colspan="2">Voltaje control</td></tr>
<tr><td>Not required</td><td>Power plants >1MW</td></tr>
<tr><td colspan="2">Condition for connection (Short-circuit level)</td></tr>
<tr><td>None</td><td>Without voltage control: Sgenmax < 0.04 Ssc
With voltage control:
4MW at 13.8kV (8MW if connected to the Substation)
8MW at 23kV (16MW if connected to the Substation)</td></tr>
<tr><td colspan="2">ΔU caused by connection/disconnection</td></tr>
<tr><td>ΔU : [+5%, -5%]</td><td>ΔU : [+5%, -10%]</td></tr>
<tr><td colspan="2">Voltage Support during fault</td></tr>
<tr><td>Not mentioned</td><td>Not required</td></tr>
<tr><td colspan="2">Power factor range/control</td></tr>
<tr><td>Not mentioned</td><td>>1MW Power Factor: 0.95 ind → 0.95 cap</td></tr>
<tr><td colspan="2">Frequency range / frequency protection</td></tr>
<tr><td><table>
<tr><th>Power range (KW)</th><th>Frequency range (Hz)</th><th>Temporization (s)</th></tr>
<tr><td rowspan="2">≤ 30</td><td>> 60. 5</td><td>0.16</td></tr>
<tr><td>< 59.3</td><td>0.16</td></tr>
<tr><td rowspan="3">> 30</td><td>> 60.5</td><td>0.16</td></tr>
<tr><td>< (59.8 a 57.9) adjustable</td><td>0.16 a 300 adjustable</td></tr>
<tr><td>< 57.0</td><td>0.16</td></tr>
</table></td><td><table>
<tr><th>Power range (KW)</th><th>Frequency range (Hz)</th><th>Temporization (s)</th></tr>
<tr><td rowspan="2">≤ 30</td><td>> 60. 5</td><td>0.16</td></tr>
<tr><td>< 59.5</td><td>0.16</td></tr>
<tr><td rowspan="3">> 30</td><td>> 60.5</td><td>0.16</td></tr>
<tr><td>< (59.8 a 57) adjustable</td><td>0.16 a 300 adjustable</td></tr>
<tr><td>< 57.0</td><td>0.16</td></tr>
</table></td></tr>
<tr><td>>30kW: Adjustable settings</td><td>Normal frequency range: ±0.8%fn</td></tr>
<tr><td colspan="2">Active Power Control</td></tr>
<tr><td>Not mentioned</td><td>>1MW : active power control required: P curtailment and P gradient of 10% for reconnecting the power plant after disconnection</td></tr>
<tr><td colspan="2">Synchronization</td></tr>
</table>

<table>
<tr><td>Not mentioned.
The installation must not cause disturbances out of the range specified by the CFE
Re-synchronization: 5 minutes delay after voltage is within normal operational limits and frequency is between 59.3 and 60.5Hz</td><td>Synchronous generators:
<table>
<tr><th>Power (KW)</th><th>Δf(Hz)</th><th>ΔU(%)</th><th>Δφ (°)</th></tr>
<tr><td>0 – 500</td><td>0.3</td><td>10</td><td>20</td></tr>
<tr><td>> 500 – 1000</td><td>0.2</td><td>5</td><td>15</td></tr>
<tr><td>> 1000</td><td>0.1</td><td>3</td><td>10</td></tr>
</table>
Induction generator: V: 0.95 → 1.05 pu
Inverter:
Auto commutated: see synchronous generator
Other: see induction generator
Doubly-fed: see Synchronous generator</td></tr>
<tr><td colspan="2">Disconnection devices</td></tr>
<tr><td>Disconnection device accessible with interlocks
Delay for reconnection (adjustable of fixed at 5min)</td><td>>500kW: automatic circuit breaker
<500kW: fuses or contactors authorized
Delay for reconnection (adjustable of fixed at 5min)</td></tr>
<tr><td colspan="2">Protections</td></tr>
<tr><td>If fuses are installed it is recommended to use type K fast fuses

</td><td>Required protections:

Under-voltage (instantaneous/temporized)
Over-voltage (instantaneous/temporized)
Under-frequency (temporized)
Over-frequency (temporized)
Islanding / loss of main

Additionally:

Neutral displacement
Over-current
Phase to Ground fault detection
Negative power

<500kW: protection can be included in the control system
>500kW: external devices</td></tr>
<tr><td colspan="2">Voltage protection settings / voltage dip – swell requirements</td></tr>
<tr><td>Recommended time settings (Adjustable settings) for >30kW
Maximum time settings for ≤30kW
<table>
<tr><th>Voltage (%)</th><th>Temporization (s)</th></tr>
<tr><td>V < 50</td><td>0.16</td></tr>
<tr><td>50 ≤ V < 88</td><td>2.00</td></tr>
<tr><td>110 < V < 120</td><td>1.00</td></tr>
<tr><td>V ≥ 120</td><td>0.16</td></tr>
</table></td><td>Recommended time settings for >30kW
Maximum time settings for ≤30kW
<table>
<tr><th>Voltage (%)</th><th>Temporization (s)</th></tr>
<tr><td>V < 50</td><td>0.16</td></tr>
<tr><td>50 ≤ V < 88</td><td>2.00</td></tr>
<tr><td>110 < V < 120</td><td>1.00</td></tr>
<tr><td>V ≥ 120</td><td>0.16</td></tr>
</table></td></tr>
<tr><td colspan="2">Voltage Imbalance</td></tr>
<tr><td>Not mentioned</td><td>Voltage unbalance (10min)
MV < 2%
LV < 3%
(power plants <10kW can be single-phase)</td></tr>
<tr><td colspan="2">DC current</td></tr>
<tr><td>Not mentioned</td><td>DC current injection < 0.5%</td></tr>
</table>

<table>
<tr><td colspan="2">Flicker</td></tr>
<tr><td>Not mentioned</td><td>
<table>
<tr><th>Indicator</th><th>Limit</th></tr>
<tr><td>Pst</td><td>≤ 0.9 – 1.0</td></tr>
<tr><td>Plt</td><td>≤ 0.65</td></tr>
<tr><td>dt</td><td>≤ 3.3 % during voltage change longer than 500 ms</td></tr>
<tr><td>dc</td><td>≤ 3.3 %</td></tr>
<tr><td>Dmax</td><td>≤ 4 % without additional conditions
≤ 6 % for equipment manually commutated or connected/disconnected more than 2x/day
≤ 7 % for equipment connected/disconnected less than 2x/day</td></tr>
</table>
</td></tr>
<tr><td colspan="2">Harmonics :</td></tr>
<tr><td>Not mentioned</td><td>Table for max current and max voltage distortion given.</td></tr>
<tr><td colspan="2">Islanding</td></tr>
<tr><td>Detection and disconnection in less than 0.5s</td><td>De-energization of the feeder before reclosing operation</td></tr>
</table>

4.3 Reglas Generales de Interconexión al SEN parte II

4.3.1 General Comments

Part II of the interconnection rules deal with the connection of renewable generators and co-generation plants having a rating above 20MW to transmission levels (115kV, 230kV and 400kV).

The general impression is that the document is a mixture between operational guidelines for system operators and actual connection conditions for power plants. In many cases, it is unclear what the actual rule will be to which a power plant operator has to comply with.

4.3.2 Comments on 2 "Requirementos de operación y control"

4.3.2.1 Comments on the Required Voltage Ranges

Section 2 starts with a table describing the required voltage ranges. However, the displayed table seems to relate to system operational practice. The sentence below states that under exceptional circumstances the limits according to the table can be exceeded by up to +/-3%.

In terms of connection conditions this means that no disconnection of a power plant is allowed in case of a voltage range of -13% and +8%.

In the case that a distinction between "normal" and "exceptional" operating conditions shall be made, a clarification about the active and reactive power requirements of the power plant should be made, e.g. is it only required to stay connected in the "exceptional range" or is the expectation that the power plant continues operating without any restriction if voltage leaves the "normal operating range".

4.3.2.2 Comments on 2.1 "Suministro de potencia reactiva"

The main aspects of this section can be summarized as follows:

- Reactive power range: power factor of 0,95 inductive/capacitive (at the generator terminals, not connection point)
- 4 different control modes have to be supported
- Synchronous generators require AVR and PSS
- Control system must be stable

The reader assumes that the first three paragraphs of the section "Control de tension transitoria" relates to synchronous generators and the last 5 paragraphs of this section relate to other generator technologies. This aspect should be made very clear.

With regard to the actual reactive power range, the required behavior under partial load conditions is not clear. A power factor definition typically implies that the max./min reactive power is in function of the actually delivered active power.

In power transmission systems however, a reactive power limit that is independent from the active power level is usually more appropriate.

Hence, it is recommended to give a detail description of the required reactive power range:

- In function of voltage
- In function of actually delivered active power

Besides this, the definition of a reactive power capability at the terminals of each individual unit is a quite unusual approach. The available reactive power range at the grid connection point is of more relevance to the system operator and therefore, this is typically the point at which a reactive power range is defined. It is then up to the wind park planner to decide whether to meet the reactive power requirements by the reactive power capability of the generators only or by the help of additional components such as switched capacitor banks or dynamic var compensators (SVCs, STATCOMS, etc.).

4.3.2.3 Comments on 2.2 "Control de frecuencia" and 2.3 "Salida de Potencia Activa"

The whole section seems to be copied from the Grid Code of National Grid/U.K. (see [9]). National Grid requires that "power park modules" (e.g. wind farms) with a rating above 50MW are equipped with the technical capability to provide primary and secondary frequency services. The requirements as such are the same for all types of power plants, including thermal power plants.

It has to be pointed out that all requirements stated in connection conditions only ask for the technical capability, which does not imply that all these features are necessarily used during actual system operation.

The actual provision of primary and secondary frequency control services actually depends on the wind farm operator who can offer such services on corresponding markets and will be remunerated for it.

It is unclear to the consultant, if the corresponding CFE requirements have to be seen in the same context, e.g. if they only ask for the technical capability of renewable generators to provide frequency control services or if they will actually have to provide it during normal operation conditions.

Equipping renewable generation plants with the required technology for frequency control is nowadays feasible and increases investment costs moderately. However, when asking renewable generators to actually contribute to the low frequency response of a system this implies that they will permanently generate below the maximum available power for being able to provide additional active power under low frequency situations. Because this is not combined with any fuel savings, this mode of operation leads to high Not Delivered Energies and is therefore very costly.

For this reason, no wind farm has ever contributed to the actual low or high frequency reserve in the U.K., even if large wind farms having such capabilities exist.

It is further unclear to the consultant if the sections relating to frequency control and active power output are consistent with the rest of the CFE power system. Only if the frequency control performance of all power plants is consistent, corresponding requirements should actually be applied.

For these reasons, it is advisable to rethink these two sections and possibly to adjust them to the performance of the Mexican power system.

4.3.2.4 Comments on 2.7 "Medición" and "Comunicación"

The document requires a number of measurements, which are described at relatively high level. Some measurements shall be taken from individual units, which is not the usual practice. Typically, wind farms are connected to the developer dispatching center. The developer dispatching center can be connected to the operator's dispatching center and send aggregated wind farm measurements P, Q or max. available capacity etc. It is not very useful for the operator to receive signals from each unit of the wind farm; it would generate a large amount of data to be sent and received.

4.3.2.5 Comments on 2.8 "Servicio de Soporte de Red"

It is understood from this section that:

- Generators, including renewable power plants and co-generation plant are asked to provide frequency control and reactive power -control services if their rating is >50MW

- Generators which a capacity <50MW that can be considered to be "parks" (e.g. wind farms) only have to provide reactive power services.

- HVDC stations have to provide frequency control and reactive power control services

- Generators of medium size have to provide only reactive power control services.

Based on this understanding of the corresponding section, the consultant has the following comments:

- Why are HVDC stations listed here? Actually they are not part of the scope of this document.

- What has to be understood by "have to support those services"? The technical capabilities with regard to reactive power control and frequency control services are already described in other sections of this document. Does it mean that they have to support it during actual operation? If this is the case, the next question would obviously be, in which way, e.g. frequency control services will be remunerated.

Generally, it is recommended to remove this section from the connection conditions. Technical capabilities for e.g. reactive power control or frequency control are already defined in other sections. The way to integrate these services into the market (if such market exists) is not subject to connection conditions but to other part of a grid code or even bilateral agreements.

However, if services such as frequency control shall be offered free of charge to the system operator, the corresponding requirement would be inacceptable to private power plant operators.

4.3.3 Comments on Section 3 "Condiciones de disturbio »

4.3.3.1 Comments 3.2 "Soporte ante Fallas"

The voltage dip shapes given in the document are taken from National Grid's grid code (UK) and don't seem to be based on the properties of the Mexican grid. The typical voltage shape for clearing a three-leg circuit (Figura 1 of the proposed document) is not inline with the stated fault clearing times according to section 3.1.

Besides this, the consultant has the impression that not all aspects of the NG Grid Code have been interpreted correctly by the authors of the proposed CFE connection conditions for renewable generation and co-generation plants.

Particularly, there are the following comments:

The meaning of the following sentence is not clear "La planta generadora será diseñada de tal forma que una falla en la red de transmisión se liberará en 140 ms y la tensión en el PAC se recuperará en 0.5 segundos." The power plant is not responsible for the clearing time of a fault in the grid; the voltage recovery time depends on the characteristics of the grid. The power plant should be, off course, designed to help the voltage to recover by limiting reactive power consumption and if possible providing reactive power.

"Las plantas generadoras de tipo inversores estarán diseñadas para cumplir con la característica de recuperación de potencia activa en el tiempo de liberación de falla indicado anteriormente": the requirement for active power restoration alter fault is not stipulated in the document; but according to the characteristics of the grid, grid codes can give a maximum time to restore the active power to the level it was before the fault or give a power restoration slope.

Making reference to the NG voltage envelope (Figura 2 of the CFE connection conditions), the document states: "En esta caso, el nivel de tensión deberá recuperarse al 80% en 1.2 segundos, al 85% en 2.5 segundos y al 90% en 3 minutos.": it can be understood that it is the responsibility of the generation plant to restore voltage up to 80% in 1.2s, 85% in 2.5s or 90% in 3 minutes. It is important to note that this figure does not represent the voltage shape of a typical voltage dip but an envelope above which National Grid assumes that all credible voltage variations will be. It is important to understand that this can be interpreted as the "survival capability" of the power plant. The power plant must remain connected in case of voltage dips of 80% during 1.2s, 85% during 2.5s or 90% for up to 3 minutes.

If low-voltage ride-through capability is required from the generator, the settings of low voltage protections should be computed to not trip or prevent the LVRT mode from running.

4.3.4 Comments on Section 4 "Calidad de la energía"

Requirements in this section are similar to what can be found in other grid codes; based on international standard like IEC 61000-3-6, 61000-3-7, IEEE 519, etc.

For harmonics, it is well indicated that measurements and assessments are done at the PCC; Also flicker requirements should be applied to the PCC, which is not state explicitly.

4.3.5 Comments on Section 5 "Formación de Islas"

It is understood from the proposed connection conditions that all power plants >100MW should be able to operate in island mode.

For renewable generators, it is extremely difficult to operate in island conditions. On the other hand, they can be restarted very quickly compared to thermal power plants. For this reason, wind farms and other renewable energy plants are typically not required to operate in island conditions.

4.3.6 Comments on Section 7 "Estudios et Información Entregada"

Section 7 details the type of data and models that have to be delivered to CFE for performing a set of power system analysis studies.

The actual description of the studies that CFE will carry out seems to be a guideline for CFE. It is unclear if it's also possible to an power plant applicant to ask a consultant to do the required range of studies and to submit the results to CFE.

4.3.7 Comments on Section 8 “Pruebas”

Section 8 lists a set of tests that have to be carried out for verifying the different requirements of the connection conditions.

Fault ride through tests on individual wind generators are not part of those tests. It would be advisable to ask for test certificates of individual generating units for verifying their actual fault ride through capability, which is nowadays common practice.

5 Lessons Learned from Other Countries

The development of wind generation and solar generation in Germany, Spain (and Denmark in case of wind generation) started around 10 years earlier than in the rest of the world.

The development of renewable energy sources was mainly driven by the support schemes (e.g. feed-in tariff schemes in Germany and Spain), which provides a very high security of investment and minimizes the administrative overhead, which made these technologies also interesting to private investors.

5.1 Connection Conditions and Grid Codes

Most of the problems related wind generation reported by Spain and Germany in the late nineties and beginning of this decade were related to the absence of reasonable technical requirements for these types of generation, particularly no FRT-capability of the connected units.

Initially, wind generators have even been asked to disconnect under low voltage conditions because network operators were afraid of dynamic voltage stability problems as they are typical for directly connected induction generators (first generation of wind generators). Only with the introduction of variable speed wind generators, either based on DFIG or fully rated converters, FRT capability could be asked for without the risk of dynamic voltage collapse.

Because of the vast growth of wind generators, system operators soon recognized that there was a risk of a high loss of generation subsequently to a fault at a major transmission level leading to a short voltage sag in a large area of the grid. As a result of such a vast drop of generation, voltage stability or frequency stability problems have been reported.

Because modern wind generators don't show any risk for dynamic voltage collapse any more, low voltage ride-through capability should be asked for from the beginning of the development of renewable generation on.

Besides low voltage ride-through, low frequency-ride-through and automatic active power reduction in case of high frequencies is essential requirements that avoid many problems when being considered in corresponding grid codes.

5.2 System Operation

Generally, the operation of the German, Spanish and Danish power systems works smoothly without an excessive overhead in terms of tools or human resources. Of course there are additional challenges but so far it has been possible to cope with those with a reasonable effort.

The operation of a power system with a high amount of solar and wind generation requires prediction tools that allow for a day-ahead and hours-ahead prediction. Such prediction tools can reduce the amount of regulatory reserve, which has to be preserved for compensating wind variations and allow for a more reliable forecast of grid congestions.

For ensuring a safe network operation, it is essential that the system operator can limit the power production of renewable energy power plants. For this reason, corresponding interfaces allowing system operators to limit the production of wind farms are nowadays mandatory in Germany.

5.3 Black Out/System Restoration

During the "brown out" of the interconnected European system in November 2007, the following observations with regard to renewable generation could be made:

- The reason for the "brown out" was not related to renewable generation but to a fault of the system operators.

- Because of the high amount of distributed generation in Germany (wind, no PV during nighttimes), the amount of shed load was higher than it would have to be for stabilizing the grid frequency. This was mainly due to the fact load shedding relays act on complete distribution feeders and therefore disconnected load and distributed generation. The ability to shed load at the MV/LV transformers would avoid this problem but add a high level of complexity to the load shedding scheme.

- During system restoration, the automatic resynchronisation of wind generators has been a disturbing effect. During system restoration, it is very important to balance the system in each island before resynchronising these islands to the rest of the system. Because of the automatic resynchronisation of wind farms the balancing has been even more challenging. As a consequence, it must be possible to the system operator to disable remotely the automatic resynchronisation feature of renewable generators.

6 Summary and Conclusions

This first draft of deliverable 1 of this project provides an overview about the international practice with regard to connection rules for power plants based on renewable energies and co-generation and summarizes the related status quo in Mexico.

Generally, the processes for obtaining a connection agreement are reasonably well defined and supported by technical guidelines that address the most relevant aspects.

However, the timelines for obtaining the required contracts and permissions sums up to around 200 working days, which is close to 10 months. These timelines probably represent the ideal situation. In practical application processes there are probably additional delays. This duration seems to be very long, especially for small scale generation projects.

Besides this, there seems to be an automatic mechanism in place leading automatically to a negative answer if CFE doesn't answer within the given time frame. A rule stating that CFE must answer within the given time frame, either with a positive answer or a negative answer together with the reasons for their decision would be advisable.

Besides this, another weak point is that there seems to be a lack of consistency between different rules for the connection of different generation technologies. There exist connection rules for individual generator technologies but no clear and consistent document that would be applicable to all types of generation in Mexico, including CFE's own power plants.

But as stated above, the quality of the actual rules is generally all right. However, according to feed-back from project developers in Mexico, it seems that the biggest problems are related to the actual implementation of the rules rather than the rules themselves. There have been complaints with regard to the availability of documents and with regard to actual time frames needed for carrying out grid impact and feasibility studies.

The newly proposed connection rules are more consistent in a way that they cover a wider range of generation technologies. However, a clear and consistent document describing the requirements for all types of power plant technologies, like The Grid Code of National Grid is still missing.

The newly proposed connection conditions [18] and [19] have been analysed in chapter 4 of this report. The general conclusion is that

- The documents address all relevant technical aspects, such as reactive power control, behaviour during grid disturbances or frequency control.

- However, the documents are not very consistent but rather copied from many international grid code standards.

- Part 2 doesn't represent a very clear set of rules for applicants but represent a mix of operational guidelines and connection conditions. The grid code for wind generators [16] has been much clearer with regard to this aspect.

- It is generally unclear what services are actually required from wind generators and for which services only the technical capabilities have to be ensured.

It is therefore recommended to revise these documents, particularly with regard to the above mentioned aspects.

Another problematic aspect seems to be related to time frame and results of feasibility and grid impact studies that are carried out be the Mexican system operator CFE. The connection conditions for wind generation for example describe the type of studies that will be carried out by CFE for evaluating the feasibility of a wind farm project and for identifying the necessary grid reinforcement, but it is not stated in any document what the evaluation criteria for accepting a wind generation project are. It is also unclear, in which way results of studies are communicated and made transparent so that a connection applicant or an independent consultant can understand or even reproduce the results.

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