Project no.: 219123

Project acronym
REALISEGRID

Project title:
REseArch, methodoLogIes and technologieS for the effective development of pan-European key GRID infrastructures to support the achievement of a reliable, competitive and sustainable electricity supply

Instrument: Collaborative project
Thematic priority: ENERGY.2007.7.3.4

Analysis and scenarios of energy infrastructure evolution
Start date of project: 01 September 2008
Duration: 30 months

D3.1.1
Review of existing methods for transmission planning and for grid connection of wind power plants

Revision: Final Version

Actual submission date: 2009-06-15

Organisation name of lead contractor for this deliverable:
Commission of the European Communities - Directorate General Joint Research Centre (JRC) - Institute for Energy

<table>
<thead>
<tr>
<th>Dissemination Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>Public</td>
</tr>
<tr>
<td>PP</td>
<td>Restricted to other programme participants (including the Commission Services)</td>
</tr>
<tr>
<td>RE</td>
<td>Restricted to a group specified by the consortium (including the Commission Services)</td>
</tr>
<tr>
<td>CO</td>
<td>Confidential, only for members of the consortium (including the Commission Services)</td>
</tr>
</tbody>
</table>
Abstract

The present Report, after offering an overview of the regulatory and market framework affecting the EU transmission system at large, and the renewable energy deployment in particular,
- lists and compares the technical requirements and the charging policy for the connection of new power plants to the European transmission grid, specifically focusing on wind generation (whenever related technical specifications are applied);
- provides an updated picture of the European transmission network planning challenges and practices, also by devoting special attention to the interactions between system development and (onshore/offshore) wind deployment.
TABLE OF CONTENTS

ACRONYMS AND DEFINITIONS .......................................................................................................................... 9
A. General terms .................................................................................................................................................. 9
B. Primary, Secondary and Tertiary control (UCTE definitions) ................................................................. 11

LIST OF TABLES AND FIGURES ...................................................................................................................... 13

ACKNOWLEDGEMENTS ........................................................................................................................................ 14

1 EXECUTIVE SUMMARY .................................................................................................................................... 15

2 INTRODUCTION .................................................................................................................................................. 21
2.1 Objectives of this deliverable ...................................................................................................................... 21
2.2 Expected outcome ......................................................................................................................................... 21
2.3 Approach ...................................................................................................................................................... 22

3 THE EUROPEAN ELECTRIC TRANSMISSION SYSTEM ............................................................................ 24
3.1 Regulatory and market framework in the EU ............................................................................................ 24
3.2 The European transmission system .......................................................................................................... 27
3.3 TSOs and Grid codes in the European transmission system ......................................................................... 29

4 CONNECTION OF WIND POWER PLANTS IN EUROPE .............................................................................. 34
4.1 Overview of technical regulations .............................................................................................................. 34
4.2 Comparison of common Grid Code requirements ..................................................................................... 35
4.2.1 Voltage and frequency operating limits .................................................................................................. 35
4.2.2 Active power control ................................................................................................................................ 38
4.2.3 Reactive power control (power factor control and voltage regulation) .................................................... 40
4.2.4 Low voltage/Fault ride through capability .............................................................................................. 44
4.3 Wind grid connection charges .................................................................................................................... 47
4.4 Developments on wind connection practices ............................................................................................ 53

5 TRANSMISSION NETWORK PLANNING IN EUROPE .................................................................................. 54
5.1 The transmission network planning challenges ........................................................................................ 54
5.2 The transmission network planning objectives .......................................................................................... 54
5.3 The transmission planning process ............................................................................................................ 55
5.3.1 Network planning horizon ...................................................................................................................... 56
5.3.2 Generation adequacy assessment .......................................................................................................... 57
5.3.3 Role of the interconnections .................................................................................................................. 58
5.3.4 Cost-benefit analyses and market value ................................................................................................. 59
5.4 Wind integration in a market environment ................................................................................................. 60
5.4.1 Planning and connection practices for wind integration ........................................................................... 60
5.4.2 Plans for offshore wind ........................................................................................................................... 61
5.5 Recent plans and planning practices in some EU countries ........................................................................ 63
5.5.1 UCTE area .............................................................................................................................................. 63
5.5.2 NORDEL area ....................................................................................................................................... 65
5.5.3 Central Western Europe area .................................................................................................................. 67
5.5.4 Austria ..................................................................................................................................................... 68
5.5.5 France ..................................................................................................................................................... 68
5.5.6 Germany ................................................................................................................................................ 71
6 CONCLUSIONS .................................................................................................................. 90
6.1 Main findings ............................................................................................................... 90
6.2 Way forward ............................................................................................................ 91
REFERENCES .................................................................................................................... 93
A. European legislation, regulatory framework and initiatives ........................................... 93
B. Main documents relevant for grid connection and planning ........................................... 94
C. Technical studies, books, scientific papers and reports .................................................. 101
D. Other documents from associations and platforms ......................................................... 102
A ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES ...................... 105
A.1 BELGIUM .................................................................................................................. 105
A.1.1 Grid access requirements for (wind) generators at transmission level ...................... 105
A.1.2 Regulatory aspects of generation connection to the grid ........................................... 107
A.2 CZECH REPUBLIC .................................................................................................... 108
A.2.1 Grid access requirements for (wind) generators at transmission level ...................... 108
A.2.2 Regulatory aspects of generation connection to the grid ........................................... 108
A.2.3 Regulatory and financial aspects of grid expansion .................................................. 109
A.3 DENMARK ................................................................................................................ 110
A.3.1 Grid access requirements for (wind) generators at transmission level ...................... 110
A.3.2 Regulatory aspects of generation connection to the grid ........................................... 113
A.3.3 Regulatory and financial aspects of grid expansion .................................................. 113
A.4 FRANCE .................................................................................................................... 114
A.4.1 Grid access requirements for (wind) generators at transmission level ...................... 114
A.4.2 Regulatory aspects of generation connection to the grid ........................................... 119
A.4.3 Regulatory and financial aspects of grid expansion .................................................. 120
A.5 GERMANY ................................................................................................................ 121
A.5.1 Grid access requirements for (wind) generators at transmission level ...................... 121
A.5.2 Regulatory aspects of generation connection to the grid ........................................... 128
A.6 IRELAND ................................................................................................................... 129
A.6.1 Grid access requirements for (wind) generators at transmission level ...................... 129
A.6.2 Regulatory aspects of generation connection to the grid ........................................... 133
A.6.3 Regulatory and financial aspects of grid expansion .................................................. 133
A.7 ITALY ........................................................................................................................ 134
A.7.1 Grid access requirements for (wind) generators at transmission level ...................... 134
A.7.2 Regulatory aspects of generation connection to the grid ........................................... 137
A.7.3 Regulatory and financial aspects of grid expansion .................................................. 137
A.8 THE NETHERLANDS ............................................................................................... 138
A.8.1 Grid access requirements for (wind) generators at transmission level ...................... 138
A.8.2 Regulatory aspects of generation connection to the grid ........................................... 139
A.8.3 Regulatory and financial aspects of grid expansion .................................................. 140
A.9 POLAND ................................................................................................................... 141
A.9.1 Grid access requirements for (wind) generators at transmission level ...................... 141
A.10 PORTUGAL ............................................................................................................. 142
A.10.1 Grid access requirements for (wind) generators at transmission level ...................... 142
A.10.2 Regulatory aspects of generation connection to the grid ........................................... 142
A.10.3 Regulatory and financial aspects of grid expansion .................................................. 143
A.11 ROMANIA ............................................................................................................... 144
A.11.1 Grid access requirements for (wind) generators at transmission level .......... 144
A.12 SPAIN ..................................................................................................................... 146
A.12.1 Grid access requirements for (wind) generators at transmission level .......... 146
A.12.2 Regulatory aspects of generation connection to the grid ......................... 148
A.12.3 Regulatory and financial aspects of grid expansion ................................. 149
A.13 UK ........................................................................................................................ 150
A.13.1 Grid access requirements for (wind) generators at transmission level .......... 150
A.13.2 Regulatory aspects of generation connection to the grid ......................... 153
A.13.3 Regulatory and financial aspects of grid expansion ................................. 153
ACRONYMS AND DEFINITIONS

A. General terms

AC: Alternating Current.

Adequacy: ability of the electric system to supply the aggregate electrical demand and meet energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of system facilities (See also Reliability, Security).

ATSOI: association of the Irish transmission system operators (See also ENTSO-E).

BALTSO: association of the Baltic transmission system operators of Estonia, Latvia and Lithuania (See also ENTSO-E).

Capacity Credit: percentage of conventional capacity that a given turbine can replace.

Capacity Factor (load factor): is the ratio between the average generated power in a given period and the installed (rated) power.

Control area: portion of the generation and transmission system controlled by a single TSO. It corresponds to a country’s area in most cases (See also TSO).

DC: Direct Current.

EC: European Commission.

EENS: Expected Energy Not Supplied (See also EUE).

EHV: Extra High Voltage.

EIA: Environmental Impact Assessment.

ETSO: European Transmission System Operators association (See also ENTSO-E).

ENTSO-E: European Network of Transmission System Operators for Electricity. New organisation grouping 42 European Transmission System Operators established in late 2008 (to be operative from mid 2009). Existing associations such as ETSO, UCTE, NORDEL, BALTSO, UKTSOA and ATSOI will be dissolved and their tasks and functions will be moved to the new organisation (See also ETSO, UCTE, NORDEL, BALTSO, UKTSOA and ATSOI).

EU: European Union.

EU15: 15 EU Member States (before 2004).

EU25: 25 EU Member States (until 2006).

EU27: 27 EU Member States (from 2007).

EPNS: Expected Power Not Served. Power measure of the electric system’s capability to serve all loads.

EUE: Expected Unserved Energy. Energy measure of the electric system’s capability to serve all loads.

FACTS: Flexible Alternating Current Transmission System. Power electronics-based devices able to control different parameters (including voltage amplitude and angular difference, active and reactive power flow, impedance) in power systems.

FRT: Fault Ride Through. Capability of a wind turbine to remain connected to the grid during severe disturbances on the electricity system, and return to normal operation after the disturbance ends.

GB: Great Britain.

HVAC: High Voltage Alternating Current.

HVDC: High Voltage Direct Current. An HVDC link consists of a cable or overhead line where current is transmitted in direct (instead of alternating) mode.
Interconnection: This document adopts the term “interconnection” solely when referring to a transmission line connecting two power systems and not – differently from what done in some technical documents - with reference to the connection and/or integration into the networks of (wind) power plants.


ISO: Independent System Operator. An ISO is responsible for the management of a transmission system, but does not own the transmission assets (See also TSO).

LOLE: Loss of Load Expectation. Expected amount of energy not served over some time frame.

LOLP: Loss of Load Probability. Probability over some period of time that the power system will fail to provide uninterrupted service to customers.

(N-1) criterion: rule according to which elements remaining in operation after failure of a single network element (such as transmission line / transformer or generating unit) must be capable of accommodating the change of flows in the network caused by that single failure, maintaining the required level of network security.

NORDEL: association of Nordic transmission system operators of Denmark, Finland, Iceland, Norway and Sweden (See also ENTSO-E).

NTC: Net Transfer Capacity. NTC is the maximum power exchange between two areas which is compatible with security standards applicable in both areas, taking into account technical uncertainties as to future network conditions. The NTC values represent technical constraints used in many transmission capacity allocation methods. Furthermore, non-binding NTC values are periodically published by ETSO. NTC=TTC-TRM (See also TTC and TRM).

Overhead line: electric line suspended by towers or poles. Since most of the insulation is provided by air, overhead lines are generally the lowest-cost method of transmission for bulk electric power. Towers for support are usually made of steel (either lattice structures or tubular poles) or concrete. The conductors are generally made of aluminium, either plain or reinforced with steel or sometimes composite materials.

PCC: Point of Common Coupling. Conventional point defining the border between the generator’s and transmission plants.

PST: Phase Shifting Transformer. Mechanical device able to control active power flow in power systems by regulating voltage angular difference.

Reliability: it describes the degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within acceptable standards and in the amount desired. Reliability on the transmission level may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply / transport / generation. Reliability is the sum of adequacy and security (See also Adequacy and Security).

RES: Renewable Energy Source.

SEA: Strategic Environmental Assessment.

Security: ability of the electric system to withstand sudden disturbances, such as electric short circuits or unanticipated loss of system components. Another aspect of security is system integrity, which is the ability to maintain interconnected operations (See also Security of Supply).

Security of supply: ability of the electric power system to provide electricity to end-users with a specified level of continuity and quality in a sustainable manner (See also Security).

Stability: the ability of an electrical system to withstand normal and abnormal system conditions or disturbances and to regain a state of equilibrium.
TEN: Trans-European Networks.
TRM: Transmission Reliability Margin. It is a security margin to cope with uncertainties in the computed TTC arising from unintended deviations in physical flows, emergency exchanges or inaccuracies (See also TTC, NTC).
TSO: Transmission System Operator. It owns the transmission assets and is responsible for the management of the transmission system in its control area (See also Control area, ISO).
TTC: Total Transfer Capacity. It is the maximum exchange between two areas which is compatible with operational security standards applicable to both areas, where future network conditions, generation and load patterns are perfectly known in advance (See also NTC, TRM).
UCTE: Union for the Coordination of the Transport of Electricity. It is the association of the transmission system operators of continental Europe (See also ENTSO-E).
UK: United Kingdom.
UKTSOA: association of the British transmission system operators (See also ENTSO-E).
WAMS: Wide Area Measurement System.
WPP: Wind Power Plant.

B. Primary, Secondary and Tertiary control (UCTE definitions)

Primary Control (or Frequency Control, or Primary Frequency Control): automatic decentralised function of the turbine governor to adjust the generator output of a unit as a consequence of a frequency deviation/offset in the synchronous area. It maintains the balance between generation and demand in the network using turbine speed governors. Primary control should be distributed as evenly as possible over units in operation in the synchronous area. The global primary control behaviour of an interconnection partner (control area / block), may be assessed by the calculation of the equivalent droop of the area (basically resulting from the droop of all generators and the self-regulation of the total demand). By the joint action of all interconnected undertakings, primary control ensures the operational reliability for the power system of the synchronous area.

Primary Control Power: power output of a generation set due to primary control.
Primary Control Range: range of adjustment of primary control power, within which primary controllers can provide automatic control, in both directions, in response to a frequency deviation. The concept of the primary control range applies to each generator, each control area / block, and the entire synchronous area.
Primary Control Reserve: (positive / negative) part of the primary control range measured from the working point prior to the disturbance up to the maximum primary control power (taking account of a limiter). The concept of the primary control reserve applies to each generator, each control area / block, and the entire synchronous area.
Primary Controller: decentralised / locally installed control equipment for a generation set to control the valves of the turbine based on the speed of the generator (for synchronous generators directly coupled to the electric system frequency). The insensitivity of the primary controller is defined by the limit frequencies between which the controller does not respond.
Secondary Control (or Load-Frequency-control): centralised automatic function to regulate the generation in a control area based on secondary control reserves in order to maintain its interchange power flow at the control program with all other control areas (and to correct the loss of capacity in a control area affected by a loss of production). At the same time, aim of this function (in case of a major frequency deviation originating from the control area,
particularly after the loss of a large generation unit) is also to restore the frequency in case of a frequency deviation originating from the control area to its set value, in order to free the capacity engaged by the primary control (and to restore the primary control reserves). In order to fulfil these functions, secondary control is applied to selected generator sets in the power plants comprising this control loop. Secondary control operates for periods of several minutes, and is therefore dissociated from primary control.

**Secondary Control Range**: range of adjustment of the secondary control power, within which the secondary controller can operate automatically, in both directions at the time concerned, from the working point of the secondary control power.

**Secondary Control Reserve**: positive / negative part of the secondary control range between the working point and the maximum / minimum value. The portion of the secondary control range already activated at the working point is the secondary control power.

**Secondary Controller**: it is the single centralised TSO-equipment per control area / block for operation of secondary control.

**Tertiary Control**: any (automatic or) manual change in the working points of generators (mainly by re-scheduling), in order to restore an adequate secondary control reserve at the right time.

**Tertiary Control Reserve (or Minute Reserve or 15-Minute Reserve)**: power which can be connected (automatically or) manually under tertiary control, in order to provide an adequate secondary control reserve. This reserve must be used in such a way that it will contribute to the restoration of the secondary control range when required. The restoration of an adequate secondary control range may take, for example, up to 15 minutes, whereas tertiary control for the optimisation of the network and generating system will not necessarily be completed after this time.
LIST OF TABLES AND FIGURES

LIST OF TABLES

Table 3-1: Operator, system and grid code features ................................................................. 30
Table 4-1: Reactive power supply requirements: a comparison among some European countries. .................................................................................................................. 42
Table 4-2: Summary of connection charging methods ................................................................. 48
Table 4-3: Grid connection charges for grid expansion in EU27 ................................................ 51
Table 5-1: Comparison of planning practices in some EU27 countries ..................................... 56

LIST OF FIGURES

Figure 1: TSOs cooperation in UCTE, NORDEL, UKTSOA, ATSOI, BALTSO [102]. ............ 28
Figure 2: Synchronous Systems in Europe [85]. ........................................................................ 29
Figure 3: Voltage – frequency operating ranges: comparison. ..................................................... 36
Figure 4: Comparison of required frequency operating limits ..................................................... 36
Figure 5: Reactive power control range for normal operation of a wind turbine ...................... 41
Figure 6: Requirements for power factor variation range in relation to the voltage, according to the German and British Grid Codes, for normal frequency range and P=P_n ...................................................... 43
Figure 7: Comparison among the LVRT requirements for wind power plants in different EU27 countries .................................................................................................................................. 45
Figure 8: Voltage support during faults by reactive current feed in Spain and Germany (present [42] and proposed [43] requirements) .............................................................................. 46
Figure 9: Economic implications of a network investment postponement .................................... 70
Figure 10: GB Generation connection opportunities [79]. ......................................................... 74
Figure 11: Example of costs and benefits in the Italian transmission planning [53] ................. 81
Figure 12: Network planning strategies for wind connection in Italy ........................................ 82
Figure 13: Vision2030 grid concept ............................................................................................ 86
ACKNOWLEDGEMENTS

A steady interaction and information exchange with the project partners and with industrial/research stakeholders has been a key to validate and consolidate the results of this Report.

The authors are particularly grateful for data provided and helpful comments on various versions of the Report to the TSO colleagues partners of REALISEGRID: Klemens Reich and Oliver Wadosch (Verbund-APG, Austria), Philippe Adam and Xavier Gallet (RTE International, France), Kees Jansen (TenneT, Netherlands), Enrico Maria Carlini and Chiara Vergine (Terna, Italy).

The authors wish also to thank Gianluigi Migliavacca (CESI RICERCA), Project Coordinator of REALISEGRID, for the useful suggestions on the Report, and Wil Kling (TU Delft), Stathis Peteves, Roberto Lacal Arantegui, Joana Correia Serpa and Helder Lopes Ferreira (JRC-Institute for Energy) for their great help at various stages of the drafting.
1 EXECUTIVE SUMMARY

The present Report aims at analysing current methods adopted for transmission planning and for grid connection/integration of large wind power plants in Europe.

After a technical and regulatory overview of the European power transmission system, the report focuses firstly on the technical requirements posed on the wind turbines in order to be connected to the power grid. Because of the constantly increasing size of both wind turbines and wind farms, wind connection requests at transmission level are more and more frequent and have become presently a common practice in many countries. Consequently, many Transmission System Operators (TSOs) are changing the grid connection rules for wind power plants. The current trend in Europe is that the amount and severity of these requirements is generally increasing with the respective wind penetration level.

The most important specifications for wind farm connection to the transmission grid, introduced over the last years and generally contained in the Grid Codes of the TSOs, refer to: voltage and frequency operating limits, active and reactive power control, and fault-ride through capability. These key requirements have been assessed through a systematic and easy-to-visualize comparison and the main outcomes are summarised in the following:

- **Voltage and frequency operating limits.** Wind farms must be capable of operating continuously within the voltage and frequency variation limits encountered in the normal system operation. Moreover, they should remain in operation in case of voltage and frequency excursions outside the normal operation limits, for a limited time and at reduced output power capability. A comparison carried out among some European countries shows how the most extreme frequency limits are 47 Hz (e.g. for Great Britain, France, Ireland and Romania) and 53 Hz (Denmark and Finland). Regarding the voltage ranges, the most extreme values are 70-80% (respectively in The Netherlands and in Czech Republic), on one side, and 115% the rated voltage (in Italy) on the other side.

- **Active power control.** In all the countries that have a Grid Code setting requirements for wind generation connection, the wind power plants must be able to control their active power production. It must be possible to limit the active power production (power curtailment) at a reference value (set-point) defined by the TSO whenever the wind power plant is in operation. The reference value must be set locally or remotely (in automatic fashion): in Germany, it corresponds to a percentage value related to the network connection capacity; in Romania, it is comprised between the technical minimum and the installed capacity; in Denmark, Finland and Sweden, it is comprised between 20% and 100% of the wind plant’s rated power.

  Frequency response and fast down regulation of active power are also required in case of wide frequency deviations (disturbances). As an example, in Ireland, Italy and Romania, it is required that a frequency response system controls active power according to a prescribed response curve.

- **Reactive power control.** Recent Grid Codes demand from wind farms to provide reactive power output regulation, often in response to power system voltage variations, as conventional power plants do. Wind turbines also have to contribute to voltage regulation in the system.
A comparison of some of the existing reactive power control ranges for normal operation of a wind turbine is conducted. The widest ranges can be encountered in Germany. In Denmark, Great Britain and Ireland there are also clear specifications on how this control should be done.

- **Low voltage / Fault-ride through capability.** The large increase in the connected wind capacity in the transmission system needs wind generation to remain in operation in the event of network disturbances. For this reason, Grid Codes issued during the last years invariably demand that wind turbines and wind farms (especially those connected to the high voltage grids) must withstand voltage dips to a certain percentage of the nominal voltage and for a specified duration. Such requirement is known as Fault Ride Through or Low Voltage Ride Through capability and is described by a voltage vs. time characteristic, denoting the severity of faults or low voltages the wind power station must be capable to withstand without disconnecting. The Fault Ride Through capability also includes fast active and reactive power restoration to the pre-fault values, after the system voltage returns to normal operation levels. Some Grid Codes (e.g. in Denmark, Germany, Great Britain, Ireland, Romania and Spain) impose increased reactive power generation by the wind turbines during the disturbance, in order to provide voltage support: this requirement resembles the behaviour of conventional synchronous generators in over-excited operation.

A comparison among the Low Voltage Ride Through requirements in different European countries shows that the most demanding TSOs are those ones of Belgium, Finland, Germany, Great Britain and Sweden, in which a capability for voltage dips bringing voltage level down to zero is required.

An assessment of the wind connection charging methods and policies in all the 27 European Union (EU) countries has been then conducted. Grid connection procedures are accompanied by grid connection costs that may include all or a part of the necessary transmission expansion costs. Hence, the connection of new wind farms is also influenced by the way the grid connection costs are shared between the involved parties. The research performed highlights extremely varying charging methods in the EU, ranging from shallow (when the generator pays only for the cost of equipment needed to make the physical connection to the grid) to deep (when the generator pays for the cost of the physical connection to the network along with the costs of any upstream grid work arising from the generator’s connection).

In some countries (France, Latvia, Portugal, Spain, Sweden), the costs are low (shallow) if the expansion is to the general public benefit, but the costs are high (deep) if the expansion is only to the benefit of the plant operator. Therefore, remotely located wind farms (especially off-shore ones) can be affected by high connection charges. Some other countries do not openly mention a favourite charging method, as it is determined on a case-by-case basis.

This Report focuses then further on a broad assessment of the network planning practices in Europe, yet devoting a special section to the planning issues for wind integration.

The transmission network planning is a very complex process and recent trends and challenges make it even more complicate.
In the past, before the electricity market liberalisation, the transmission network was expanded with the aim to minimise both generation and transmission costs, while meeting static and dynamic technical constraints, to ensure a secure and economically efficient operation.

According to UCTE (Union for the Coordination of the Transport of Electricity), the association of continental Europe TSOs, today the TSOs aim at two main objectives when planning the development of the transmission grid: maximising system reliability and security of supply and fostering market, to allow an efficient use of generation, thereby minimising the total costs. In a competitive market, the TSO plans the expansion of its network by minimising transmission cost (investment and operation) and pursuing maximum social welfare, while meeting static and dynamic technical constraints to ensure a secure and economically efficient operation. Resolving then the trade-off between minimum transmission investment cost versus maximum social welfare is a complicated task and results in different objective functions for different TSOs. A major challenge for the TSO planning departments is to reconcile short-term market-based needs with longer-term policy-based and security of supply needs. Transmission investments certainly help also to mitigate the possible exercise of market power, which generally leads to socio-economic losses.

The basic tasks of the grid planners can be summarised as follows: to forecast the power and energy flows on the transmission network, drawing upon a set of scenarios of generation/demand evolution for the targeted period; to check whether or not acceptable technical limits might be exceeded, in standard conditions as well as in case of loss of system components; to devise a set of possible strategies/solutions to overcome the criticalities and to select the one(s) having the best cost/benefit performance.

The TSOs must nowadays take timely actions in an environment characterised by increasing uncertainties. In this context, with several decisions being out of TSOs’ control, proper assumptions must be made not only on the evolution of parameters such as production and consumption, but also policy measures and market mechanisms shall be considered accordingly.

What emerges clearly by the screening of many Grid Codes and planning documents is that the network planning and the generation connection processes are two separate yet intrinsically interlinked procedures. Power production evolution in general - and large wind deployment in particular - (rather than demand) tends to exert the greatest influence in terms of new requirements placed on the transmission system. This particularly applies to wind electricity, which has not simply to be connected to the closest busbar of the grid but, most importantly, has to be effectively integrated into the system through targeted network development and optimization actions.

An overview of the deterministic and probabilistic analyses carried out by the TSOs has been then executed. The results show how, notwithstanding stochastic elements are more and more pervading the current power systems, probabilistic approaches - which would help in better capturing the evolution of the system to take into account e.g. the stochastic nature of wind production - are not yet fully implemented; in some cases, they mainly aim to complement deterministic analyses, upon which the planning decisions are primarily made (i.e. the probabilistic analyses are not integrated with the overall planning process).
Transmission planning should be focused on two directions: a better coordination between national TSOs and an improvement of the transmission planning methods. The main keys to obtaining a reliable and effective European grid are integrated strategic planning and cross-border coordination. To this purpose Grid Codes, policies and regulations should be harmonised for facilitating trans-national projects. Existing transmission planning methods commonly make use of a worst-case scenario approach: power flow analysis is performed for a small number of cases selected by experienced network planners. However, this approach is not sufficient anymore, as the reduced number of cases analyzed limits the validity of the results. With the increased uncertainty and the many assumptions necessary for the analysis, the need of capturing more combinations of load, (renewable) generation and international exchange is becoming essential for gaining a robust planning under a variety of possible scenarios. A probabilistic approach to deal with such uncertainties should be developed. For each combination the risk for insufficient transmission capacity (e.g. line overloads, voltage limit violations) should be evaluated.

The network planning procedures of NORDEL, the association of Nordic TSOs, can be certainly mentioned as best practice, especially now that the time horizon of the planning/adequacy assessment has been stretched beyond the short-term market dynamics. During the last decade, the planning process of NORDEL has proceeded in the direction of an integrated Nordic cooperation concerning grid reinforcements and expansions, in order to ensure a well functioning regional electricity market. International aspects and environmental impacts are also duly taken into account.

Additionally, it is worth reminding that, 42 European TSO companies - from 34 countries - proactively founded in 2008 the new organisation European Network of Transmission System Operators for Electricity (ENTSO-E), as asked for by the European Commission in the proposal for a third electricity & gas liberalisation package. This new association, incorporating the main European Transmission System Operators organisations, will be crucial to further strengthen the cooperation in a number of key areas, such as the production of technical and market-related network codes, and the coordination of system operation and grid planning and development.

Concerning the multinational interactions on planning activities, whilst in the past TSOs consulted the bordering counterparts only in case of new interconnection projects, nowadays this cooperation is becoming recurrent and involves more TSOs potentially affected by the new projects. As far as merchant interconnections are concerned, there is no much experience in the continental Europe, except for Italy (even if local opposition hampers also the building of such lines). Successful international cooperation on merchant lines is on the other hand recorded in North Europe (e.g. The Netherlands and NORDEL countries).

Another major stumbling block for the network planning and development activities lies in the authorisation for building new transmission assets. Unfortunately, the time required to get the permit is generally much longer than the time needed to build new power plants (by at least a factor 3 to 5). The extensive and time consuming permitting procedures needs to be streamlined in order to accelerate the modernisation of ageing transmission infrastructures. The recent tendency to involve several stakeholders – including general public – at an early stage of the planning and development process aims to overcome the local resistances which can indefinitely prolong the authorisation phase. To this respect, a valued initiative has been the
appointment of European coordinators by the European Commission to monitor and foster the implementation of critical European priority projects. By means of the facilitation of the cross-border dialogue and the help on the coordination of national procedures for consulting stakeholders, some promising results on accelerating the authorisation process (e.g. on the new France-Spain) begin to be achieved.

An aspect not yet appearing among the priority concerns of most of the network planners is the intertwined development of transmission and distribution networks, due to the deployment of distributed generation and SmartGrids concepts. In general, TSOs still have to devise strategies to address in a systemic way the issues deriving from future developments towards SmartGrids. These aspects should not be neglected in the near future.

Coming to the offshore wind deployment in North Europe, several stakeholders are now proposing and discussing dedicated plans for multinational grids. Their contribution to increased security of supply, their function for the aggregation and dispatch of power from offshore wind farms (by e.g. allowing hydro power import from Norway to the British and the UCTE system), and their role as exchange and trade facilitator between power systems are among the recognised benefits of such grids.

The development of offshore wind power will increase the need for grid reinforcements of the existing onshore grid. In some countries (e.g. Germany), bottlenecks already exist and/or are expected to increase in the event of significant wind capacity expansion in the North Sea. Offshore projects can represent an opportunity for creating lines that both connect new generation capacity and establish or increase transmission capacity between different regions in the EU internal electricity market. Clearly, such potential synergies between offshore projects and cross-border inter-connectors face the additional complexities of dealing with different planning and regulatory regimes. The prospects of regional offshore energy grid plans also call for the development of a more harmonised and market-based framework of support to trade. Additionally, in contrast to spatial planning on land, the European countries generally have limited experience with integrated spatial planning in the marine environment.

In conclusion, whilst this assessment confirms the existence of a significant degree of fragmentation and inconsistency of the technical and regulatory rules adopted for wind power connection in Europe, it also highlights preliminary attempts for increased harmonisation of generation connection practices and promising initiatives for an improved interregional and international collaboration on planning issues. Notwithstanding this, it is apparent how the transmission planning will have to drastically change and to adapt to new situations and uncertainties given by market opening from one side and renewable power integration on the other side.

Additionally, it is also noted that further efforts both in terms of harmonized approaches and cooperation initiatives – for example by engaging stakeholders supporting different interests (e.g. such as wind proponents and network operators) - are needed for the effective wind integration in the European liberalised power system. As an example, a tighter cooperation in the framework of the European industrial initiatives on grids, wind (and solar) energy, to be launched in the context of the European Strategic Energy Technology Plan (SET-Plan), would certainly contribute to serve this purpose.
The review conducted through this work - particularly the part comparing the actual grid planning criteria - serves also to set the scene for further work within the REALISEGRID project, focusing on new transmission planning methods and tools to support, monitor and steer the ongoing changes in the European power system.
2 INTRODUCTION

This Chapter firstly recaps the main objectives of this report: the description of the European state-of-play of the TSO transmission planning methods and of the grid connection rules (especially for wind power plants). The outcome of the deliverable is then defined, by detailing the contents of the different Chapters touching upon technical and regulatory aspects for grid planning and generation connection. Finally, the twofold approach followed to pursue these targets is illustrated in terms of methodology and line of action.

2.1 Objectives of this deliverable

The present report has two main objectives: to describe the state-of-play, at European transmission level, of the network planning approaches and methodologies, as carried out by the Transmission System Operators (TSOs); and to assess the current procedures and requirements for the connection to the grid of new power plants. With regard to this latter point, wind generating units are the main subject of this analysis, to the extent to which dedicated criteria and specifications are already defined and deployed by the TSOs in Europe.

Since the existing methods for transmission planning widely vary over the European countries and the same lack of harmonisation characterises the grid connection rules of wind plants, this report intends:

- to gauge the current degree of fragmentation of these planning and connection processes and to single out best practices;
- to highlight the techno-economic drivers underpinning the investment decisions of the transmission network planners and of the wind generation applicants;
- to set the scene for further work within the REALISEGRID project focusing on new transmission planning methods and tools to support, monitor and steer the ongoing changes in the European power system.

The geographic perimeter of most of the analyses performed in this report is the transmission system of the 27 countries currently member of the European Union (EU27 or EU 27 Member States); a selected number of EU27 national/regional transmission grids already experiencing a large wind power penetration and/or having high potentials on this front are then the subject of a more in-depth assessment.

As far as the voltage levels boundaries are concerned, this work mainly concentrates on the Extra High Voltage (EHV) network, here defined as the infrastructure featuring a rated voltage equal to or higher than 220 kV. Nevertheless, some aspects related to transmission networks at lower voltage levels - in particular, the High Voltage (HV) grid (having voltages higher than 100 kV) - are also addressed, especially in the more detailed country screening available in the Annex.

2.2 Expected outcome

In order to achieve the above described objectives, this report has been structured in two main Chapters, Chapter 4 and Chapter 5, respectively tackling the wind grid connection issues and the network planning challenges, reporting the experiences of a selected number of EU countries. The reader interested in having an insight of data underpinning the analyses or in consulting specific aspects especially of certain national connection practices, can find in the Annex A information on a vast number of EU Member States.
Chapter 3 firstly gives an overview of the regulatory framework for the electricity and the wind sectors. Then it introduces the European electric transmission system by providing brief information on the main features of the electricity network and of the TSOs system operation and planning.

Chapter 4 describes the current practices adopted by the TSOs for the connection of wind power plants to the transmission network, focusing on the technical regulations and executing a comparison of the main Grid Code requirements. This Chapter also introduces the most common terms related to grid connection costs, briefly comparing the wind connection charging philosophies in Europe as well.

Chapter 5 focuses on the transmission planning challenges in a market environment with increasing wind deployment. The methods and practices adopted by industry for transmission planning in Europe are therefore described. With more specific regard to transmission planning for wind integration in Europe, the barriers for the applicant vis-à-vis the criticalities for the system are illustrated. Subsequently, a summary of the transmission planning criteria and methods for wind integration and a list of network planning challenges for on-shore and off-shore wind farms are addressed. Finally, specific industrial experiences of some European countries are portrayed.

In the end, Chapter 6 summarises the main findings and suggests a way forward.

The Annex A includes an extended collection of the research efforts made - for a large number of EU27 transmission systems - for mining data, summarising information and highlighting features from the main documents relevant for grid connection and planning. Specifically it covers: the grid access requirements for wind at transmission level (in particular low voltage/fault ride through capability, voltage/frequency operating limits, active and reactive power control), the specifications for the connection to the grid, the regulatory framework for grid expansion.

2.3 Approach

The approach followed to gather data and information needed for this report has been twofold:

- On one side, a country-based scrutiny of national grid codes, TSOs’ and regulatory authorities’ websites, technical guidelines, planning documents and regulations has been performed. In several cases the research highlighted the absence of explicit provisions and rules for wind connection, so that the focus had to be shifted to the general rules for generation connection.

- On the other side, a multi-national cross-cutting analysis of the outcomes of recent relevant European research projects, papers from sector associations, scientific articles and studies of international organisations has been conducted.

The bottom-up national-based assessment has been then matched with the top-down multi-national research in order to obtain an updated and clear picture of the practices currently adopted by the European Transmission System Operators for network planning and wind connection.

The evaluation and comparison of the existing practices and rules has proved to be arduous, mostly due to: the continuously changing provisions; the lack of harmonization, also in terms of a common technical glossary and language; the non-structured organization of information; the variety of legislation and regulations.
It has to be stressed that the present Deliverable D3.1.1 aims to illustrate real TSOs’ practices in transmission planning (i.e. present and future operative procedures as affected by market and wind), while the description of general transmission planning approaches and methodologies available in the scientific literature is part of another Deliverable, the D3.3.1. A steady interaction and information exchange with the other project partners and with other industrial stakeholders has been a key to validate and consolidate the results.
3 THE EUROPEAN ELECTRIC TRANSMISSION SYSTEM

This Chapter introduces the European electric transmission system in terms of regulatory and market framework at EU level and then focuses on the role of the TSOs in managing the European power grids.

3.1 Regulatory and market framework in the EU

Society and industry, in Europe and elsewhere, are increasingly dependent on the availability of electrical energy and therefore on the reliable operation of the electricity systems. In Europe, in response to concerns over security of energy supply, energy market restructuring and environmental pressures, the electric generation and transmission systems are experiencing trends which may significantly impact on their design and operation.

In Europe, as well as in other continents/countries, electricity industry is in the midst of a transition from a structure dominated by vertically integrated utilities to one dominated by competitive markets [83][102]. One of the consequences of the electricity market liberalisation has been the so-called ‘unbundling’ (separation) of former vertically integrated, monopolist utilities. This unbundling, in terms of ownership or functions, has concerned particularly the separation of generation from transmission. This entails that the returns on transmission investments are regulated, today, entirely at country level, while the profitability of generation investments, on the other hand, is determined largely by interactions in the frameworks of competitive markets.

The liberalisation process in Europe with the resulting electricity markets, has led to the facilitation of international trade between countries; consequently, inter-area power exchanges in electricity networks have significantly increased and further growth can be foreseen. Moreover, the penetration of Renewable Energy Sources for Electricity (RES-E) in particular onshore wind power plants, connected to the European grids, has been impressive in recent years; further grid connection of large-scale onshore and offshore wind power plants is expected, in order to meet Europe’s environmental and energy targets for 2020 and beyond.

Over the last ten years, the changes affecting the European system have led to: regularly occurring and quick shifts of power flows; increased interconnection of large synchronous areas (such as the Scandinavian and the Continental ones); and an increasing number of Direct Current interconnections and phase-shifting transformers installed [102].

The current electricity transmission system in Europe does not generally seem adequate to reliably cope with large-scale penetration of such variable power generation plants. Main common barriers to wind large-scale deployment are indeed represented by grid access and system integration. Flexible, coordinated and adequate transmission networks - designed according to modern architectural schemes and embedding innovative technological solutions - appear therefore crucial to globally address the above mentioned challenges and in particular to drive the process of integrating further renewable energy sources.

Even though it is clear that the increasing share of renewable electricity needs to be accommodated into the system, it is also apparent that a lack of harmonisation among the EU Member States presently characterises the grid connection for renewable technologies. The increasing share of renewable electricity does not simply have to be connected to the grid but it most importantly has to be effectively integrated into the system.

In most EU Member States the electricity grid has been developed under public ownership over decades, especially following the developments of the conventional energy sector. It is therefore
not surprising that access to the grid for new, private renewable energy producers is problematic. Grid access reforms are difficult to agree, even though the European Union already put forward legislative provisions requiring guaranteed access, rules for sharing and bearing the various grid investment costs necessary to integrate renewable electricity into the networks, and the use of system charges. Renewable energy is generally connected to network infrastructure as any other form of production. In particular, large-size wind farms are very dependent on adequate transmission capacity, as they are often situated further away from consumption centres. Thus, adequate development of network infrastructures is a precondition for the development and effective integration of renewable electricity.

Here in the following a brief, non-exhaustive summary of the recent EU legislation and actions primarily affecting the electricity transmission (with a special focus on planning and development) and wind sectors is reported.

- **Directive 2001/77/EC** [1] (promoting renewable electricity) encourages EU Member States to apply various support mechanisms in favour of green electricity production and it sets for the 2010 share of renewable electricity a EU25 target of 21% referred to the overall electricity consumption. The Directive includes provisions aimed at reducing or removing administrative and grid barriers: firstly, it requires Member States to evaluate rules and regulations relating to the authorisation of the construction and operation of renewable electricity plants, with a view to simplifying these procedures; secondly, it requires that renewable electricity is guaranteed access to the electricity grid, and if necessary, given priority access. In addition, Member States must put in place objective, non-discriminatory and transparent rules on the sharing and bearing of costs for grid infrastructure investments.

- **Directive 2003/54/EC** [2] (establishing common rules for the internal electricity market), while confirming that Grid Codes - including the requirements for connecting wind power plants - are a national responsibility, specifies that Member States have to ensure that the criteria are developed and made public, that these rules are objective and non-discriminatory, and that they ensure the interoperability of systems.

- **Directive 2005/89/EC** [3] (addressing security of supply issues) requires TSOs (and DSOs in some cases) to ensure that an appropriate level of network security is maintained and that stable and transparent market rules are in place to balance supply and demand. In addition, networks must have performance targets and the regulatory framework must provide appropriate signals for network development and support network maintenance.

- The Decision issued in 2006, laying down guidelines for trans-European energy networks [4], foresees the appointment of European coordinators in order to monitor and to facilitate the implementation of the most critical identified priority projects. The first four European coordinators (including the coordinator for offshore wind in Northern Europe) have been appointed on the 12 September 2007 by the European Commission to monitor high priority projects facing technical, political or financial difficulties [5]. They have specifically been tasked with promoting the European dimension of certain projects by facilitating cross-border dialogue and with helping to coordinate national procedures for consulting stakeholders.

- In 2007 the European Commission presented - and the EU Council endorsed - an 'energy and climate change package', including a Strategic Energy Review [5] focusing on both external and internal aspects of EU energy policy. The package contains proposals for specific targets on: renewable energy penetration (covering 20% of overall energy consumption by 2020);
biofuels penetration (10% in transport by 2020); greenhouse gas emissions reduction (20% respect to 1990 level by 2020); system efficiency increase (20% reduction of total energy demand). A Priority Interconnection Plan [7] was also presented.

• To make the internal market work for all consumers whether large or small, and to help the EU achieve more secure, competitive and sustainable energy, the European Commission proposed in September 2007, in its third liberalisation package [8]-[10], a number of measures to complement the existing rules. In relation to grid infrastructure development and large scale wind incorporation, the most relevant elements are:
  − New proposals for unbundling the transmission system from supply and production activities and for a closer international cooperation between TSOs in a European Network of Transmission System Operators for Electricity (ENTSO-E) [8]. Technical codes for grid connection should be consented under ENTSO-E, with strengthened European regulatory supervision and an open consultation with the relevant industry associations. The proposal creates the opportunity to strike a proper balance between requirements at wind plant and at network level, in order to ensure the most efficient and economically sound connection solutions.
  − The establishment of an independent Agency for Cooperation of Energy Regulators (ACER) [9].
  − The creation of a mechanism for transmission system operators to improve the coordination of cross-border trade, networks operation and grid security [10].
  A compromise on this legislative package was reached in April 2009 by the Council and the European Parliament in the context of a co-decision procedure.
  
• With the Communication on a Strategic Energy Technology Plan (SET-Plan) issued in 2007 [11], the Commission proposed to initiate a number of actions on European energy infrastructure networks, wind energy and systems transition planning. The underlying objective is to optimise and harmonise the development of low carbon integrated energy systems across the EU and its neighbouring countries and foster the development of tools and models for European level foresight in areas such as smart, bi-directional electricity grids, CO2 transport and storage and hydrogen distribution.

• The proposal for a new Directive on the promotion of energy from renewable energy sources, adopted in January 2008 and endorsed by the European Parliament in December 2008 [12], calls for the removal of unnecessary barriers to the growth of renewable energy. The proposal includes, amongst others, a stricter requirement on priority access of renewable electricity to the grid, and binding national targets for renewable energy. The proposal also includes strengthened provisions to reduce administrative barriers, to put in place planning mechanisms and improve the transparency of consenting procedures for building and operating renewable energy plants.

• Via the Communication on the Second Strategic Energy Review (An EU Energy Security and Solidarity Action Plan) [13], the European Commission has proposed a wide-ranging energy package which gives a new boost to energy security in Europe. This is done by putting forward a new strategy to build up energy solidarity among Member States and a new policy on energy networks to stimulate investments in more efficient, low-carbon energy systems. This Energy Security and Solidarity Action Plan aims at securing sustainable energy supplies in the EU within the challenges that Europe will face between 2020 and 2050, also adopting a package of energy efficiency proposals aims to make energy savings in key areas
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

(such as buildings and energy-using products). The most relevant specific pieces of legislation issued in 2008 are:

- Green Paper "Towards a secure, sustainable and competitive European energy network" [14].
- Report on the implementation of the trans-European energy networks programme in the period 2002-2006 [15].
- Communication "Offshore Wind Energy: Action needed to deliver on the energy policy objectives for 2020 and beyond" [16].

- The European Commission in November 2008 presented a comprehensive plan to drive Europe's recovery from the current economic crisis [17]. This European Economic Recovery Plan (EERP) considers "smart investment" to yield higher growth and sustainable prosperity in the longer-term. The EERP aims to boost efforts to tackle climate change, also promoting research and innovation, while creating much-needed jobs at the same time, through for example strategic investment in energy efficient buildings and technologies.
- In April 2009 the EU Council confirmed its agreement on a joint declaration with the European Parliament and the Commission on the financing of the EERP totalling 5.0 b€. The EERP provides for 3.98 b€ for energy projects [18]. In particular, several wind offshore and electricity interconnection projects are going to be co-financed by the EU funds.

3.2 The European transmission system

The pan-European transmission system consists of seven major supranational power systems:

- UCTE\(^1\) (Union for the Co-ordination of Transmission of Electricity) is the interconnected transmission system of continental Europe;
- NORDEL (Association of Nordic TSOs) includes the transmission systems of the Nordic countries (part of Denmark, Finland, Iceland, Norway and Sweden), which are interconnected except for Iceland;
- BALTSO (Association of Baltic TSOs) consists of the power systems of Estonia, Latvia and Lithuania, synchronously interconnected with the Russian IPS/UPS system and since 2006 asynchronously interconnected (via HVDC) with the Finnish power system;
- ATSOI (Association of TSOs of Ireland) covers the transmission systems of Republic of Ireland and Northern Ireland, which are now operated by the Irish TSO EirGrid;
- UKTSOA (United Kingdom’s TSOs Association) consists of the power transmission systems of England, Wales and Scotland (Great Britain) and is now operated by the British TSO NGT;
- IPS/UPS consists of the Integrated Power System of several Asian countries and the Unified Power System of Russia (IPS/UPS countries, in addition to Baltics, include: Belarus, Ukraine, Moldova, Russia, Georgia, Azerbaijan, Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Mongolia);
- TEIAS is the Turkish TSO operating the transmission system in Turkey.

---

\(^1\) The Albanian system is actually interconnected to the bordering UCTE transmission systems, but the Albanian TSO is still in the process of joining the UCTE organisation.
These networks are currently either weakly interconnected with each other through HVDC (High Voltage Direct Current) or back-to-back links (except for BALTSO, which is synchronously and strongly interconnected with the IPS/UPS system), or even not interconnected with each other. (It has to be remarked that some existing HVAC interconnection links between UCTE and IPS/UPS and between UCTE and TEIAS systems are presently not in operation, but they might be soon resumed [85][102]. The electricity networks of Cyprus and Malta are independent and presently not connected to the continental systems. The UCTE system is synchronously interconnected with the Maghreb countries in North Africa (via Morocco) and with Western Ukraine (Burshtyn island).

The high/extra high voltage electricity network across the EU consists of approximately 141,000 km of 380-400 kV overhead lines and 173,000 km of 220-330 kV lines. There are also roughly 4,500 km of underground cable at these voltages [84].

As reported by UCTE [102][103], most of the organisations supervising these different power systems implement some coordination among the involved TSOs, at the operational stage (see Figure 1) as well as at the planning stage. For example, the UCTE Operation Handbook [107] is a multilateral binding agreement between all the UCTE TSOs and it defines standards for security of supply and other important aspects for grid operation. The basic objective of the Operation Handbook is to ensure the interoperability among all TSOs connected to the UCTE synchronous areas.

On 19th December 2008, 42 European TSO companies - from 34 countries - proactively founded the new organisation European Network of Transmission System Operators for Electricity (ENTSO-E), as asked for in the proposal for a third electricity & gas liberalisation package by the European Commission, described in Section 3.1. This new ENTSO-E association incorporates the European Transmission System Operators association (ETSO) and the five TSO organisations shown in Figure 1: UCTE, NORDEL, UKTSOA, BALTSO and ATSOI.

**Figure 1: TSOs cooperation in UCTE, NORDEL, UKTSOA, ATSOI, BALTSO [103].**
The establishment of ENTSO-E aims to further strengthen TSO cooperation in a number of key areas, such as the development of technical and market-related network codes, and the coordination of system operation and grid development, with the goal of enhancing the integration of the European electricity market, contributing to a sustainable energy environment and ensuring secure and reliable operation of the European power transmission system.

A geographical overview with some key figures on the different synchronous systems in Europe is given in Figure 2, drawing upon the information reported in the study for the synchronous interconnection of the UCTE and IPS/UPS systems [85].

![Figure 2: Synchronous Systems in Europe [85].](image)

### 3.3 TSOs and Grid codes in the European transmission system

The following Table 3-1 reports the main elements and information related to the Transmission System Operators and the relevant Grid codes of the EU countries [27]-[80]. The Grid Codes consist of a set of technical/procedural rules - which transmission network operators and users are required to comply with - related to connection to and the operation and use of the transmission system.
Table 3-1: Operator, system and grid code features of EU countries.

<table>
<thead>
<tr>
<th>EU Country</th>
<th>Operator and system features</th>
<th>Grid code (or similar document)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>TIWAG Netz AG (<a href="http://www.tiwag-netz.at">www.tiwag-netz.at</a>)</td>
<td>380 kV 220 kV 110 kV (and lower)</td>
</tr>
<tr>
<td></td>
<td>Verbund APG (<a href="http://www.apg.at">www.apg.at</a>)</td>
<td>380 kV 220 kV 110 kV (and lower)</td>
</tr>
<tr>
<td></td>
<td>VKW-Netz AG (<a href="http://www.vkw-netz.at">www.vkw-netz.at</a>)</td>
<td>380 kV 220 kV 110 kV (and lower)</td>
</tr>
<tr>
<td>Cyprus</td>
<td>DSM (<a href="http://www.dsm.org.cy">www.dsm.org.cy</a>)</td>
<td>220 kV 132 kV</td>
</tr>
<tr>
<td>EU Country</td>
<td>Operator and system features</td>
<td>Network voltage levels operated</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Finland</td>
<td>Fingrid OyJ (<a href="http://www.fingrid.fi">www.fingrid.fi</a>)</td>
<td>400 kV, 220 kV, 110 kV</td>
</tr>
<tr>
<td>France</td>
<td>RTE (<a href="http://www.rte-france.com">www.rte-france.com</a>)</td>
<td>400 kV, 225 kV, 150 kV, 90 kV, 63 kV</td>
</tr>
<tr>
<td></td>
<td>E.ON Netz (<a href="http://www.eon-netz.com">www.eon-netz.com</a>)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RWE (<a href="http://www.rwetransportnetzstrome.com">www.rwetransportnetzstrome.com</a>)</td>
<td>380 kV, 220 kV</td>
</tr>
<tr>
<td></td>
<td>EnBW TNG (<a href="http://www.enbw.com">www.enbw.com</a>)</td>
<td>380 kV, 220 kV</td>
</tr>
<tr>
<td></td>
<td>Vattenfall Europe T. (<a href="http://www.vattenfall.de">www.vattenfall.de</a>)</td>
<td>380 kV, 220 kV</td>
</tr>
<tr>
<td>Greece</td>
<td>HTSO/DESMIE (<a href="http://www.desmie.gr">www.desmie.gr</a>)</td>
<td>380 kV, 150 kV, 66 kV</td>
</tr>
<tr>
<td>Italy</td>
<td>Terna (<a href="http://www.terna.it">www.terna.it</a>)</td>
<td>380 kV, 220 kV, 120-150 kV</td>
</tr>
<tr>
<td>EU Country</td>
<td>Operator and system features</td>
<td>Network voltage levels operated</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Netherlands</td>
<td>TenneT (<a href="http://www.tennet.org">www.tennet.org</a>)</td>
<td>380 kV/220 kV/150 kV/110 kV</td>
</tr>
</tbody>
</table>
### Operator and system features

<table>
<thead>
<tr>
<th>EU Country</th>
<th>TSO (webpage)</th>
<th>Network voltage levels operated</th>
<th>Name (Issue date)</th>
<th>Weblink</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SONI (<a href="http://www.soni.btd.uk">www.soni.btd.uk</a>)</td>
<td>380 kV 275 kV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SSE (<a href="http://www.scottish-southern.co.uk">www.scottish-southern.co.uk</a>)</td>
<td>380 kV 275 kV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SPT (<a href="http://www.scottishpower.com">www.scottishpower.com</a>)</td>
<td>380 kV 275 kV</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

² This Grid Code is applied in Great Britain, not in Northern Ireland.
4 CONNECTION OF WIND POWER PLANTS IN EUROPE

This Chapter, after introducing the wind connection challenges, describes the peculiarities of wind farms for the connection to the transmission grids in Europe, listing and comparing the requirements for wind farms stipulated by European TSOs.

4.1 Overview of technical regulations

In absence of international standards regarding the connection of wind power plants to the grid, there are a large number of national or regional requirements, rules and guidelines for the grid connection of wind turbines or wind farms all over the globe [96]. Since their introduction, connection rules for wind turbines have been continuously modified, especially at distribution network level, where most of the wind power plants have been initially connected. This incessant adjustment is due to the increasing wind power penetration, the rapid development of wind turbine technology [96] and in general to the global pursuit for green energy.

Because of the continuously increasing size of both wind turbines and wind farms, connection requests of wind farms at transmission level are more and more frequent and at present have become a common practice in some countries with a developed wind power industry (e.g. Germany, Spain). Therefore, grid connection rules for wind power plants at transmission level have become necessary, also in Europe. Consequently, many European countries have developed such regulations and the amount and severity of these requirements are generally proportional to the respective wind penetration level.

The guidelines for wind connection to the transmission networks are generally included in the so-called Grid Codes. The Grid Codes consist of a set of technical/procedural rules - which transmission network operators and users are required to comply with - related to connection to and the operation and use of the transmission system.

The evaluation and comparison of the existing grid connection rules for the European countries have proved to be complex, mostly due to:

- the continuously changing grid connection requirements [98];
- the lack of harmonisation of Grid Codes between countries (the differences in the type of requirements and in the manner in which they are presented make their comparison rather difficult; the unavailability of some Grid Codes in English or in other internationally used language is also a barrier);
- the lack of an organised information structure (not all countries have a clear Grid Code posted on the Transmission System Operator’s web page; there are many cases with several Decisions and Decrees concerning grid connection rules which may be scattered, not consistently organised and sometimes ambiguous).

According to [96] a comparison might be useful for reducing controversies between wind farm developers and network operators, for understanding better the relevant issues for each country, for helping the turbine manufacturers to comply with the requirements and for contributing to the European harmonisation of connection rules.

The following paragraphs provide a comparison of the existing European grid connection rules for wind power plants and also an evaluation of the most important ones. The international standards (IEC 61400-21, IEEE 519) that deal with power quality issues are not the subject of
this report. Only the most important aspects of wind farm transmission grid connection will be
discussed and therefore the main emphasis is placed on the requirements that have been
introduced in the last few years and concern active and reactive power regulation, voltage
regulation and wind farm behaviour during grid disturbances [23].
As the main focus of this Report is on the transmission system, only the connection rules for
wind plants and wind farms at voltage level of 110 kV or higher will be analysed.

4.2 Comparison of common Grid Code requirements

This section focuses on the most common grid connection requirements [23] for wind power
plants, which are those addressing the following features: system voltage and frequency control,
active power control, reactive power (power factor and voltage regulation) control, fault-ride
through capabilities.
The following comparison aims at giving an updated overview on the conditions for wind
connection to the grid of the European TSOs.
The grid connection requirements for wind turbines are generally valid at the PCC (Point of
Common Coupling) with the transmission system. The PCC is in most cases defined on the high-
voltage side of the step-up transformer [22]. The information and the requirements hereinafter
presented have been taken from the national Grid Codes and from other different documents
[19], [27]-[80].

4.2.1 Voltage and frequency operating limits

Wind farms must be capable of operating continuously within the voltage and frequency
variation limits encountered in the normal operation of the system. Moreover, they should
remain in operation in case of voltage and frequency excursions outside the normal operation
limits, for a limited time and at reduced output power capability [23].
Figure 3 shows a comparison between the voltage-frequency operating ranges for some of the
EU27 countries. Similarly, for other EU27 countries, for which complete f-U requirements are
not available, Figure 4 illustrates a comparison between frequency operating ranges with some
indications regarding the duration of operation and a few voltage limits. All EU27 countries
operate at a nominal frequency of 50 Hz.
It can be noticed that the most extreme frequency limits are 47 and 53 Hz. Finland and
Denmark require operation for frequencies between 47.5 Hz and 53 Hz. In Czech Republic [33]
and in Sweden [77] also there are stringent requirements regarding the frequency operating
range at nominal active power. In Great Britain [78] a continuous operation for \(47.5 \text{ Hz} \leq f \leq 52 \text{ Hz}\) is required. In Italy the requirement is a continuous operation for a frequency range
between 47.5 Hz and 51.5 Hz and between 85% and 115% \(U_n\), without any specifications
regarding the output power [53].
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

Figure 3: Voltage – frequency operating ranges: comparison.

Figure 4: Comparison of required frequency operating limits.
In Great Britain the active power output of wind power plants shall be independent of system frequency within the normal operating range 49.5 – 50.5 Hz and should not drop with system frequency by greater than 5% [78].

Regarding the voltage ranges, in addition to the illustrated information, there are the following voltage ranges:

- In Ireland: 350 ÷ 420 kV for the 380 kV system; 200 ÷ 245 kV for the 220 kV system and 99 ÷ 123 kV for the 110 kV system. Inside these ranges the WPP (wind power plant) must operate continuously at maximum available active power or controlled active power and for step changes in the grid of up to 10% [46].
- In Romania the WPP must operate continuously if the voltage at the PCC is comprised in the interval 0.90 ÷ 1.10 Un [70].
- In France any power plant must be able to connect synchronously to the transmission grid when simultaneously the system’s frequency is within 49 Hz and 51 Hz and the voltage at the PCC takes any value within ±12 % Un.
- Unless abnormal conditions prevail, the voltage on the 400 kV part of the Great Britain’s (GB) transmission system at each PCC will normally have to remain within ±5% of the nominal value, the minimum voltage is -10% and the maximum voltage is +10%, but voltages between +5% and +10% will not last longer than 15 minutes. Voltages on the 275 kV and 132 kV parts of the GB transmission system PCC will normally have to remain within the limits ±10% of the nominal value unless abnormal conditions prevail [78].
- In the Czech Republic values for permitted delivered active and reactive power or alternatively their time limitations must be defined by the unit for the frequency ranges \( f_{\text{min}} \) to 48.5 Hz and 50.5 Hz to \( f_{\text{max}} \) and simultaneously for terminal voltage ranges 80% to 95% and 105% to 110% of the nominal voltage [33]. The most extreme voltage ranges are 70% Un (in the Netherlands [62]) and 115% Un (in Italy). However in the Netherlands the requirements are valid for all power plants, as a special code for wind generation has not been developed yet. Consequently, the next lower voltage limit is 80% Un in the Czech Republic.

In addition, the Grid Code in Germany [42] also requires the following conditions:

- The generating facility must be disconnected from the network with a time delay of 0.5 seconds if the voltage at the grid connection point decreases and remains at or below a value of 85% of the reference voltage (380/220/110 kV) and if reactive power is simultaneously consumed at the grid connection point (under-excited operation).
- One fourth of the generators must disconnect from the network after 1.5 s, after 1.8 s, after 2.1 s and after 2.4 s, respectively, if the voltage at the generator’s point (i.e. at the low-voltage side of the generator’s transformer, while the high voltage side corresponds to a voltage value of 380/220/110 kV) remains at or below 80% of the lower value of the normal voltage range. The voltage value relates to the largest value of the three phase-to-phase network voltages.
- If the voltage at the low side of each individual generator’s transformer rises and remains at or above a value of 120% of the upper value of the voltage range, the concerned generator must disconnect from the network with a time delay of 100 ms. The voltage value relates to the lowest value of the three line-to-line network voltages.
4.2.2 Active power control

These requirements refer to the ability of wind farms to regulate their output power to a defined level (e.g. in case of active power curtailment requests), either by disconnecting turbines or by pitch control action. In addition, in certain cases/systems, wind farms are required to provide frequency response, which is the automatic adjustment of their active power output in response to frequency deviations [23].

In general, power production and consumption have to be in balance within a power system. Changes in power supply or demand can lead to a temporary imbalance in the system and affect operating conditions of power plants as well as of consumers’ loads. In order to avoid long-term unbalanced conditions the power demand is forecasted and power plants accordingly adjust their power production. In the power system, the frequency is an indicator of the balance or imbalance between production and consumption. For normal power system operation, the frequency has to be close to its nominal value. In the European power systems, the frequency most generally lies in the range 50±0.1 Hz. In the case of an imbalance between production and consumption, primary, secondary and tertiary control are used to return to a balanced system [83], [96].

The requirements regarding active power control of wind farms aim to ensure a stable frequency in the system, to prevent overloading of transmission lines, to ensure compliance with power quality standards and to avoid large voltage jumps and in-rush currents during start-up and shutdown of wind turbines [96].

Modern variable speed wind turbines are connected to the system through power electronics interfaces, which have the capability of providing a primary frequency response similar to that one of conventional generators [100]. However this response is limited by minimum rotating speed and stability margin of the controller at low wind speeds, and by the converter rating at high wind speeds.

In all the countries that have a Grid Code which includes requirements for wind generation connection, the WPPs must be able to control their active power production. The following control functions can be required:

- It must be possible to limit the active power production (power curtailment) of the WPP at a reference value (set-point) defined by the grid operator whenever the WPP is in operation. The size of the reference value must be set locally or automatically and corresponds to a percentage value related to the network connection capacity in **Germany** [42], it is comprised between the technical minimum and the installed capacity in **Romania** and between 20% and 100% of the wind plant’s rated power in **Finland, Sweden** and **Denmark (NORDEL)**. In **NORDEL** [19] and **Romania** [70], the set-point shall control that the active power production, measured as a 10 minute average value, does not have to exceed a specified level; the active power control at the connection point must be ensured with a precision of ±5% of the installed capacity. In **Ireland** [46] the implementation of the set-point shall commence within 10 seconds of receipt of the signal from the TSO. During normal operation, ramping control of active power production to the reference value must be possible. Ramping control is also required for start-ups and shut-downs of wind farms.
  - In **Germany** [42], the reduction of the power output to the signalized value must take place with at least 10% of the network connection capacity per minute without disconnection of the plant from the network.
o Also in Romania [70] the power ramp rate setting must be done with at least 10% of the installed capacity per minute.

o In Ireland [52], the rate of change of output to achieve active power control set-point should be no less than maximum ramp rate settings of the wind farm control system, as advised by the TSO.

o In NORDEL [19] it must be possible to limit the ramping speed of active power production from the wind turbine in upwards direction to 10% of the rated power per minute and it must be also possible to limit the down ramping speed to 10% of rated power per minute when the maximum power output is reduced by a control action.

o In addition, in Sweden, at a stop due to strong wind, not all the wind turbines in a wind farm may be stopped at the same time and not more than 30 MW/min may be disconnected [77].

o In Italy, in the presence of suitable weather conditions the plant has to make the parallel with the network by increasing gradually the power injected in the network. When increasing the produced active power, a positive gradient of maximum 20% of the installed active power per minute is allowed. A wind power plant should not be connected to the network at frequencies above 50.3 Hz [53].

• Frequency response and fast down regulation of active power are also required in case of wide frequency deviations (disturbances). According to UCTE [103] the whole primary control reserve of an area must be completely activated in answer to a quasi-state frequency deviation of more than ±200 mHz. For restricting the action of the primary control reserve only to unscheduled power unbalances, under undisturbed conditions the frequency deviations should not exceed for long periods the ±20 mHz range.

o In Germany, all renewables-based generating units must reduce, while in operation at a frequency higher than 50.2 Hz, the instantaneous active power with a gradient of 40% of the generator’s instantaneously available capacity per Hertz. If the frequency returns to a value of \( f \leq 50.05 \) Hz, the active power may be increased again as long as the actual frequency does not exceed 50.2 Hz. This control is realised in a decentralized manner (at each individual generator) and the neutral zone must be below 10 mHz [42].

o In NORDEL [19], it must be possible to regulate the active power from the wind turbine down from 100% to 20% of rated power in less than 5 seconds; in addition frequency control should be provided with a control function proportional to frequency deviations.

o In Ireland [52], Romania [70] it is required that a frequency response system controls active power according to a prescribed response curve. In Ireland, the response rate of each available wind generator shall be a minimum be at least 60% of its rated capacity per minute (MW/min). The Romanian Grid Code requires that at frequency variations from the electrical power system, the WPP must have the capability to ensure the reduction of the active power with at least 40% of the installed capacity per Hz at the rise of frequency above 50.2 Hz; also it must be able to ensure the rise of active power up to the maximum limit of available active power, at the frequency drop below 49.8 Hz. Additionally, the modification of the produced active power due to frequency deviations must be made as much as possible by modifying the produced active power of each group.
of the wind farm, and not by starting and stopping groups. The response time of each operating wind power generator must be at least 60% of the nominal power per minute (MW/min).

- In **Italy** the Grid Code requires all groups with rated power over 10 MVA to contribute to the primary frequency control, excepting the ones that are not controllable. It is therefore required that the wind power plants are equipped with frequency response system that controls active power according to a prescribed response curve. The active power control system must enable the reduction of the active power production according to the value of the positive frequency error, overall equivalent speed droop within the interval 2% - 5% for frequencies between to 50.3 Hz 51.5 Hz. Usually the required speed-droop is 2.4%. Also the control system must guarantee response times that allow the reduction of half of the controllable active power in maximum 15 seconds and of the entire power reserve in 30 seconds from the frequency deviation. Moreover the regulator should have a dead band calibrated between 0 mHz and 200 mHz.

- In **Great Britain** it is required that all wind farms with an installed capacity equal or higher than 50 MW must be fit with an appropriate device for providing frequency response under normal operating conditions. The frequency control device must meet some minimum requirements. Firstly, when a WPP becomes isolated from the rest of the system, but still supplies customers, it must be able to control system frequency below 52 Hz unless it has to operate below its designed minimum operating level; the WPP is only required to operate within the range 47÷52 Hz (see Figure 4). Secondly, the frequency control device must be capable of being set so that it operates with an overall equivalent speed droop of between 3% and 5%. Lastly, the dead band should be no greater than 30 mHz (±15 mHz).

- In **France** wind farms do not have to participate at the active power control but they have to be equipped with a controller that enables them to reduce the output power when the frequency exceeds 50.5 Hz. The power must decrease by 25% from 500 mHz of frequency deviation and must be zero at 52 Hz. In the **Netherlands** wind power plants are exempted from active power control.

### 4.2.3 Reactive power control (power factor control and voltage regulation)

Reactive power control is essential for wind farms, as wind farms are often installed in remote areas and therefore reactive power has to be transported over long distances resulting in losses. Recent Grid Codes demand from wind farms to provide reactive power output regulation, often in response to power system voltage variations, as conventional power plants do. The reactive power control requirements are related to the characteristics of each network, since the influence of the reactive power injection on the voltage level depends on the network short circuit capacity and impedance. Some codes prescribe that the TSO may define a set-point value for voltage or power factor or reactive power at the wind farm’s connection point [23].

Utility and customer equipment is designed to operate at a certain voltage rating. Voltage regulators and reactive power controllers at connection points are used in order to keep the voltage within the required limits and avoid voltage stability problems. Wind turbines also have to contribute to voltage regulation in the system; the requirements either refer to a certain voltage
range that has to be maintained at the point of connection of a wind turbine or wind farm, or to a certain reactive power compensation that has to be provided. Required reactive power compensation is defined in terms of power factor range [96].

![Diagram of reactive power control range for normal operation of a wind turbine.](image)

**Figure 5: Reactive power control range for normal operation of a wind turbine.**

Figure 5 shows a comparison between some of the existing reactive power control ranges for normal operation of a wind turbine (normal voltage domain). The widest ranges can be encountered in Germany, where in [43] three variants of such ranges are proposed; wind farms must agree with the TSO which of the three variants they should respect. In Ireland, Great Britain and Denmark there are also clear specifications on how this control should be done.

In Great Britain, all wind power plants must be capable of maintaining zero transfer of reactive power at the PCC at all active power output levels under steady state voltage conditions; the steady state tolerance on reactive power transfer to and from the GB transmission system expressed in MVar shall not exceed 5% of the rated MW. The reactive power output under steady state conditions should be fully available within the voltage range ±5% at 400 kV, 275 kV and 132 kV. Moreover all WPPs must be capable of supplying rated active power at the PCC within the range of power factors 0.95 lead to 0.95 lag as illustrated in Figure 5. With all plants in service, the reactive power limits defined at rated MW will apply at all active power output
levels above 20% of the rated MW. These reactive power limits will be reduced pro rata to the amount of plants in service.

Moreover, Table 4-1 summarizes the reactive power supply requirements at normal operating voltage and at different values of the active power output for different EU countries. The information was taken from the national Grid Codes and from other additional documents [19], [28]-[80].

Table 4-1: Reactive power supply requirements: a comparison among some European countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Q/P_n [p.u.] (network)</th>
<th>cos φ (network)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From (leading)</td>
<td>To (lagging)</td>
</tr>
<tr>
<td>Belgium (for P_{min,tech} &lt; P ≤ P_n)</td>
<td>0,1</td>
<td>0,45</td>
</tr>
<tr>
<td>Czech Republic (at P=P_n)</td>
<td>0,33</td>
<td>0,62</td>
</tr>
<tr>
<td>Czech Republic (at P&lt;P_n)</td>
<td>from unit operations diagrams</td>
<td></td>
</tr>
<tr>
<td>Denmark (normal operation)</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>France (at P_{max} &amp; U=U_{dim})</td>
<td>0,35</td>
<td>0,32</td>
</tr>
<tr>
<td>France (at any P &lt; P_{max} &amp; U = U_{dim})</td>
<td>0,28</td>
<td>0,3</td>
</tr>
<tr>
<td>France (at any P &amp; U = 0,9 U_{dim})</td>
<td>0,3</td>
<td></td>
</tr>
<tr>
<td>Germany (V1) (at P_n &amp; normal operation)</td>
<td>0,228</td>
<td>0,48</td>
</tr>
<tr>
<td>Germany (V2) (at P_n &amp; normal operation)</td>
<td>0,33</td>
<td>0,41</td>
</tr>
<tr>
<td>Germany (V3) (at P_n &amp; normal operation)</td>
<td>0,41</td>
<td>0,33</td>
</tr>
<tr>
<td>Germany (at P &lt; P_n)</td>
<td>in every possible working point of the generator output diagram</td>
<td></td>
</tr>
<tr>
<td>Ireland (P = P_n)</td>
<td>0,33</td>
<td>0,33</td>
</tr>
<tr>
<td>Ireland (P ≤ 0,5 P_n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poland (0 &lt; P ≤ P_n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Romania</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Britain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 illustrates detailed requirements upon the network side-supply of reactive power from generating units to the network in Germany and Great Britain for the normal frequency range and at rated active power output. The nominal voltages are 400 kV and 275 kV for Great
Britain and 380 kV, 220 kV and 110 kV for Germany. According to the German code, wind farms may operate in leading or lagging power factor in case of over-voltages; the TSO shall select one of the three possible variants on the basis of relevant network requirements. Meanwhile, the British code indicates that the wind power plants must be able to provide their full reactive power at voltages within ±5% around the rated voltages (400 and 275 kV).

Figure 6: Requirements for power factor variation range in relation to the voltage, according to the German and British Grid Codes, for normal frequency range and $P=P_n$.

In the NORDEL [19] member countries, the wind plant must have adequate reactive capacity to be able to be operated with zero reactive exchange with the network measured at the connection point, when the voltage and the frequency are within normal operation limits. The reactive output of the wind plant must be controllable in one of the two following control modes according to TSO specifications:

- the wind plant shall be able to control the reactive exchange with the system. The control shall operate automatically and on a continuous basis. The wind plant shall be able to maintain acceptable small exchange of reactive power at all active power production levels; in addition the Swedish code [77] requires that the WPP are designed so that the exchanged reactive power can be regulated to zero.
- The wind plant must be able to automatically control its reactive power output as a function of the voltage at the connection point with the purpose of controlling the voltage.
In Romania, the response of the voltage control system must be at least 95% of the available reactive power per second [70]. In some of the analysed countries the detailed terms regarding the reactive power control are decided by the grid operator for each wind power plant in particular. In the Netherlands [62], wind power plants are exempted from reactive power control while for other countries there are no specifications yet for wind power plants.

4.2.4 Low voltage/Fault ride through capability

In the past, during grid failure the practice was to disconnect wind farms and wind turbines by fast protection systems. This disconnection might lead to a collapse of voltage in the transmission system in some regions featuring high wind energy penetration, with a resulting loss of thousands of MW of wind power generation [22].

The large increase in the installed wind capacity at transmission system level needs wind generation to remain in operation in the event of network disturbances. For this reason, grid codes issued during the last years invariably demand that wind turbines and wind farms (especially those connected to the high voltage grids) must withstand voltage dips to a certain percentage of the nominal voltage (down to 0% in some cases) and for a specified duration. Such requirement is known as Fault Ride Through (FRT) or Low Voltage Ride Through (LVRT) capability and is described by a voltage vs. time characteristic, denoting the minimum required immunity of the wind power station. The FRT capability also includes fast active and reactive power restoration to the pre-fault values, after the system voltage returns to normal operation levels. Some grid codes impose increased reactive power generation by the wind turbines during the disturbance, in order to provide voltage support: this requirement resembles the behaviour of conventional synchronous generators in over-excited operation [22].

A comparison among the LVRT requirements in different European countries is here presented (see Figure 7) based on all the information available in [19], [28]-[80]. Wind turbines must remain connected if the voltage remains above the illustrated lines and for the time specified in Figure 7. For Germany, disconnection is generally not permitted above limit line 2. For the rest of the countries the wind turbines should not disconnect above their corresponding lines in Figure 7.

- The most restrictive countries are Germany, Belgium, Great Britain, Finland, France (after the 30th of September 2009) and Sweden \( (P_n \geq 100 \text{ MW}) \) in which a LVRT capability for voltage dips down to zero, at the PCC (generally at HV level) is required.
- In France for the 225 kV and 400 kV meshed grids, a LVRT capability down to a voltage at the PCC of 5% \( U_n \) is required until the 30th of September 2009 and for the 225 kV, 90 kV and 63 kV not meshed networks after the 30th of September 2009;
- In Poland, Ireland, Romania, and France (for the 225 kV, 90 kV and 63 kV not meshed networks before the 30th of September 2009), a LVRT capability down to voltages at the PCC of 15% \( U_n \) is required;
- In Spain and Italy, a LVRT capability down to voltages of 20% \( U_n \) is required;
- In Sweden (for power plants with a rated power \( P_n < 100 \text{ MW} \)) and Denmark, a LVRT capability down to voltages of 25% \( U_n \) is required.
In **Great Britain**, the illustrated LVRT capability does not apply when the WPP is operating at less than 5% of its rated capacity or during very high wind conditions when more than 50% of the wind turbine generator units in the wind farm have been shut down or disconnected under an emergency shutdown sequence.

![Figure 7: Comparison among the LVRT requirements for wind power plants in different EU27 countries.](image)

In general it has been noticed that specifications may vary for the same country with: the voltage level at which the wind power plant is connected; the structure of the network (meshed or not meshed); the magnitude of the voltage dip; the rated capacity of the power plant.

In **France** there are more strict requirements for the EHV grids (225 kV and 400 kV) that have a meshed structure than for the 225 kV, 90 kV and 63 kV not meshed grids. These specifications are more severe in both voltage dip magnitude and duration. Moreover, the provisions of the **French** grid code [38] are divided in two: temporary and valid until the 30th of September 2009 and permanent after the 30th of September 2009. Also in **Sweden** there are less severe requirements for the WPPs with a rated capacity below 100 MW. In **Belgium** there are two LVRT requirements [28], one for severe voltage dips and one for mild voltage dips (down to maximum 70% \(U_n\)). In the last situation the WPP must withstand a 25% percent decrease from
the nominal voltage for 1500 ms. The **German** code [42] has a special requirement. Between Limit 1 and Limit 2, and below 1500 ms, brief disconnection of the wind turbines might be allowed, if re-synchronization times defined by the TSO are kept. If after 1500 ms the system voltage does not recover to 90% of the highest phase-to-phase value, a selective disconnection of generators depending on their state is admissible only through system automatics.

The difference between the active power restoration rates should also be noted: in **Germany** all the generating facilities that did not disconnect from the grid during the fault must continue their active power supply with an increasing gradient of at least 20% of the nominal capacity per second until the original value is reached. The **Romanian** code requires also that after voltage recovery the WPP must produce its whole available active power as quickly as possible and with a variation gradient of minimum 20% of the installed capacity per second. The **Irish** and **British** codes require at least 90% of the maximum available active power of the power plant as quickly as possible and within 1 second after the voltage has been restored to the normal operating range.

In some countries the generating facilities must support the network voltage during a voltage drop by means of additional reactive current. That means that the generating units must stop absorbing reactive power from the grid and start injecting it instead.

![Figure 8: Voltage support during faults by reactive current feed in Spain and Germany (present [42] and proposed [43] requirements)](image)

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants
In Germany the present voltage support requirements are illustrated in Figure 8 with a black line: the voltage control is activated for voltage drops larger than 10% of the effective value of the generator voltage, and it must ensure a supply of reactive current at the low-side of the generator-transformer with a contribution of at least 2% of the rated current per percent of the voltage drop. The facility must have a control response time of maximum 20 ms and if required it must be able to supply reactive current of at least 100% of the rated current [42]. However in [43], a modified principle of voltage support during faults is proposed (see in Figure 8 the brown line and the yellow surface) as in the present case there is a reactive current jump at the exit from the dead band. According to the proposed variant, the reactive current feed should start smoothly from zero and should be done within the yellow surface delimited by the brown lines. The current’s deviation ($\Delta I_B$) of the WPP must thereby take place proportionally to the relevant voltage deviation ($\Delta U$) ($\Delta I_B/I_n = K \cdot \Delta U/U_n$) and in the yellow volume defined by $2 \leq K \leq 5$. A fluctuation margin of the constant $K$ of up to 20% is allowed in the linear range.

In Spain, according to [76], within 100 ms of a voltage drop the wind power plants are required to stop drawing reactive power from the system and they must be able to inject reactive power within 150 ms of grid recovery, as shown in Figure 8 with a red line.

According to [34], in Denmark, during a voltage dip the reactive power control must be changed from normal operation to a maximum voltage support strategy, so that the normal grid voltage is re-established as soon as possible. Moreover, this control must be able to avoid overshoots.

In Great Britain and Ireland the respective Grid Codes specify that wind farms must produce their maximum reactive current during a voltage dip caused by a network fault [23].

In Romania [70], during voltage dips, the WPP must provide active power in proportion to the retained voltage and must maximize the reactive current injected to the transmission system without exceeding the WPP limits. The WPP must be able to provide the maximum reactive current continuously for at least 3 seconds.

In France wind farms are exempted from voltage support.

4.3 Wind grid connection charges

The purpose of this paragraph is to introduce the most common terms related to grid connection costs and to make a brief comparison between the wind connection charging methods and policies among the European countries.

Connecting a new generation facility can be extremely affected by the way the connection costs are divided between the generator, the grid owner and the customer and, in the case of wind generation, the question is who of the latter three is going to pay for the wind farm connection. Generally the wind power plants imply greater investment costs per unit of energy supplied in comparison to other conventional sources. This is also due to the fact that the wind farms are generally located rather remotely from concentrated load centres, especially in the off-shore cases.
In general, the wind farm developer has to make a formal application to the Transmission System Operator, who after analyzing the request will make him a connection offer including also the “connection charge”, which is generally composed of the costs of making the physical connection to the grid and those for network reinforcements [24].

The various approaches used within Europe can be classified in four charging methods [95] as summarised in Table 4-2.

**Table 4-2: Summary of connection charging methods**

<table>
<thead>
<tr>
<th>Charging Method</th>
<th>Brief Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Shallow”</td>
<td>Generator pays only for the cost of equipment needed to make the physical connection to the grid. Any upstream costs of grid reinforcement due to the generator’s connection are borne by the TSO. Often these costs are recovered through Use of System (UoS) tariffs or other tariffs.</td>
</tr>
<tr>
<td>“Deep”</td>
<td>The generator pays for all costs associated with its connection. This includes the cost of the physical connection to the grid along with the costs of any upstream network work arising from the generator’s connection.</td>
</tr>
<tr>
<td>“Mixed” or “Shallowish”</td>
<td>A hybrid of the shallow and deep charging methods. The generator generally bears the cost of the physical connection to the grid (the shallow costs) plus a proportion of any upstream network reinforcement costs. This proportion is usually based on an assessment of the proportional use of any new infrastructure by the generator.</td>
</tr>
<tr>
<td>“True”</td>
<td>The costs paid by the generator for the new connection are equivalent to the cost of connecting the generator to the nearest point on the grid system at which the grid has sufficient capacity to accommodate the generator without network reinforcement.</td>
</tr>
</tbody>
</table>

The most important study in this direction was performed within the GreenNet-Europe project [86] that researches how to guide a large scale and least cost and market integration of RES generation in Europe. Grid connection charging methods and strategies for an optimum cost integration of RES were analysed, and recommendations were made for policy developers. It was highlighted that due to its natural monopoly character, the electricity grid has to be regulated and it is of great importance to accurately define the boundaries of the grid infrastructure with both electricity generators and end-users. However, the practice proves that the boundary definitions and responsibilities on both ends of the grid infrastructure are inconsistent. While the grid operator’s responsibility (and cost allocation) towards the end-user starts directly at the end-user, on the generation side this is only the case of the “super-shallow” integration approach. But in practice on the generation side in almost all EU Member States still the “deep” or “shallow” integration approach is implemented.
After the issue of the EC Directive on Electricity from Renewable Energy Sources (RES-E) [1] a rapid growth in European RES-E deployment, especially with respect to wind power, has been observed. Offshore installations though are facing a delay compared to previous expectations. This is not only due to particular technological challenges but also due to uncertainties concerning regulatory treatment of grid related costs [97]. By summarising the information available at [21] for EU25 and adding information found at [30] for Bulgaria and in [21] and [72] for Romania,
Table 4-3 shows RES grid connection charges for EU27. The column entitled “charging” refers to the way the connection charges are divided between the involved parties and the charging method was deducted by using the above mentioned data together with the definitions from Table 4-2.

As it can be seen the grid expansion policies for wind integration are various in the EU Member States:

- In more than half of the cases the legal basis between the entitled and the obligated party is contractual, while the rest have a statutory basis, a special claim for Great Britain or no special basis at all for Belgium and the Netherlands. Also usually the entitled party is the plant operator and the obligated one is the grid operator (for contractual basis always), but also the entitled party may be the grid user.

- While Austria, Belgium, Germany, Malta and Bulgaria give priority to RES, most of the countries do not, adopting a non-discriminatory policy.

- The charging methods for grid expansion are various, being shallow, shallowish, deep or not clearly mentioned for the general case, as the competent authorities must determine it for each situation (Romania, Malta).

- In some countries (France, Latvia, Portugal, Spain, Sweden) if the expansion is to the general public benefit the costs are shallow but if the expansion is only to the benefit of the plant operator the costs are deep. Therefore remotely located wind farms (especially off-shore ones) can be affected by high connection charges.

- Also in Slovenia, for above average costs, the charging method is the shallowish one.
### Table 4-3: Grid connection charges for grid expansion in EU27.

<table>
<thead>
<tr>
<th>Country</th>
<th>Legal basis</th>
<th>Entitled party</th>
<th>Obligated party</th>
<th>Priority to RES</th>
<th>Charging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Contractual basis</td>
<td>The grid user</td>
<td>Grid operator</td>
<td>Yes</td>
<td>Shallow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>N/A. Expansion according to the TSO’s development plan</td>
<td>N/A. Expansion according to the TSO’s development plan</td>
<td>Yes</td>
<td>Shallow</td>
<td></td>
</tr>
<tr>
<td>Bulgaria</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>?</td>
<td>Yes</td>
<td>Shallow</td>
</tr>
<tr>
<td>Cyprus</td>
<td>Wind farm operator that has a supply license</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallowish</td>
<td></td>
</tr>
<tr>
<td>Czech Republic</td>
<td>Contractual basis</td>
<td>The RES producer</td>
<td>Grid operator, unless capacity shortage is proven.</td>
<td>No</td>
<td>Deep</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N/A. Grid operator has the statutory obligation to expand the grid</td>
<td>No</td>
<td>Shallow</td>
</tr>
<tr>
<td>Denmark</td>
<td>Statutory basis</td>
<td>N/A</td>
<td>N/A. Grid operator has the statutory obligation to expand the grid</td>
<td>No</td>
<td>Shallow</td>
</tr>
<tr>
<td>Estonia</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow</td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>Contractual basis</td>
<td>No</td>
<td>Deep</td>
</tr>
<tr>
<td>France</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow – regular expansion case. Deep – if special (not regular) expansion is needed</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>Statutory basis</td>
<td>Yes</td>
<td>Shallow</td>
</tr>
<tr>
<td>Great Britain</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>The agreement between the grid operator and the plant operator may give cause for a claim if access to the grid can be granted through a grid expansion only</td>
<td>No</td>
<td>Shallowish</td>
</tr>
<tr>
<td>Greece</td>
<td>Plant operator that is a contracting party to connection contract and holds a generation license.</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow</td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>Contractual basis</td>
<td>No</td>
<td>Shallowish</td>
</tr>
<tr>
<td>Ireland</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>Contractual basis</td>
<td>No</td>
<td>Shallow</td>
</tr>
<tr>
<td>Italy</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>Contractual basis</td>
<td>No</td>
<td>Shallow</td>
</tr>
<tr>
<td>Country</td>
<td>Entitled party</td>
<td>Obligated party</td>
<td>Priority to RES</td>
<td>Charging</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Latvia</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow – regular expansion case. Deep – if special expansion is needed</td>
<td></td>
</tr>
<tr>
<td>Lithuania</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallowish</td>
<td></td>
</tr>
<tr>
<td>Luxembourg</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Deep</td>
<td></td>
</tr>
<tr>
<td>Malta</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>Yes</td>
<td>Shallow or shallowish, depending on the decision of competent authorities</td>
<td></td>
</tr>
<tr>
<td>Netherlands</td>
<td>N/A</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow</td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>Plant operator meeting grid connection requirements</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallowish – specified in the contract.</td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>Plant operators if they apply for an early grid expansion</td>
<td>Grid operator</td>
<td>No</td>
<td>Deep – in case the plant operator applied for an early grid expansion</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shallow – if the expansion is included in the general grid’s operator expansion plan.</td>
<td></td>
</tr>
<tr>
<td>Romania</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Charges determined by competent authorities. Deep – if special expansion needed</td>
<td></td>
</tr>
<tr>
<td>Slovakia</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Specified in the connection contract</td>
<td></td>
</tr>
<tr>
<td>Slovenia</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow – average costs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grid operator</td>
<td></td>
<td></td>
<td>Shallowish- for above-average costs</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>Plant operators – if a special expansion is necessary</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow – for general expansion case. Deep – if only the plant operator benefits from the expansion.</td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>Plant operator</td>
<td>Grid operator</td>
<td>No</td>
<td>Shallow – if the expansion is to the benefit of the general public. Deep – if only the plant operator benefits from the expansion.</td>
<td></td>
</tr>
</tbody>
</table>
4.4 Developments on wind connection practices

Many grid operators, in response to ongoing increase of wind generation accessing the electrical system, are changing the interconnection requirements for wind power, especially on the transmission systems. Some parts claimed that these specifications did not always reflect the real penetration and impact of the wind power in a given area [25]. As mentioned above, connection requests of wind farms at transmission level are more and more frequent and a new trend seems to be recorded in Europe, whereby the amount and severity of these requirements is becoming generally proportional to the respective wind penetration level. In the case of Europe, a regulatory frame of national Grid Codes comprising also the wind grid connection rules surely represents an important need for the pan-European transmission system. Information and requirements need to be presented in a clear, transparent and uniform manner, in order to improve their understanding and comparison. As an example, the EWEA Working Group on Grid Code Requirements has proposed in [110] a two step harmonization approach: a structural harmonization exercise providing a Grid Code template, and a technical harmonization exercise that has to adapt the existing Grid Code parameters to the new Grid Code template.

As reported by GreenNet-Europe [86], for large-scale RES-E grid integration a clear definition of the boundaries between the RES-E power plant, the grid infrastructure and overall system is indispensable. In the past, not least due to small amounts of RES-E penetration the share of extra grid-related and system-related costs has been small compared to the long-run marginal generation costs of the different RES-E power plants. The practice of allocating these extra costs to the corresponding RES-E promotion instruments increasingly causes problems with increasing shares of RES-E generation in the different European electricity systems.

Member States may also give priority access to networks. This is the case in Germany, Spain and Denmark, countries with high shares of wind power. However, it remains important for the functioning of the electricity market that the renewable electricity is traded on the market, so that renewable operators meet and respond to the price signals.
5 TRANSMISSION NETWORK PLANNING IN EUROPE

This Chapter illustrates the different approaches and guidelines for transmission planning in Europe, focusing in particular on the transmission planning challenges in the EU countries exhibiting higher levels of onshore and offshore wind installations. The Chapter highlights real TSO’s practices in transmission planning and analyses present procedures as affected by the ongoing electricity market liberalisation and the increasingly higher wind penetration.

5.1 The transmission network planning challenges

The transmission network planning is a very complex process. The trends and challenges experienced by the electric generation and transmission systems in Europe, as introduced in Section 3.1, make it harder for transmission planners to carry out their tasks nowadays. In the past, before the electricity market liberalisation, in a centrally managed power system, the system operator generally controlled the generating units, the transmission and distribution networks and the demand. The goal of the planners was then to expand the transmission network in such a manner that both generation and transmission costs were minimised subject to meeting static and dynamic technical constraints to ensure a secure and economically efficient operation.

Today, in a competitive European system, the TSO, in charge of the only transmission after the utilities’ unbundling, plans the expansion of its network minimising transmission cost (investment and operation) and pursuing maximum social welfare, while meeting static and dynamic technical constraints to ensure a secure and economically efficient operation.

Resolving then the trade-off between minimum transmission investment cost versus maximum social welfare is a further complicate task.

Moreover, the network planning and development process currently face specific issues: due to environmental constraints, the time required to get the authorisations to build new transmission assets is generally much longer than the time needed to build new power plants; the TSOs must take timely actions in an environment characterised by increasing uncertainties, mostly related to market decisions and growing variable RES deployment. In addition, as generation is affected by major changes resulting not only from the development of RES but also from the renewal and/or phasing-out of thermal power plants, in most EU countries generation tends to exert the greater influence in terms of new requirements placed on the transmission system [80][102].

In this context, with decisions being out of TSOs’ control (e.g. energy policy objectives at European and national level, strategies adopted by the generating companies, etc.), proper assumptions must be made on the evolution of different parameters, such as consumption, generation and also market mechanisms.

5.2 The transmission network planning objectives

Focusing on the European system, the UCTE [102] recalls that the TSOs aim at two main objectives when planning the development of the transmission grid: maximising system reliability and security of supply and fostering market, to allow an efficient use of generation, thereby minimising the total costs. Most of the transmission projects should meet the following objectives: connect new generation capacity, whether from conventional or renewable sources, to the networks; increase transmission capacity to allow the most efficient use of the generating units according to national and European energy and economic objectives. This similarly applies to the other European, non-UCTE systems.
Meeting those main targets results in different objective functions for different TSOs. Different criteria include: maximising network reliability; maximising trading possibilities (pool and contracting) to the benefit of the different market players; maximising social welfare as defined by the market operator while clearing the market; minimising environmental impact [99]. In some cases TSOs practice also multi-criteria analyses.

The objectives of transmission planning and development vary throughout Europe [19]-[82]; for a selected number of EU countries (see also Section 5.5), as reported in [19][38][46][52], they are:

- **NORDEL.** All parts of the power system shall be designed so that the electric power consumption will be met at the lowest cost. This means that the power system shall be planned, built and operated so that sufficient transmission capacity will be available for utilising the generation capacity and meeting the needs of the consumers in a way which is economically best. The long-term economic design of the grid aims to balance between costs of investments and costs of maintenance, operation and supply interruptions, taking into account the environmental demands and other limitations.

- **France.** The mission of the transmission network development is to guarantee: a grid covering the national territory in a rational fashion and respecting the environment, and interconnected to the networks of the bordering countries; a non-discriminatory connection and access of the users to the network. The TSO ensures the balance of power flows on the network, as well as the system security, safety and efficiency, by taking into account the technical constraints.

- **Ireland.** The primary aim of transmission planning is the maintenance of the integrity of the bulk transmission system for any eventuality. The adequacy and security of supply to any particular load or area is secondary to this primary aim. The technical considerations are continually mitigated by economic issues and all other significant factors brought up by the various transmission system stakeholders.

- **Italy.** By developing the transmission grid, the TSO aims at the security, reliability, efficiency, continuity of supply of the electrical energy system and cost reduction of transmission and of supplies. This objective is pursued through suitable planning of the network development, aimed at reaching an appropriate level of quality of the transmission service and reduction of possible grid congestion, while complying with environmental and landscape law restrictions.

### 5.3 The transmission planning process

The basic tasks for the transmission network planners can be summarised as hereinafter: to forecast the load flows (scenarios) on the power grid; to check whether or not the acceptable limits (constraints) might be exceeded (in standard conditions as well as in case of loss of system components); to devise a set of possible strategies/solutions to overcome the criticalities and to select the one(s) having the best cost/benefit performance [102].

In order to fulfil their tasks, the TSOs rely on scenarios of forecasted consumption, generation development, and power exchanges evolution. For each scenario, they have to take into account the stochastic aspects of the phenomena: load varies on the basis of human activity and weather conditions; generating units may produce or not, depending also upon external factors such as
wind or hydro conditions and forced outages; the scenarios should reflect the asset and bidding strategies of the generation companies and other market players; cross-border exchanges may largely vary also depending on the behaviour of the different market players.

Table 5-1 provides a first comparison of key features of the planning practices in some EU27 countries. Among these elements, features like the timeframe for network planning, the utilisation of deterministic and probabilistic planning criteria, also with consideration of market issues, are quantitatively and qualitatively compared (see also 5.5).

Table 5-1: Comparison of planning practices in some EU27 countries.

<table>
<thead>
<tr>
<th>Country / Area</th>
<th>Time horizon for adequacy and planning studies</th>
<th>Deterministic (D) and probabilistic (P) network planning criteria</th>
<th>Consideration of market issues in network planning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>D with P items</td>
<td>Low</td>
</tr>
<tr>
<td>NORDEL</td>
<td>5-10 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>7 - 15 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Britain</td>
<td>7 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ireland</td>
<td>5-10 years (15-20 years time frame for a limited set of studies)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>5-10 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>10 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Netherlands</td>
<td>7 years (21 years in the strategic Vision2030 document)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3.1 Network planning horizon

According to [26], there are typically three time horizons for network planning studies:
- long-term studies which are characterised by a high degree of uncertainty as the planning horizon may be up to twenty years.
- medium-term studies where the uncertainties are reduced as the planning horizon may be up to ten years.
- short-term studies where the uncertainties are even more reduced as the planning horizon may be up to five years.

The 10-year time horizon is the most adopted by the EU TSOs assessed in this Report: the planning practices of **NORDEL, Ireland, Spain** and **Italy** refer for example to this timeline.

As far as longer term analyses are concerned, there are several examples of countries conducting and publishing such kind of strategic studies, as for example **Ireland** and **The Netherlands**.

5.3.2 Generation adequacy assessment

The assessment of generation adequacy, which represents the ability of the generation on the power system to match the power consumption [106], is an important aspect to be considered in the execution of the planning tasks.

The regulatory and technical framework adopted by the European countries to monitor system adequacy has evolved after the liberalisation of electricity markets [91][92]: today, there is no coordination between companies to collectively reach an optimal generation capacity expansion plan as defined by the former public utilities and controlled by public authorities. Before the liberalisation of the electricity markets, decisions regarding new investments were determined by a capacity expansion plan which entailed enough generation margins while respecting a maximum level of risk of outage. A trade-off between the investment costs for new generation capacity in peak units and the reduction in outage cost for consumers would in theory determine the optimal risk of outage.

Two methods for generation adequacy assessment were mainly used, deterministic and probabilistic:
- The typical adequacy criterion with deterministic methods refers to generation margin to be equal to a fixed percentage of the peak demand and operating reserve margins sufficient to cope with the most likely contingencies. One of the drawbacks of these methods is that the stochastic nature of supply and demand is not taken into account.
- Probabilistic methods provide therefore a more meaningful picture of the random events that may affect supply and demand. Two criteria are often used: the Loss of Load Probability (LOLP), defined as the probability over some period of time that the power system will fail to provide uninterrupted service to customers, and the Loss of Load Expectation (LOLE), defined as the expected amount of energy not served over some time frame.

Nowadays, in some electric systems, the old planning criteria are maintained as reference schemes, as long as the market cannot provide the new ones. In those systems, the TSO typically publishes reliability reports, in which it evaluates what investments in production capacity the system needs in order to meet the old planning criteria. These outcomes may be purely informative, if no implementation mechanism is put in place (as it is the case for **England and Wales**) or may lead to binding implementation mechanisms (which is the case of **France** where the TSO can organise public tenders for new generation capacity).

An analysis of TSOs’ methods for assessing long-term adequacy in many Western European countries is reported in [91]. In all the countries reviewed, TSOs produce regular long-term security of supply reports evaluating the capacity of the electric system to cope with future...
electric demand, given plausible scenarios of investment in new capacity as well as decommissioning. Most TSOs use the same range of planning horizon, from 6 to 13 years.

The three main approaches used by TSOs to evaluate the adequacy levels [91] are:

- **Capacity margin analysis.** It evaluates the system’s ability to serve the peak demand. This approach is used in Great Britain, Spain, the Netherlands, Germany, Austria, Italy and NORDEL countries. The peak demand is typically defined as one or two points in the year (winter peak, or summer and winter peaks), and is estimated according to plausible scenarios for the evolution of electricity consumption. The peak system capacity can be defined in several ways, which may be source of confusion when comparing security of supply data. For instance, the TSOs of Germany and Austria use an available capacity at peak according to the UCTE definition [106] (it is calculated as the installed capacity, minus the unavailable capacity, minus the largest production unit’s capacity, minus the reserve capacity of the primary, secondary and tertiary reserves). A very similar approach is followed in NORDEL countries. The TSOs of Great Britain and Italy simply use the installed capacity. The TSO of Spain uses the installed capacity, minus the unavailable capacity (due to potential outages and planned maintenance). It also considers dry year conditions to estimate the available capacity of hydraulic resources. The TSO in the Netherlands use an available capacity indicator. The variety of methods, detail, terminology, and approaches for calculating system capacity at peak load makes the comparison of security of supply level among countries quite problematic.

- **Energy balance analysis.** This method evaluates the system’s ability to serve the yearly demand in energy. This approach is used in France, Spain, the Netherlands, Italy, and the NORDEL zone. It is more meaningful to use an energy balance analysis in systems where stock-based production (essentially hydraulic production) is important. Besides, an energy balance analysis also allows taking into consideration maintenance constraints, such as fuel charging of nuclear units, which are planned in off-peak seasons.

- **Loss of load expectation (LOLE) analysis.** It measures the expected duration of power cuts. TSOs generally calculate the power cuts duration resulting from numerous generation and demand scenarios. The obtained power cuts duration for each scenario allows calculating an expected value of loss of load duration (LOLE, in hours/year). This approach is used only by France, Belgium, and the Netherlands, probably because of its complexity.

Based on their investment criteria, the TSOs of Belgium, France, Spain and Italy also propose an estimation of the system needs of new investment capacity. The TSOs of Germany and Austria do not have any regulated criteria, but they use the UCTE criteria as an explicit reference for their evaluation of security of supply. Finally, in the Netherlands, Great Britain and NORDEL countries generation investment criteria are not present in the respective security of supply reports.

### 5.3.3 Role of the interconnections

Interconnection adds a new dimension to the approach of capacity adequacy assessment and to the whole planning process. Despite the interdependency between different systems, the adequacy levels have been generally assessed from a national point of view. The interaction between generation adequacy of a system and interconnection capacity is not fully considered in most generation adequacy studies [92].
As illustrated in [96], the methods adopted and the assumptions made by the TSOs for determining the transmission capacity within each area and at the border between two areas largely differ: the internal area transmission capacity mainly depends on known technical features of the system operated by the TSO, whereas the cross-border transmission capacity is assessed by relying upon a number of assumptions made by the respectively involved TSOs. In sum, determining the transmission capacity is a complex task and its results do not always reflect only the technical properties of the system. Although the general scheme for capacity allocation is similar for all European TSOs, differences in definitions and assumptions (related e.g. to the dispatched generation or the maximum carrying capacity on some network’s elements) can lead to lower calculated transmission capacities.

The UCTE [104] takes into account interconnections in its System Adequacy Forecast by identifying whether the observed residual generation capacity of a country is higher or lower than the net transmission capacity; it allows integrating the effect of limited transmission capacity in energy exchanges in stressed periods.

TSOs’ methods for taking interconnections into account to assess security of supply differ widely. The TSO in the Netherlands takes into account the maximal possible imports in the evaluation of security of supply. In England and Wales, the cross-border capacity from France to England is considered to be available to import in case of supply and demand disequilibrium. The TSOs of France and Spain take into account long term cross-border contracts for electricity in their analyses, but quite differently. In the Spanish case, REE integrate imports contracts from France in reliable supply at peak. The French TSO considers that the net French imports are null on peak. The TSOs of Germany and Austria assess security of supply without integrating interconnections.

During the last decade, the planning process of NORDEL has proceeded in the direction of an integrated Nordic cooperation concerning grid reinforcements and expansions. This regional cooperation is unique in Europe and shows that NORDEL is a forerunner in the work to ensure a well functioning regional electricity market. This cooperation on system planning aims at developing the grid from a Nordic perspective taking into account the international aspects and paying attention to environmental impacts. The work has resulted in three common Nordic grid master plans in the last 10 years.

Internal transmission capacities are taken into account, and import possibilities from neighbouring systems are assumed to be half of the existing capacity.

5.3.4 Cost-benefit analyses and market value

Most TSOs, taking also into account the aspects of environmental safeguard, evaluate and rank from the techno-economic point of view the several possible alternatives stemming from the planning analyses and which - as a necessary pre-condition - fulfil the priority target of realising a secure transmission grid.

For example, in Italy, the various development alternatives are evaluated from the technical-economic point of view by comparing the estimated investment costs of each option with the related benefits in terms of reduction of overall system costs (including production, transmission and distribution costs that are passed to the users of the national electricity system). These cost-benefit evaluations take into account, where possible, costs of grid congestion, foreseeable trends in the electricity market, the possibility of increasing the level of imports/exports with other countries, network losses, and risks of not supplying the users. The benefit attached to the energy
unlocked by a new electric link represents one of the most important gains deriving from transmission expansion [54].

In Spain, the network expansion planning methodology consists of four fundamental steps: multiple scenario generation covering the whole planning horizon and detailed analysis of these scenarios; information structuring and index calculation (cost-benefit analyses); identification of competitive and necessary network reinforcements; decision making [99].

In the experience of NORDEL countries, it is difficult to quantify the costs and benefits in a more well-functioning market. However, it is quite obvious that the energy market will become more robust and efficient when investments are made to remove congestion. Such investments should be based on socio-economic analyses to ensure that the benefits are higher than the costs. After the investments, the prices will be more stable at least in the short term.

Transmission investments will also help to mitigate the possible exercise of market power. Abuse of market power in the electricity market will lead to socio-economic losses. There is a clear link between transmission capacity and the possibility of exercising market power. Sufficient transmission capacity contributes to enlarging the market and thereby possibly reducing the risk of abusing market power.

It is not economically efficient to invest in transmission capacity that covers all patterns of trade. This is especially relevant for the Nordic market that has a large proportion of hydropower production. The hydropower situation will differ over the years and thereby affect the energy trade. A transmission system that covers all patterns of trade without any congestion will clearly be considered as over-invested.

5.4 Wind integration in a market environment

5.4.1 Planning and connection practices for wind integration

Drawing a clear and static border between the wind connection processes and the network planning practices aiming to integrate wind power generation is challenging and in some cases misleading.

Wind power affects the power flows, the losses and the bottleneck occurrence in the network. Still, as seen already for the connection requirements in Chapter 4, also at the planning stage, not all the EU countries (particularly those experiencing a low wind penetration) yet address the planning issues for wind integration in a separate stage.

The large-scale development of offshore wind energy may make bottlenecks in the existing electricity grid more frequent and also more crucial if the grid is not adapted to accommodate this new generation. This problem is being explored for example within the European Priority Interconnection Project for offshore wind in Northern Europe [5], and it is also subject to detailed technical investigations in projects such as TradeWind [90] and the European Wind Integration Study [83].

Wind project developers still face different grid related barriers. These are for a large part related to insufficient grid capacity available, non-uniform and sometimes non-transparent procedures for grid connection, high grid connection costs as well as long lead times to obtain authorisation for grid connections.

In Italy (and also in other countries), as extensively described in the following (see Section 5.5), a combined connection and planning approach is adopted to connect sizeable amount of wind power. It foresees planning the construction of new 380/150 kV substations, aimed to collect and
wheel at higher voltage level the wind power actually injected on certain portions of 150 kV network. This method allows connecting wind generation in a more secure fashion and with environmental and economic advantages, by reducing power congestions and the length of network infrastructures to be built.

As illustrated in [96], the integration of wind power may, however, put additional constraints on the determination of transmission capacity, such as: low utilisation factor, spatial smoothing effect, power output function of ambient conditions, and distance from existing network infrastructures. For several reasons the integration of large-scale wind power may have a particular impact on the methods that are used for determining the available transmission capacity. In fact, the power output of wind farms depends on wind speed, so that there may be higher uncertainties associated with prediction errors regarding the generation distribution; this may result in an increased transmission reliability margin, which in other word corresponds to a decrease in transmission capacity. In comparison with conventional generation, less sophisticated models of generator characteristics are used for wind farms. This could make simulation results less reliable (i.e. some TSOs may choose to increase transmission reliability margins to account for that). Apart from the impact that wind power may have on the methods for determining transmission capacity, its integration also requires greater investment regarding some of the measures for achieving an increased transmission capacity. For example, it may be significantly more expensive to provide sophisticated protection schemes for wind farms that are distributed over a certain area than for conventional generation of an equivalent capacity. Wind farms are built in remote areas where the grid reinforcements are more expensive than in areas close to loads, where conventional generation is generally situated. Owing to the low utilisation rate of the wind turbines, the energy produced per MW of new transmission capacity is low.

According to [86], in the long-term, in competitive electricity systems the market itself shall be responsible for providing adequate generation capacities to meet peak demand in the system. This is also true for systems with large amounts of variable RES-E (wind) generation. The relevant parameter in estimating the system capacity requirement caused by variable wind generation is the capacity credit. More precisely, the capacity credit is the amount of capacity of conventional or non-intermittent RES-E generation that can be displaced by variable wind capacity whilst maintaining the same degree of system security. Many stakeholders agree on considering the capacity credit close to the average capacity factor of wind generation at low wind penetrations; these values then decrease with increasing wind penetration [95].

As far as transmission planning practices are concerned, in Italy the load flow analyses for defining the reinforcement of the transmission grid are in general carried out according to the (N–1) criterion; they include, in particular for plants running on renewable sources which can not be scheduled, appropriate evaluation of the probability of production of these types of plant [52].

### 5.4.2 Plans for offshore wind

A large-scale development of offshore wind power will challenge the capability of the existing system to balance generation and demand and to transmit the power to the inland consumption centres. In some countries (e.g. Germany), bottlenecks already exist and/or are expected to increase in the event of significant wind capacity expansion in the North Sea [83]. The need for further interconnection capacity has been demonstrated also by the German Dena I study [87]. It is interesting to report the ongoing process of review of the security standards in Great Britain to take into account offshore transmission developments. This draws upon the following...
considerations on the fundamental differences between onshore and offshore transmission in relation to the cost of assets and variability of the generation connected: the level of redundancy of onshore transmission is unsuitable for offshore transmission applications; different (and lower) security requirements for offshore transmission systems are justified; however, no deterioration of security and quality of supply for users of the onshore transmission system is permissible; and, finally, cost-benefit analyses are deemed a sound basis for the development of an offshore deterministic standard [82].

As described in [16], the absence of points of access to the electricity grids at sea leads to uncertainties about the ability to, or costs of, connecting to the grid and creates additional risks for offshore projects. Offshore projects can represent an opportunity for creating lines that both connect new generation capacity and establish or increase transmission capacity between different regions in the EU internal electricity market. However, such potential synergies between offshore projects and cross-border inter-connectors are currently not being exploited.

One reason for this is the additional complexities that cross-border cooperation entails because of the need to deal with different planning and regulatory regimes. Nevertheless, without cross-border coordination, grid investments risk being sub-optimal in that they will be viewed from an individual project perspective rather than from a system perspective. Offshore projects that depend on new cross-border connectors are thus more vulnerable to uncertainties arising from differences in regulatory regimes such as support schemes and rules on grid investment cost recovery. The need for better cross-border cooperation is not only limited to network planning and development, but also relates to system operation and management. Increasing offshore wind penetration may have consequences which need to be reflected in power congestion management strategies and generation/demand balancing plans, and in improved mechanisms for cross-border trade and balancing power markets. In this respect, a key cross-border offshore wind project is the one planned at Krieger’s Flak (between Germany, Denmark and Sweden), which is also supported and partially funded by the European Commission within the EERP [18].

According to ETSO [109], constraints in the grid of neighbouring countries and/or constraints on interconnectors will affect the effectiveness of possible offshore wind parks and could result in uneconomic projects. An offshore wind energy grid plan could also serve as important information for future investors in offshore wind energy projects, giving investors specific information on the possibilities of transporting their electricity. When offshore wind farms are connected to the grid, different devices may be used ranging from well known to more advanced technologies (such as HVDC, FACTS, WAMS, storage) for a smoother control of wind plants outputs. Research & Development (R&D) on the electrical infrastructure is required to evaluate the different options.

ETSO therefore proposes dedicated regional multinational offshore wind energy grid plans to coordinate the development and implementation of the necessary infrastructure on a regional and European level, thus minimising the total costs of offshore projects (e.g. coordinated planning in the North Sea and the Baltic Sea) [109]. An offshore grid plan should take grid possibilities into account but should also include an assessment and mitigation of the impact on security of supply at different levels - both locally, nationally and regionally. The offshore wind energy grid plan could be written as a result of a consultation with all relevant stakeholders, meaning that they get involved in the early stages of planning. A strong European grid (which could be the result of an offshore wind energy grid plan) will help the TSOs by creating more flexibility and more possibilities for activating reserves from more remote locations. A large-scale investment in a
transmission superhighway plan in Europe is a critical first step and several attempts in this direction are being made [95] [104].

Also Greenpeace [112] openly supported the development of an offshore grid in the North Sea. Its contribution to increased security of supply, its function for the aggregation and dispatch of power from offshore wind farms (by allowing the import of hydropower electricity from Norway to the British and the UCTE system), and its role as a facilitator for power exchange and trade between regions and power systems are among the recognised benefits of such grid. Integrating interconnectors with connection lines for offshore wind farms can yield efficiency gains for the development of both wind power projects and commercial interconnectors.

According to ETSO [104], to understand the full scope of costs related to offshore wind power and to mitigate and manage the risks associated herewith, there has to be full transparency of all costs including e.g. connection, grid development and maintenance costs.

The development of offshore wind power will increase the need for grid reinforcements of the existing onshore grid. For TSOs to be able to meet this demand, it is important to speed up the authorisation process for the necessary grid development. Today, due to several constraints (environmental, socio-political, legal), these procedures are much more time consuming than the authorisation process for wind parks. It is therefore also important that the grid authorisation process is coordinated with the authorisation process for offshore wind parks.

Large offshore wind parks should also be able to participate in the regulation power market. ETSO therefore believes that it is important to keep promoting and developing technology that improves the wind farms abilities to e.g. downward regulate.

The future perspectives of regional offshore energy grid plans, where the parks may be developed jointly and the electricity from the wind parks to a larger extent will be shared among countries, also call for the development of a more harmonised and market-based framework of support to trade.

As reported in [16], there is a lack of integrated strategic planning and cross-border coordination. In contrast to spatial planning on land, the European countries generally have limited experience with, and sometimes inadequate governance structures and rules for, integrated spatial planning in the marine environment. The lack of processes looking simultaneously at the spatial distribution of the wind resources, at constraints imposed by other marine activities or interests, and at electricity grid aspects tends to increase uncertainty and the risk of delays in or failure of projects at sea. It has also to be noted that nowadays, no specific prediction systems are available for offshore wind farms, whereas interaction between wind and waves have to be modelled in greater detail to allow reliable wind power predictions offshore [90].

Very recently (early 2009) the European Commission in the EERP has decided to substantially fund offshore wind projects in the North Sea and in the Baltic Sea [18] (see also Section 3.1).

5.5 Recent plans and planning practices in some EU countries

5.5.1 UCTE area

On the Extra High Voltage network of continental Europe (UCTE), power flows basically from the substations where generation units are connected to those ones where loads are to be fed. As this network is meshed, power flows use every parallel path according to physical laws. As every grid of UCTE is interconnected with the bordering networks, the UCTE system is able to
crucially ensure the European security of supply, support the EU Internal Electricity Market with cross-border capacities and allow for the exploitation of renewable energy sources. Thus, it matches the three main criteria of the European Commission regarding Trans European Networks in the field of electricity.

On the other hand, the transmission capacities of the grid elements (lines and transformers) are limited by their physical characteristics and the voltage must be kept within rated limits, in order to guarantee a safe and secure operation of the grid. TSOs’ operators permanently monitor electrical parameters for every element in the power system in order to make sure that they remain within their rated limits, even in case of contingency (e. g. additional forced outage of a generation or network element). If they detect a risk of exceeding the acceptable limits, i. e. a congestion situation, they take appropriate countermeasures, such as asking some generators to modify their output power; this has a cost for the TSO, which is called a congestion cost.

In the same way, the basic job of TSOs’ planning experts consists of activities related to grid development.

The basic tasks could be summarised as in the following [102]:

- to forecast the load flows (scenarios) on the power grid;
- to check whether or not the acceptable limits (constraints) might be exceeded (in standard conditions as well as in case of loss of a grid or generation element), i.e. the so-called (N -1) security criteria are met;
- to imagine and evaluate a set of possible strategies and to select the one(s) having the best cost / benefit performance.

In order to fulfil their tasks, TSOs rely on scenarios of forecasted consumption, development of generation projects, and power exchanges evolution.

For each scenario, they have to take into account the stochastic aspects of the phenomena. First, forecasted load continuously varies according not only to human activity, but also outdoor temperature. Generating units may produce or not according to their availability, which results either from external factors (e. g. wind or hydro conditions, or forced outage) or from generation companies decisions which can be hardly forecasted (place of thermal units in the merit order).

Second, the scenarios should reflect the asset strategy of the generation companies; however, these resulting decisions are not known in advance by the TSOs and are even made at the last moment by the asset owners in order to minimise the uncertainties liable to affect their projects.

Last but not least, cross-border exchanges may vary greatly depending on the different strategies of European market players. The TSOs’ task therefore becomes more and more critical as the uncertainty about new projects (particularly new generation projects) increases and expands to the neighbouring systems.

Besides, the global transmission capacity of the UCTE network can be increased by several means, such as:

- Adding transformers in existing substations in order to be generally able to feed higher load and in some cases to evacuate higher generated power;
- Upgrading some assets, e. g. operate a line at higher voltage (the line must have been originally designed for that), increasing the transmission capacity of a power line by tightening the conductors and reinforcing the towers;
- Installing new facilities in some grid substations, that will improve the distribution of power flows among the different parallel paths in order to fit better with the capacities of
lines, e. g. series reactors or phase shifters/FACTS, or that will increase voltage support, e. g. shunt reactive devices, static VAR compensators;

- Taking greater advantage of existing assets when possible, e. g. changing the conductors of a line using high temperature ones or adding a second circuit on an existing line, the towers of which have been originally designed for that purpose;
- Replacing existing assets by new ones with higher transmission capacity, e. g. building a 400 kV double circuit line in place of an existing 220 kV one that will be dismantled;
- Adding new infrastructures, e. g. building new (HVAC/HVDC) transmission lines/cables and/or new substations/converters stations.

Of course, all these solutions are neither always feasible for implementation, nor appropriate to provide the suitable transmission capacity increase. Therefore, TSOs have to conduct a case-by-case analysis comparing expected future needs and actual possibilities, taking into account the existing network characteristics and environment. In particular, the insertion of new facilities is only proposed if other actions that would have less impact on the environment are not sufficient, or not possible in the specific context. Particular techniques like underground cables may be envisaged where appropriate.

Last, it is worth pointing out that the improvement of transmission grid performance generally implies that some facilities should be taken out of operation for the safety of persons and equipment during some phases of the works. Although operating modes are adapted in order to minimise these planned periods of unavailability, some reductions in transmission or interconnection capacities may be experienced by transmission grid users during the works [102].

5.5.2 NORDEL area

During the last decade, the planning process of NORDEL has proceeded in the direction of integrated Nordic cooperation concerning grid reinforcements and expansions. This regional cooperation is still a unique example in Europe and shows that NORDEL is a forerunner in the work to ensure a well functioning regional electricity market. This cooperation on system planning aims at developing the grid from a Nordic perspective taking into account the international aspects and paying attention to environmental impacts. The work has resulted in three common Nordic grid master plans in the last 10 years.

In NORDEL, all countries have system requirements for maintaining satisfactory security of supply. The security of supply is evaluated by using statistics of interruption and by using a calculated status indicator, the Loss of Load Probability (LOLP), for the security of supply. The system requirement in NORDEL is such that the LOLP should not exceed 1‰, which corresponds to the UCTE requirements for security of supply.

NORDEL is using two different criteria for security of supply: one criterion for the risk of system failure and one for the risk of market failure. In a system-failure situation the supply capability is not sufficient to meet the demand in the hour of operation without disconnection of some load. In a market-failure situation, supply and demand do not meet in the day-ahead spot market as the supply bids are not able to meet the demand bids. Production units used for system reserves are not taken into account.

The security of supply calculations are made with the MAPS model. Internal transmission capacities are taken into account, and import possibilities from neighbouring systems are assumed to be half of the existing capacity.
The planning criteria for the Nordic transmission system are still deterministic, although probabilistic considerations have been taken into account. In the criteria, requirements are made on disturbance consequences that are acceptable for various combinations of operating conditions and fault types. In principle, more serious consequences are acceptable for less common combinations of faults and operating conditions [19].

Cost-benefit analysis
The benefits included in the analysis are given as:
- Market value from production optimisation and energy turnover
- Reduced risk of power shortage
- Reduced electrical losses
- Reduced risk of energy rationing
- Trade in regulating power and ancillary services
- Value of reduced market power

The market value from production optimisation, reduced electrical losses and reduced risk of energy rationing have been calculated in the Samlast model developed by Sintef. The reduced risk of power shortage has been calculated in the MAPS model. The MAPS model calculates the loss of load probability (LOLP), expected unserved energy (EUE) and expected power not served (EPNS).

Trade in regulating power and ancillary services and the value of reduced market power have not been analysed specifically. The influence on the benefit from the elements has only been estimated.

The socio-economic benefits are calculated both for the Nordic area and the Continental area. The results for the Nordic market are not divided between the different countries.

Market power
It is difficult to quantify the costs and benefits in a more well-functioning market. However, it is quite obvious that the energy market will become more robust and efficient when investments are made to remove congestion. Such investments should be based on socio-economic analyses to ensure that the benefits are higher than the costs. After the investments, the prices will be more stable at least in the short term.

Transmission investments will also help to mitigate the possible exercise of market power. Abuse of market power in the electricity market will lead to socio-economic losses. There is a clear link between transmission capacity and the possibility of exercising market power. Sufficient transmission capacity contributes to enlarging the market and thereby possibly reducing the risk of abusing market power.

It is not economically efficient to invest in transmission capacity that covers all patterns of trade. This is especially relevant for the Nordic market that has a large proportion of hydropower production. The hydropower situation will differ over the years and thereby affect the energy trade. A transmission system that covers all patterns of trade without any congestion would clearly be over-invested.

Deviations in the hydro inflows and failures in thermal production units have exposed the Nordic electricity market to several tests during the last few years. More or less extreme situations have given high surplus as well as deficit in some areas with sharply increased and reduced prices as a result. Such situations often generate public discussions about the deregulated Nordic electricity market. It is common to the situations that confidence in the deregulated market is under pressure. Several national political and regulatory instruments are also launched and debated.
One question for the TSOs is to what extent these issues should be included into the calculation of new transmission investments. Today, the TSOs have no common model for this calculation. It is however obvious that the efficiency of the Nordic electricity market is based on the trust of all stakeholders and the value of a more well-functioning market should be considered and gives additional value when new transmission investments are taken into account.

Costs included in the analysis
The calculated investment costs include:
- Investments in a given transmission line and auxiliary parts
- Operation and maintenance of the line

Investments are based on a calculation of national cost levels for investments. Necessary reinforcements of the internal grid as a result of reinforcements of the interconnectors are not included in the investment costs. The total costs of the reinforcements is therefore higher and the resulting cost-benefit lower. This aspect must be investigated more thoroughly for the suggested reinforcements. This is of special interest when it comes to external Nordic reinforcements as there may be limiting intersections within the other countries that are not included in the analysis.

Cost-benefit for lifetime
The costs and benefits for each year have been analysed for a total lifetime of 30 years. The present value has been calculated by using a 5% rate of interest.

The total costs and benefits for the reinforcements have been calculated and the cost-benefit has been calculated as:

\[
\text{Benefit of reinforcements} = \text{Total benefits} - \text{Total costs}
\]

5.5.3 Central Western Europe area

A Memorandum of Understanding on Electricity Market Coupling and Security of Supply in the Central Western European region was signed by Belgium, France, Germany, Luxembourg and The Netherlands in the context of the Pentalateral Energy Forum on 6 June 2007 [20].

Under this framework, several international studies related to Market coupling, Security of supply analysis and Regional Transmission Capacity Plan have been initiated.

The MoU sets out four objectives in the field of security of electricity supply.
- It is intended to elaborate an improved regional System Adequacy Forecast (SAF) 2008-2015 based on all available data. The SAF will take into account network extension planning, generation planning and forecast of load based on commonly defined scenarios.
- A harmonised incidents classification scale should enable the sector stakeholders to have a common view and a common assessment of the incidents affecting the system reliability.
- TSO cooperation platform. The TSOs commit themselves to improving their broad existing cooperation. They will focus on: an emergency communication platform; a future unique TSO platform of TSO experts for communication and cooperation on a daily basis to share common non real time studies.
- Development of a regional transmission capacity plan for the region to show structural bottlenecks in a transparent and coherent way and to help identify investment projects in a regional perspective.
5.5.4 Austria

The main criterion for the transmission planning is techno-economic and concerns the security of the system and the minimisation of costs. The planning method is based on a deterministic approach and considers a dynamic timeframe. The time horizons are respectively 5 years for short-term planning and 10-20 years for long-term planning.

The cost-benefit analysis carried out is described in a document issued by the Regulatory Authority. Higher costs derive from congestion management.

According to Verbund-APG, the Austrian TSO, currently the biggest challenge for TSOs is to fulfil the expectancy of the EC for a fast grid development and improvement of security of supply because of the difficulty to get necessary projects approved. The extensive and time consuming EIA (environmental impact assessment) covers all aspects of the realisation of infrastructure projects and needs to be simplified in order to accelerate the improvement and modernisation of current transmission networks. Local resistance can block and prolong EIA procedures. Political support is still too weak.

Due to the delay of important transmission line projects, difficult operation situations occur which can only be handled by the use of phase shifters, special switching states or constraints of certain power plants (including pumped hydro). Of course, these procedures increase operational expenditures and have to be handled with care. These situations result in the need of congestion charges and the limitation of cross-border exchanges.

The whole wind power capacity is currently installed at the high voltage distribution level (110 kV): the wind connection does then not lie under the TSO responsibility at moment. The wind installed capacity currently amounts to 1000 MW ca. and is projected to reach 1700 MW by 2015. Problems are reported on the transmission network caused by wind plants connected to the downstream distribution: an extra node on the transmission system is currently used to collect wind power inflows.

5.5.5 France

The main criterion for the transmission planning is techno-economic and concerns the security of supply of the system and the minimisation of costs.

Within the cost-benefit analysis the reliability increase benefit is accounted for by the calculation of indices like the EENS (Expected Energy Not Supplied); another important benefit taken into account is the loss reduction; environmental benefits are not quantified.

The time horizons are respectively 7 years for short-term planning and 15-20 years for long-term planning: the transmission development plan is updated every two years.

The network studies are carried out for different time horizons, knowing it takes 6 to 10 years (or more) to build a new line, particularly due to legal procedures and consultation time [40].

The French TSO, RTE, follows these steps for the network planning studies:

- **First step: Detecting the constraints**
  - Transmission capacity constraints: they refer to the lines' transmission capacities (which vary depending on the season); an overload is allowed for 400 kV lines (for a maximum of 20 minutes)
- Voltage drops constraints: a maximum voltage amplitude deviation of 10% and 8% respect to the nominal value is allowed on EHV nodes and on HV nodes, respectively
- Short circuit power constraints: Maximum short circuit currents values depend on substations components
- Constraints are detected in normal operating conditions or in the event of the tripping of any network component (line, transformer, generation unit): N and (N-1) criteria are applied
- If the constraint cannot be solved by changing the topology of the network or by corrective redispatch, a reinforcement study is needed.

• **Second step: Defining strategies**
  - Generally, several reinforcements are necessary along time (at year 6, 10 or 15 of observation)
  - A reinforcement strategy is a succession of several reinforcements in time, to solve constraints until year 15 of observation (at least)
  - Each strategy is adjusted to take into account technical, environmental and legal issues: adaptation of geographical route, choice of overhead lines vs. underground cables
  - Environmental issues, such as local and national natural parks, specially protected areas, architectural sites, density of housings near the route, have to be considered
  - Contextual issues, such as presence of influential political actors in the considered area, level of difficulty encountered in past network reinforcement projects, might have to be tackled as well.

• **Third step: Evaluating and comparing strategies**

  Strategies are compared taking into account: the investment cost of the strategy; the operating costs (cost of thermal losses, generation schedule adjustment costs); the estimated cost of unsupplied energy.

  For each strategy, a discounted balance is calculated via the NPV (Net Present Value) so that:
  - Strategies with positive NPV are taken into account
  - Strategies are always compared to the “doing nothing” strategy
  - In complex situations (uncertainty), “minimax regret” approaches are used
  - In addition to the issues previously taken into account, the strategies include also:
    - the sociological, political and economical context of the areas,
    - other legal requirements,
    - other structuring projects (new roads, transportation facilities) in terms of risks or opportunities.

• **Fourth step: Finding the optimal date for the first investment**

  Once the reinforcement strategy is chosen, the date of the first investment must be specified. The postponement of the investment might be profitable, but with time the constraints increase: the operating costs increase, the non-quality costs increase. There is therefore an optimum year to be found (see also Figure 9).
Among the network reinforcement solutions there are: upgrading of assets (changing conductors, foundations); optimisation (introduction of e.g. phase shifters, compensators); adding new infrastructures (stations, lines, transformers etc.).

Figure 9: Economic implications of a network investment postponement.

The following describes the modes and the assumptions applied to initiate RTE planning studies. The network is represented in a realistic configuration for the considered time horizon, taking into account future reinforcements (decided but not built yet). Hypotheses are deduced from the long-term system adequacy studies. Concerning the load, the national forecast (baseline scenario) is translated in load forecast for each supply node. Concerning the generation, new scheduled and planned units are taken into account, while local generation development (wind power) is difficult to assess, in volume and in location. Few scenarios with exchanges (export, import) with bordering systems are studied.

Load flow analyses via deterministic methods are performed in compliance with the following principles:
- a network strong enough for some typically difficult moments is a network strong enough for most of the time
- a single scenario is forecasted, generally based on winter peak; in case of uncertainty, several scenarios are evaluated in steps
- different generation situations are forecasted, based on “best estimates”
- for each step of the method, for each studied year: focus on one typical winter day, one typical summer day, one mid-season day; off-peak snapshots are evaluated to detect local congestions due to distributed generation; studies on several snapshots in time are performed
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

- for N situations: the load is analysed with respect to the worst winter temperature out of ten years of observation
- for (N-1) situations: the load is analysed with respect to the normal temperature

The advantage of this approach is that it is well-suited to conduct a fine analysis of the reasons of the constraints, whether they are related to the generation plan, to the level of the consumptions or other issues.

The drawback is the difficulty to evaluate the sensitivity of the constraints (and the reinforcements) to a variation of the assumptions related e.g. to the generation plan, to the cross-border flows, etc.

Load flow analyses performed via probabilistic methods are mainly used for the 400 kV network and in those cases:
- the network is quite influenced by the generation plan and the cross-border flows
- different load situations are forecasted (winter peak, winter off-peak, summer peak, summer off-peak, inter-season peak)
- different scenarios are also established for exchanges on interconnections
- thousands of generation scenarios playing on availability of the different units and on wind level on French wind areas are sampled
- constraints are detected in all situations and computed statistically

The advantage of this approach is the ability to account for the uncertainty of data and assumptions: reinforcement solutions are more secure.

The drawback is that the analysis of the origin of constraints is more complicated; there is also a difficulty to assume the probability of the situations.

5.5.6 Germany

As also reported in [95], better regulations are needed for interconnection: in November 2006, there was an important breakthrough for the offshore market, when the German federal Council of Ministers passed a law, aiming to speed up the planning procedure for infrastructural projects. Central to this new legislation was that the grid connection of offshore wind farms has to be provided and financed by the national grid operators. Thanks to the new rules the costs will have to be distributed over the total grid – as it is for all other types of power plants. Suddenly, investments in German offshore wind energy projects were becoming much more lucrative.

The German Grid Code [42] describes the main features for transmission network development planning in Germany.

The TSO plans the development of its network in order to have a transmission system which is adequately dimensioned for the projected tasks, and which permits secure, consumer-friendly, efficient and environmentally compatible operation and economical system use at an adequate quality of supply.

The TSO draws up economic network plans on the basis of the current load and generation situation and the projected development of the facilities which are already connected or which exist according to the requests for connection to the grid. Congestion occurring at short notice as a result of changing loop flows and transits cannot be taken into consideration in network development planning.
The system has to be dimensioned in accordance with deterministic methods. In addition, probabilistic methods can be utilised. Owing to uncertainties in terms of forecasts, observance of the defined minimum requirements at the planning stage is essential. The (N-1) criteria are addressed separately for the 380/220 kV transmission system and for the 110 kV system with transmission functions. The criteria represent the framework of technical evaluation for specification of the network connection scheme for customer facilities and for network development.

Observance of the (N-1) criterion permits the provision of adequate reliability of supply (continuity of supply) for all connection owners/connection users, secure power transfers, and provision of system services. The (N-1) criterion addresses all issues relating to network technology, in particular the system services to be provided (e.g. voltage control including provision of reactive power), equipment utilisation, the protection concept, and, where applicable, stability issues.

At the planning stage, the TSO has to design its network in accordance with the (N-1) criterion such that the network functions are fulfilled for the projected maximum transmission and supply tasks in the case of a single failure triggered by an event. In addition, maintenance work carried out in power stations and on network equipment have to be taken into consideration for selected transmission and distribution functions.

For evaluation of the security within a network area, the (N-1) criterion has to be applied for relevant time horizons with the generation schedule expected for that time from the instantaneous perspective (including injections from installations for HVDC transmission from plants using renewable energies) and with due regard to transits. The (N-1) criterion shall be applied to networks on the basis of postulation of a forced outage of the generating unit having the greatest effect upon the security of supply. The (N-1) criterion shall be fulfilled when the total feed-in capacity can still be transmitted in the event of a failure of an item of network equipment (except for busbar faults). Consideration shall be given to the network capacity contracted or forecasted for the subordinate voltage level.

For evaluation of the security of supply of 110 kV network with a transmission function, the (N-1) network design criterion has to be applied to networks with a maximum and minimum power station commitment in accordance with the agreements concluded with the power station operators and the variations in power availability.

The TSO is responsible for initiating the public approval procedures required for the development of its network, and for launching the construction measures upon the granting of approval.

Stability of transmission systems
Stable synchronous operation of the generating units is a prerequisite for secure and reliable interconnected operation and for customer supply. The dynamic behaviour of an electric power system is a product of the physical interaction between the generating units, the European synchronously interconnected transmission system of UCTE and the connection users with their respective control equipment. The TSO must therefore have exact knowledge of the dynamic behaviour of the installations connected or to be connected to its network. To this end, the connection owner/connection user shall supply the needed data upon request.

Stable operation has to be ensured for all relevant conditions by suitable dimensioning/parameterization of the primary and secondary control equipment in customer facilities and in
the network. A distinction must be drawn between the steady-state and transient stability in the evaluation of stability and the resulting technical requirements placed upon the network. Steady-state stability is an essential prerequisite for operation of an electric power system, and must be ensured at all times and at every working point. Steady-state stability is no longer ensured if, during disturbance-free system operation, minor changes in system states (e.g. variations in power transfers, switching operations) result in steady-state operation no longer being maintained and in the occurrence of self-induced oscillations which may result in large-scale collapse of the system or damage to the customer facilities. Transient stability is no longer ensured when, following clearance of a system short circuit, one or more generating units lose synchronism with respect to the transmission system. Major changes in frequency and voltage and high transient currents between the transmission system and asynchronous (pole-slipping) generating units may seriously impair secure operation of the electric power system.

5.5.7 Great Britain

5.5.7.1 Planning Code
The Grid Code [78] is divided into several sections and one of these is the Planning Code, which provides generally for the supply of certain information by the network users in order for the TSO to undertake the planning and development of the transmission system of Great Britain (GB).

The GB Security and Quality of Supply Standards establish a coordinated set of criteria and methodologies that the TSO shall use in the planning and operation of the GB transmission system. The criteria presented in these Standards represent the minimum requirements for the planning and operation of the GB transmission system.

In planning the Main Interconnected Transmission System, a minimum number of deterministic criteria must be met. It is permissible to design to higher standards provided that the higher standards can be economically justified.

The minimum transmission capacity requirements at ACS (Average Cold Spell) peak demand with an intact system are reported in the following. The transmission system shall be planned such that, prior to any fault, there shall not be: equipment loadings exceeding the pre-fault rating; voltages outside the pre-fault planning voltage limits or insufficient voltage performance margins; or system instability. The transmission system shall also be planned such that for the secured event of a fault outage of any of the following: a single transmission circuit; a reactive compensator or other reactive power provider; a double circuit overhead line; a section of busbar or mesh corner [and others not mentioned here], there shall not be any of the following: loss of supply capacity; unacceptable overloading of any primary transmission equipment; unacceptable voltage conditions or insufficient voltage performance margins; or system instability [78].
5.5.7.2 Great Britain Seven Year Statement

The 2008 Great Britain (GB) Seven Year Statement (SYS) [80] presents a wide range of information related to the power system in Great Britain regarding demand, generation, plant margins, the characteristics of the existing and planned GB transmission system, its expected performance and capability. One of the most interesting features of the SYS is the indication of the Generation Opportunities, meant as the ability to connect new generation without an associated need for major transmission reinforcement (which could in turn lead to delays caused by the need for planning consent and possible public inquiries).

Figure 10 separates the 17 Study Zones into five opportunity groups, namely: Very Low, Low, Medium, High and Very High. The figure also provides an indication of the capacity of new generation that can be accepted in the individual zones of each opportunity group without the need for major transmission reinforcement.

It does not follow that all the generation capacity within an opportunity group could be located at one site within a zone. In some zones, for example the London Zones, a considerable spread would be necessary. Nor does it follow that the capacities indicated for each zone within an opportunity group could be accepted together. The proposed connection of a significant volume of new transmission contracted generation in the North of Scotland, substantially made up of wind farms, is dependant on the completion of transmission reinforcements.

Figure 10: GB Generation connection opportunities [80].
A general message is that new generation located in the South would less need major inter-zonal transmission reinforcements and possible time delays than generation located in the North. The analyses of boundary power transfers show that, with the increase in new generation (30.2 GW) planned for the following seven years, the resultant power flows through the Scottish and English grid systems to the South would require significant reinforcements.

5.5.7.3 Offshore transmission
As reported in [80][81], the UK Government expects the development of offshore renewable generation to make a major contribution to the achievement of its emission targets. Up to 33 GW of offshore renewable generation may be developed. The majority of this generation will be connected to the GB electricity grid through offshore transmission cables. Offshore transmission is defined as being any offshore transmission network that operates at 132 kV or above. Offshore transmission will be a licensed activity, regulated by Ofgem. It is anticipated that several billions Euros of new transmission investment will be required.

A new regulatory regime for offshore transmission networks is being developed by Ofgem in partnership with the Department of Energy and Climate Change (DECC), and previously the Department for Business Enterprise and Regulatory Reform (BERR).

A key feature of this regime is that each new tranche of transmission assets required by offshore generators will be awarded through a competitive tender process. Introducing competition will: encourage new players to enter the industry, provide more scope for innovation, and allow a longer term and lighter touch for the regulatory regime.

Some proposed changes for the Grid Code focus on:
- For Planning Code: Extension of existing data exchange requirements to offshore generators that are directly connected to an offshore transmission system; explanation that data exchange requirements for offshore generators connected to an offshore transmission system will be defined (as requested) in bilateral agreements.
- For the Connection Conditions: Extension of relevant, existing obligations that apply in England and Wales, to offshore generators; introduction of different reactive power capability requirements for offshore generators (compared to onshore generators); inclusion of an alternative fault ride through capability requirement as an option for offshore generators; explanation that generator capability requirements for offshore generators connected to an offshore transmission system will be defined (as requested) in bilateral agreements.

The ongoing process of review of the security standards draws upon the following conclusions on the fundamental differences between onshore and offshore transmission in relation to the cost of assets and variability of the generation connected: the level of redundancy of onshore transmission is unsuitable for offshore transmission; different (and lower) security requirements for offshore transmission systems are justified; however, no deterioration of security and quality of supply for users of the onshore transmission system is permissible; and, finally, cost-benefit analyses are deemed as a sound basis for the development of an offshore deterministic standard [82].
5.5.8 Ireland

EirGrid, as the Irish TSO, has the responsibility for planning, operating and maintaining the transmission system, which comprises 400 kV, 220 kV and 110 kV networks linked through substations. The former national utility, ESB (Electricity Supply Board), is now also the Transmission Asset Owner (TAO), in charge of constructing the assets for the transmission system infrastructure as specified by the TSO. ESB also has the role of Distribution System Operator (DSO) with which the TSO coordinates planning and development requirements.

An objective of the TSO is to develop a safe, secure, reliable, economical, and efficient electricity transmission system to meet reasonable demands for the transmission of electricity in accordance with its legal obligations. The TSO plans the development of the grid taking account of the long-term needs and the economics of various development options.

The requirement for grid development is identified when simulation of the future conditions indicates that the transmission planning standards would be breached. These standards, which are in line with international standards, are set out in the Transmission Planning Criteria [50].

These criteria are deterministic as generally throughout the world in transmission planning. They set out objective reliability standards which have been found to deliver an acceptable compromise between the cost of development and the level of transmission service delivered. Transmission investment planning consists of many different decisions to address different problems.

Once a violation of the criteria has been identified, a wide range of issues is taken into account in selecting a transmission enhancement strategy. The objective is to come up with investment plans that meet the transmission requirements in an efficient and cost effective manner in compliance with the principles of the Transmission Planning Criteria.

The criteria include standards for voltage range and deviations, maximum thermal loading of grid equipment, system security, dynamic stability and short circuit levels. The grid must operate within these specified standards for intact network conditions, and following an unexpected outage of any circuit or generator ((N-1) security criteria). This also applies during maintenance outages of any other lines, cables, transformers or generators.

The Transmission Planning Criteria are reported in an ESB official document [50] and they include the following items:

Objective
The primary aim of transmission planning is the maintenance of the integrity of the bulk transmission system for any eventuality. The adequacy and security of supply to any particular load or area is secondary to this primary aim. The technical considerations are continually mitigated by economic issues and all other significant factors (like the environmental one) brought up by the various transmission system stakeholders.

Reliability Criteria
Reliability criteria are defined and measured in terms of performance of a system under various contingencies. Prediction of performance is based on simulation, rather than actual tests. These criteria are based on the fundamental assumption that system integrity will be maintained for the more probable and less probable contingencies and that there is no loss of load for the common more probable contingencies.
The system shall be designed to operate within normal operating ranges for credible load and generation patterns for base case operation. The system shall be designed to withstand the more probable contingencies without widespread system failure and instability, maintaining power quality within specified voltage and frequency fluctuation ranges and maintaining voltage and thermal loadings within operating limits. The more probable contingencies are comprised of single contingency (N-1), overlapping single contingency and generator outage (N-G-1) and trip - maintenance (N-1-1) disturbances.

In the immediate aftermath of a disturbance, the system should reach a steady state that is within emergency limits. Then, by use of remedial actions specified in the criteria, the system should be capable of being returned to normal limits.

The simulation tests do not preclude further, detailed tests that would enhance planning for specific components of the transmission systems. Additional detailed tests may include: substation reliability evaluation, voltage collapse simulation, subsynchronous resonance calculations, dynamic stability, switching simulations etc.

For system integrity, the system should be able to withstand more severe but less probable contingencies without going into voltage collapse or uncontrolled cascading outages. Examples of this class of contingencies are busbar faults, busbar coupler faults, breaker failures, relay misoperation, loss of double circuit, etc.

Overall Assessment
Any transmission plan proposed for adoption under these criteria must ultimately be justifiable taking account of economic, financial, strategic and environmental considerations.

Planning Horizons
These criteria and performance tests are applied to medium-term planning horizons (five to ten years) upon which Transmission Development Reports are to be based. Planning time frames in the near term (one year ahead) and long-term (15-20 years ahead) are subject to a limited set of performance tests which at least includes the cases with more probable contingencies.

EirGrid has also conceived a long-term vision of the development of the electricity transmission grid in Ireland (including also Northern Ireland): this is the so-called Grid25 [51]. In this view the Irish power system will have to deal with a wind capacity of 5 GW by 2025: for this reason the needs for alternative and flexible solutions to transmission development have emerged. In Grid25 there is a forecast of large investments (4 b€ ca.) necessary for circuits doubling, network upgrades, utilisation of innovative technologies (HVDC, PSTs, cables, high temperature conductors etc.) useful for a smoother control of wind plants outputs. In this context, also offshore HVDC networks for wind integration are taken into account.

5.5.9 Italy

5.5.9.1 The development planning process in the grid code
The strategies for the Italian transmission grid development, with the description of the planned activities in the short-to-medium term (generally no more than three-year ahead) and in the long term (in general no more than a ten-year time span), are contained in the Transmission
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

Development Plan (TDP) [52]. This document illustrates and periodically updates the programme of activities of the Italian TSO, TERNA, with reference, in particular, to the scheduled dates, for starting the authorisation procedure and for implementing the development of the transmission grid.

The TDP is also a useful mean for timely informing the local authorities of the needs for development of the transmission grid that affect the various regional territories. This, together with the Strategic Environmental Assessment (SEA), enables the coordination of infrastructural and energy-related policies and plans at local level with the programmes for development of the electrical system in the various regions.

The TSO will strive, using the most suitable means, to inform institutions and make the final customers aware of the planned developments of the transmission grid and of the state of their implementation in compliance with the current legislation regarding the protection of health and the environment.

Developments of the transmission grid are considered:
(a) Variation of the transmission capacity, transforming capacity, interconnection capacity or capacity to withstand short circuit;
(b) Geographic extension of the transmission grid obtained by means of constructing new electrical lines or new power stations;
(c) Increase in the operating flexibility, for example by means of the installation of suitable devices for compensation of reactive power and control of power flows (PSTs, FACTS);
(d) Decommissioning of elements of the transmission grid, linked essentially to rationalisation of the grid;
(e) Downgrading or upgrading that imply changes to the level of voltage for power lines and stations, with consequent variations in consistency in the various voltage levels affected.

As reported in [52], the planning process for development activities on the Italian transmission grid begins with the collection, selection and analysis of essential information about: forecasts of electricity demand and its geographical distribution; location and power capacity rating of new power generation plants; forecasts of electrical energy exchanges with other countries; development programmes of other grids with third party access interoperating with the transmission grid.

For the target year of the planning analysis, one or more probable operational scenarios for the electrical system are identified, and, based on these, “reference cases” are created for studies on the grid under development; the goal is the identification of the possible critical states in the grid operation and their resolution through transmission development.

These scenarios also take into account assumptions for power dispatching which are based, among other factors, on the estimated costs of production, differentiated depending on the type of fuel and the efficiency of the plants, and on the market results.

The TSO verifies the operating conditions of the grid under development in terms of static security, using the (N – 1) security criterion. The (N – 1) analyses allow to identify grid problems to be solved (configurations which are critical or unacceptable from the point of view of static security) and then also possible grid reinforcement solutions to address these problems.

The development of the transmission grid is closely correlated to the connection of new users to the grid, even though the two processes, “identification of solutions for connecting new users to the grid” and “planning related grid reinforcements”, are distinct, both in terms of timing and method used.
(a) Regarding the timing of these processes, the analysis of connections to the transmission grid is a continuous process, performed at every new connection request, while the planning process cycles annually and in any case follows the connection stage. This is mainly with the scope to get a more reliable overview of programmes to be realised.

(b) Concerning the method used to define the connection solutions, the TSO analyses each connection project, deferring to the subsequent development stage of the transmission grid the solution to any problems associated with excessive concentration of connections in the same area.

In the process of planning grid reinforcements, the TSO carries out its own analyses on the reference scenarios considering the power plants already existing and expected in future, in order to guarantee the security of the entire transmission grid.

This stage defines the necessary grid reinforcements, with the following objectives:

(i) maintain (N – 1) security of the reference grid under development;
(ii) reduce any grid congestion caused by new plants connection;
(iii) reduce the restrictions for the constrained production centres.

The related load flow analyses for defining the grid reinforcements are in general carried out according to the (N – 1) criterion and include, in particular for plants running on renewable sources which cannot be scheduled, appropriate evaluation of the probability of production of these types of plant.

Concerning the network planning process in Italy, some issues faced in the coordinated development of transmission and distribution interoperating networks according to the Italian experience [55] [83] have to be finally remarked. These are described in the following points:

- **New connections between transmission and distribution networks.** The main consequence of such connections is an alteration of the power flows registered on both the systems. Several typologies of link can be distinguished: transmission substations or lines connected to distribution lines or substations, distribution substations or lines connected to transmission lines or substations.

- **Intertwined development of transmission and distribution networks.** In certain rationalisation activities, in case of new substations construction and in particular network reinforcement implementation, it may be necessary to involve also other bordering interoperating networks. The scope of this would be to effectively relieve network constraints and manage operational issues. As the involved systems are tightly interconnected, it is often unclear how to share the investment costs and how to coordinate construction activities. The change in power flow pattern is not the only consequence stemming from a mixed development of interoperating network. Even the short circuit level increase is another aspect to be duly taken into account so as to evaluate the need to upgrade electrical equipment.

- **New transforming substations.** Some transforming substations are planned to supply both high voltage transmission and distribution networks. In some cases, building new substations allows to avoid generally more substantial (from the economic and environmental point of view) reinforcement of surrounding high voltage network.

- **Network restructuring to mitigate territorial/environmental impact.** Rationalisation activities carried out to reduce environmental impact are a recurring and sensitive issue attached to the interoperating transmission and distribution network development. Rationalisation activities stem from: initiatives from the network operator, when new plants construction implies
dismantling/modifying existing facilities for operational/environmental/authorisation needs; initiatives from third parties such as local administrations, distributors and power producers.

Some of these issues are expected to be bypassed after the TSO has recently acquired the subtransmission assets from the largest distributor.

5.5.9.2 Cost-benefit analysis performed by the Italian TSO

As reported in [54], the network development projects are based on a cost-benefit analysis translating the electric values of the reinforcements in economic value for the national electricity system. On one side, the main driver for planning a grid expansion work is to cover the national electric demand under defined adequacy and security conditions for the transmission system; on the other side, every project has an impact in terms of economic benefit for the whole country. The projects included in the Transmission Development Plan are solely those ones offering an overall economic benefit larger than the total cost. The Italian TSO Terna carries out every year a systematic update of the costs and benefits calculation for the development projects included in the Plan. This update is needed owing to the regularly changing costs of raw materials and fuels, the variability of the electric system in terms of load and generation patterns and the evolving emission taxation schemes.

The ratio between the actualised benefits and costs of a development project is defined as Profitability Index (PI) and it represents the economic return on the investment for the whole national system. A project is profitable when its PI is higher than one, which implies benefits ensuring a future return making up for the investments initially made.

The cost items considered by Terna in the cost-benefit analysis are:
- The Capital Expenditure (CAPEX): these costs are allocated over the three years preceding the entry into operation of the project under consideration. A conservative approach is followed whereby these costs are increased by a 10% factor in order to take into account possible changes occurring at the time the work is actually executed.
- The Operation and Maintenance Expenditure (OPEX): these costs are spread annually over the investment and are assumed to amount to some 1.5% the CAPEX.
- The spending for possible dismantling works.

The categories of possible benefits deriving from transmission expansion and here considered are: network losses reduction; congestions relief; generation park constraints reduction (i.e. leading in principle to the full availability of more efficient generation); increase of system adequacy to cover demand and network operation security; increase in foreign energy imported at a more convenient price margin; value of avoided energy not supplied; elimination of constraints to the production from renewable energy sources; investments avoided (including the works needed for the fulfilment of environmental legislation); CO2 emissions reductions; reduction of costs for the ancillary services market.

Figure 11 indicates an example of the monetary flows correlated to the costs and benefits of an expansion project. The red-coloured costs represent negative monetary flows, whereas the green-coloured benefits denote positive flows. Whenever the sum of the costs and benefits lays in the upper part of the graph, then the reinforcement is proven as profitable for the national system and its Net Present Value (NPV) is positive. The higher is the PI, the higher is the NPV and the associated urgency in implementing that particular project.
The benefit attached to the energy unlocked by a new electric link generally represents the most relevant benefit. The current structure of the Italian transmission system features numerous sections where power congestions occur. One of the main targets of the Transmission Development Plan is therefore to reduce the congestions so that the economic efficiency of the Italian power system increases. Some reinforcements, in particular power lines, indeed allow to existing and future power plants to inject larger energy amounts into the network, thus removing those bottlenecks which render, or may render, the power production, and then the system, less efficient.

The construction of a new line on the more congested sections brings about the larger benefits for the whole national system, also because the system becomes less dependent on the power market and the strategic choices of dominant market players. In particular, the benefits linked with the congestion reduction have a twofold nature, in terms of power and energy: namely, they avoid further installation of production capacity to meet the demand; furthermore, they avoid the production from less competitive power plants, thus favouring other more efficient generating units.

The assessment of the benefits of a new development project draws upon the notion of the cost of the alternative to the reinforcements under consideration. Basically, the benefit of a new transmission project represents, for the whole country, the cost eventually borne due to the missed realisation of the same project: if the proposed grid reinforcements are not implemented, the national system will spend more money than in case of successful completion of the works indicated in the Transmission Development Plan.

For example, if a new link in the power grid manages to carry energy from areas with a production surplus (unlock of constrained power generation parks and increase in inter-area transfer capacity), it not only avoids to build up new power plants in areas with production lack, but also avoids investments in alternative grid reinforcements (e.g. a new transformer in a substation or new lower voltage lines) usually having only a short-term effectiveness.
5.5.9.3 Combined network planning and wind connection schemes
An integrated and proactive approach, entailing combined connection and planning decisions, is being adopted by TERNA (and also other European TSOs), to cope with the numerous wind connection requests affecting relatively small areas of territory. Such approach, named by TERNA “Power Collectors Method”, foresees planning the construction of new 380/150 kV substations, aimed to collect and wheel at higher voltage level the wind power actually injected on certain portions of 150 kV network. More specifically (see Figure 12), the implementation strategy follows these steps: the whole wind connection requests are assessed, so as to detect a macro-area of wind production; the closest 380 kV line and the optimal location for a new 380/150 kV substation is then recognised within the macro-area; the surrounding 380 kV and 150 kV networks are adequately reinforced to allow the connection and the exploitation of this new wind generation.

![Figure 12: Network planning strategies for wind connection in Italy](image)

This method allows connecting sizeable amount of wind power (valued by TERNA in excess of 200 MW within a defined macro-area) in a more secure fashion and with environmental and economic advantages. As matter of fact, this scheme allows reducing congestions – also brought about by wind production – on the typically weaker 150 kV network and ensures a lower environmental impact of the network infrastructures to be built. The length of reinforced 150 kV links needed is in fact much lower than in the case only the 150 kV grid should carry the whole wind production, without a near outlet towards the much more capable 380 kV network.
5.5.10 The Netherlands

Regarding the long-term planning, the Dutch TSO, TenneT, adopts the following deterministic approach (as stipulated in the Netcode [62]):

- Conditions for consumers: each year in the first week of February consumers connected at a voltage of 10 kV and higher, with contracted and provided capacity of higher than 2 MW, shall submit to the network operator their best possible estimate of the following matters for the coming period of seven years: development of the maximum annual power to be taken up (MW/MVAR); description of the pattern of the active power to be taken up; expected breaks in trends.

- Conditions for generation units: each year in the first week of February, operators of generation units with a capacity of higher than 2 MW shall submit to the network operator their best possible estimate of the following matters for the coming period of seven years: place, capacity, technical data, operational limits and regulating behaviour of the individual generation units; place, dates, technical data, operational limits and regulating behaviour of generation units to be started up; place of generation units to be decommissioned and the date of decommissioning; maintenance planning for each generation unit (stating period and duration in weeks).

- Operators of generation units, other than captive consumers within the meaning of the Electricity Act [65], whose generation units are connected to a network with a voltage of 10 kV or higher, shall further submit to the network operator each year in the first week of February their best possible estimate of the expected operating plan for each generation unit, in time intervals of at least one week for the coming period of seven years. This submission is needed in the form of an indication of how the generation unit shall operate in respect of such matters as: base load; medium load; peak load; capacity that cannot be regulated; hot standby reserve/regulating unit; cold standby reserve; idle state.

- Conditions for interconnected network operators: operators of interconnected transmission, subtransmission and distribution networks shall provide each other each year in April with the following data (for simultaneous operation of all connections):
  - Load data: development of winter peak, summer peak and off-peak load on an annual basis for a period of seven years (MW/MVAR); description of the load pattern (e.g. standard day merit order for a working day, Saturday and Sunday); distribution over relevant substations (MW/MVAR).
  - Generation data: maintenance planning for generation units larger than 60 MW connected to the network concerned; operating plan prepared for generation units connected to the network concerned for a period of seven years.
  - Network data: technical data and transmission capacities of connections and transformers of the 380/220/150/110 kV networks; installed compensation capacity; infeed of short-circuit power; topology and standard switching state.

It has to be remarked that TenneT, the Dutch TSO, has become (in 2008) the owner of 110/150 kV assets in the Netherlands and the operator of those grids. This may not be without effects on the Netcode rules implementation.
The design of the 380/220 kV networks, including transformers connected for interfacing with the 150/110 kV grids, must be checked against the following criteria present in the Grid Code [62] (now adopted also in the Quality and Capacity Plan [63]):

a. with a fully operational network, the supplies or take-ups required by the connected parties shall be achievable, also in presence of failure of a network element ((N-1) criterion);

b. if any circuit, any transformer, any generation unit or any large consumer load is unavailable for maintenance purposes, the supplies or take-ups required by the connected parties shall be achievable, also in presence of failure of another network element. Allowance needs to be made in this respect only for loads occurring during the maintenance period as a result of the supplies or take-ups (this is a kind of (N-2) criterion or (N-1) criterion during maintenance);

c. it shall be possible to assure the (N-1) criterion by means of adjusted generation distribution or through other pre-agreed measures, even on the occurrence of the peak load, in case of non-operation of any circuit, any transformer, any two generation units or a large consumer load. The national-to-regional grid interconnections are tested against criterion c. by calculating whether the (N-1) criterion could still be met if all the production units in the relevant regional grid were deployed, with the exception of the two largest units.

The design of high voltage networks at 110 kV and 150 kV shall be checked against the following criteria:

a. with a fully operational network, the supplies or take-ups required by the connected parties shall be achievable, also in presence of failure of a network element. If a single failure occurs, an interruption of not longer than 10 minutes with a maximum load of 100 MW is permissible;

b. if any circuit, any transformer or any generation unit is unavailable for maintenance purposes, the supplies or take-ups required by the connected parties shall be achievable, also in presence of failure of a network element. This condition needs to be met only for loads occurring during the maintenance period as a result of the supplies or take-ups. A deviation is allowed if the duration of the interruption does not exceed 6 hours and 100 MW.

The designs of the 380/220 kV networks and of the 110/150 kV networks shall further be checked against the following criterion: at all load conditions and with a fully operational network, it shall be possible, after the failure of any generation unit, to fully use the system, also in presence of failure of a network element.

Considering the Grid Code’s guidelines, every two year the Quality and Capacity Plan [63] for the upcoming 7 years is developed. To this purpose a scenario analysis is performed: 4 different scenarios for the 1st, 4th and 7th year are created and then analysed. In order to test the existing grid against the applicable Grid Code criteria, load flow calculations are performed for each of the transmission scenarios, thus quantifying the maximum power flows to be expected. Power flows in high voltage grids are determined by the topology of and switches status in the grid, the deployment of production capacity and the distribution of the load among the high voltage substations. Every change in topology (e.g. in the event of maintenance or failure of grid elements)
elements), in deployment of production capacity and/or in load is associated with a particular power flow pattern, which needs to be determined by means of a new load flow calculation. A power flow through a circuit or transformer is considered permissible if it does not exceed 110% of the nominal transmission capacity of the circuit or transformer in question (except where the failure of a busbar system is concerned, in which case flows of up to 150% of the nominal transmission capacity are permitted through transformers connected to the parallel busbar system). Load flow calculations are also used to determine the voltages at the substations under various conditions. The calculated values are not permitted to deviate from the nominal values by more than 10%. Short-circuit resistance and stability problems in the existing grid are reported where it is relevant to the case or situation in question.

No special criteria for wind integration have been developed yet. However, the Dutch TSO considers that probabilistic approaches will be needed.

At present, new national regulations regarding congestion management and green before grey (for transport capacity allocation) are under construction.

TenneT has conceived a clear and coherent long-term vision of the development of the electricity transmission grid in the Netherlands: this is the so-called Vision2030. The vision reflects the desire for flexible and sustainable solutions. Vision2030 is intended to be an integrated view of the entire Dutch electricity transmission grid between 380 kV and 110 kV. That comprehensive vision is being developed in stages, with a first report covering those elements of the grid rated at between 380 and 220 kV [64]. Figure 13 illustrates the Vision2030 grid concept and suggests the locations of the 6,000 MW of wind farms expected off the Dutch coast.
5.5.11 Portugal

The planning of the Portuguese transmission grid up to 2014, and also a vision on the evolution of the network up to 2019, is presented by the Portuguese TSO, REN, in the Plano de Desenvolvimento e Investimento da Rede de Tranporte 2009-2014 (2019) [68].

This document describes the evolutions of the Portuguese network according to several paradigm modifications. Among these, the most important ones are the adaptations needed due to the changes in the production sector, either in conventional thermal and large hydro plants or in the increasing “other renewables” plants, mainly wind farms. These last ones are expected to be mainly built in the North and Center areas of the country: this situation will create the need of transferring power to the South.
Another important grid development is the reinforcement of the connections with neighbouring Spain. This is planned through two new 400 kV interconnections, one between the Northwest of Portugal and Galicia and another one between Algarve and Andalucia, so that the interconnected power capacity between the two countries will reach 3000 MW.

The transmission grid will also have to be reinforced due to the new high speed train to be built. Finally, it is foreseen the increase of the connections to the distribution grid in several points, being this accomplished by the construction of new substations and/or lines.

The major part of the reinforcements above mentioned will be executed at 400 kV, but some also at 220 kV level.

In terms of penetration scenario for the wind generation, 7500 MW onshore wind and 550 MW offshore wind power might be deployed by 2019 in different potential locations [68].

Concerning stability, REN, the TSO, has commissioned several studies also presented in [68]. One study specifically addresses the wind generation deployment on Iberian Peninsula and highlights the importance to provide the wind generators of the Iberian Peninsula with Fault Ride Through capabilities. This study analyses also the impact of a new Spain-France 400 kV line, that would allow an increase on wind generation in both Spain and Portugal.

5.5.12 Spain

This subsection illustrates the transmission expansion planning methodology used in mainland Spain by the Spanish TSO, Red Eléctrica de España (REE), in an electricity market context [99]. The fundamental criteria, on which transmission expansion planning by REE within a competitive environment is based, aim for all plausible operating conditions, including the extreme ones, at:

- minimising investment and operations network cost
- achieving a secure and efficient static and dynamic functioning of the network
- complying with appropriate environmental, administrative, and social requirements.

It should be emphasized that the transmission expansion planning problem is essentially multiyear (dynamic) as investment decisions span and are carried out throughout several years. However, a common simplification is to consider a single target year.

The transmission planning analysis in REE spans a 10-year horizon and focuses on the final year and on an intermediate year.

The expansion planning methodology in REE consists of the following four fundamental steps:

- Step 1: Multiple scenario generation covering the whole planning horizon and detailed analysis of these scenarios.
- Step 2: Information structuring and index calculation.
- Step 3: Identification of competitive and necessary network reinforcements.
- Step 4: Decision making.

These steps are detailed below [99].

Step 1

About 400 scenarios are generated to identify all plausible operating conditions defined as combinations of load conditions, generation profile, and network status. Particular care is exercised to identify the extreme scenarios. Each scenario has associated a probability of
occurrence. It should be noted that this set of scenarios properly describes the operating conditions related to the 8,760 hours of the target year.

The scenarios must comply with the following requirements:

- to cover the expected range of demands for the duration of the considered target year: peak and extreme peak loads, extreme off-peak load, as well as other relevant load conditions
- to characterize all the technical constraint violations in the system (overloads and high and low voltage bounds)
- to exhibit the expected variability of fuel prices, hydro conditions (wet and dry), wind conditions (high and low), international exchanges, etc., throughout the considered target year.

Scenarios are characterized for both the static and the dynamic viewpoints. For the static analysis an optimal power flow (OPF) tool is used, while for the dynamic analysis a transient stability tool is used. From the dynamic perspective, exhaustive transient stability analyses are carried out. From the static point of view, the (N-1) criterion is used for generating units, lines and transformers, and the (N-2) criterion for double circuit lines, substations with a high level of generation or transformation, and substations with very short fault clearance times.

Generating costs for OPF simulations are obtained for each available technology by properly forecasting fuel costs.

Step 2

Once scenario information for a whole year is gathered, different criteria and indices are used to summarize the information embedded in the scenarios.

Two criteria are introduced towards the assessment of scenarios and reinforcement alternatives:

- Criticality: Impact that the failure of a given element has on the other elements, in terms of overloads and noncompliance with voltage limits.
- Sensitivity: Impact on a given element (overloads in lines or transformers and voltage deviations at nodes) as a result of the failure of the other elements of the system.

Three types of indices are used to characterize scenarios:

1. Extreme values (maxima and minima). These values enable the detection of the largest overloads, overvoltages and undervoltages, regardless of the probability of the contingencies that cause them and of the probability of the scenarios that originate them.
2. Probability-weighted RMS (root mean square) values. These indices are calculated as the root mean square value of relevant magnitude (overloads, overvoltages, and undervoltages) values expressed in per unit and weighted with the corresponding probabilities.
3. Probability-weighted deviations over limits. These indices are calculated using the products of the deviations (observed values minus limit values) and the probabilities of the corresponding scenarios.

The combined use of the three types of indexes above gives the planner an overall view that would not otherwise be obtained, and which enables the decision-maker to make decisions knowing that the calculated values already include a double perspective of impact-probability and sensitivity-probability.

Step 3
Based on the planner experience, the identification of the relevant reinforcements is achieved by taking into account the degree of criticality and sensitivity of each transmission corridor. The objective is to achieve a network that works without limit violations for all (or most) scenario realizations. Then, a cost-benefit analysis is carried out to identify the most competitive reinforcements from the relevant ones.

Within the cost-benefit analysis, investment and operating costs must be properly balanced so that the whole operating lives of the diverse reinforcement elements are considered. Investment network costs include the actual investment in new equipment and its operating and maintenance cost, as well as its replacement cost. Operating network costs include basically the costs associated with active power losses and the reliability costs.

Step 4
Once scenario information and indices are available, appropriate charts and graphs are produced to facilitate the decision-making process to the managers in charge of such decisions. Using this information, the decision maker defines the most appropriate expansion plan. It is relevant to note that, on average, building a new line requires six years; a new substation four years; a transformer, reactance, or capacitor bank three years; and the repowering of an existing line two years.
6 CONCLUSIONS

This Chapter recaps the results of comparison, identified lacks, suggestions for further developments.

6.1 Main findings

The present Report describes the state-of-the-art of network planning approaches and methodologies, and grid connection requirements for wind power plants at European transmission level.

After the Introduction (Chapter 2), an overview of the European transmission system and the related regulatory framework are presented in Chapter 3.

As already stated in the UCTE Transmission Development Plan, the fast changes and the increases in the large power flows within the pan-European transmission system, the creation of regional electricity markets, the penetration of renewable, variable generation (especially wind power), distributed generation and the new technologies (HVDC, phase-shifting transformer) are all affecting the planning and operation of the European power system. All these augmented uncertainties are the main drivers for creating a new harmonised approach involving an increased coordination between the TSOs in the planning but also the operation of the transmission systems.

For enabling an optimal and efficient development of the integrated European grid, harmonised codes and technical standards need to be created, including grid connection requirements for conventional and renewable generation. Regarding the technical requirements for large wind farms, Chapter 4 shows that they are very different in shape and content from country to country, varying with the system type, voltage level, network structure. Moreover, the existent regulations regarding grid connection charges and policies for wind power plants have the same inconsistency as the technical requirements. As priority is not given to renewables in all countries, and the related grid expansion costs are shared differently in the EU countries and not always in a transparent manner, these policies are actually an important barrier in the integration of RES generation, influencing the existence and future location of new renewable power plants. For example, due to unfriendly policies in a country with a good RES potential, investors will prefer to build power plants in another country that facilitates their investment but does not necessarily have the same potential.

Chapter 5 investigates the current practices of transmission planning in Europe. The separation of generation, transmission and retail services complicates the transmission planning process. If in a former vertically integrated utility all data were available, at present the planners face high challenges for performing their studies also related to systems that they do not control any more. Competitive information such as the timing, installed capacity and location of new generation facilities is hard to be obtained from power plant developers. To a lower extent data regarding the magnitudes and location of future loads may also be difficult to obtain.

All the TSOs rely on scenarios of forecasted consumption, generation development and power exchanges and they have to consider the stochastic nature of these phenomena; in addition the
methods used by the TSOs in making their assumptions largely differ. In the current competitive environment the role of generation adequacy criteria is not clear anymore. The practices are different as some countries prefer to rely on such criteria when planning their system, while others regard the evolution of supply and demand in a more general way. The TSOs practices vary with the time horizons, used analysis methods and the investment criteria. Two approaches are mainly used: deterministic (capacity margin, energy balance) and probabilistic, the latter considering the stochastic nature of supply and demand. However, the probabilistic approach is currently mostly used by TSOs as complementary to the deterministic one. The premises used in the capacity adequacy analysis for treating the interconnections are also diverse and sometimes contradictory. While most generation adequacy studies do not fully regard the influence of cross border lines, it is clear that the interaction between the interconnection and the generation capacity should be thoroughly considered when assessing the security of supply. Transmission planning can be regarded as an “iterative” process, which is usually updated once every two years when the scenarios are being developed and the security of supply is checked. For assessing the network reliability, for each of the developed scenarios the network design must be verified with the security analysis. Generally, load flow analyses are performed for normal operation of the network (N), and contingency situations (N-1 and sometimes even N-2 security criteria). The contingency analyses allow the identification of bottlenecks in the existing transmission network, and, in addition, they are a means to verify if possible grid reinforcements will solve these problems.

6.2 Way forward

It is clear that the energy sector has entered a new era where international cooperation and coordination are the main drivers in achieving effective results.

Further efforts both in terms of harmonized approaches and cooperation initiatives - putting together stakeholders supporting different interests (e.g. such as wind proponents and network operators) - are needed for the effective wind integration in the European liberalised power system. As an example, a tighter cooperation in the framework of the European industrial initiatives on grids and wind energy, to be launched in the context of the European Strategic Energy Technology Plan (SET-Plan), would certainly contribute to serve this purpose.

Harmonisation of connection requirements, policies and regulatory aspects for RES

Connection requests of wind farms at transmission level are more and more frequent and a new trend can be observed in Europe, whereby the complexity of these requirements is increasing with the wind penetration level.

A regulatory frame of national/regional Grid Codes comprising also the wind grid connection rules is needed for the development of the pan-European transmission system. Information and requirements should be presented in a clear, transparent and uniform manner, in order to improve their understanding and comparison. The existing discrepancies need to be reduced to the extent allowed by the specifics of the control area, in order to facilitate the further integration of RES
technologies. System operators, plant owners and wind turbine manufacturers would all benefit from this harmonizing action. As an example, the EWEA Working Group on Grid Code Requirements has proposed a two step harmonization approach: a structural harmonization exercise providing a Grid Code template, and a technical harmonization exercise that has to adapt the existing Grid Code parameters to the new Grid Code template. In addition, a common European viewpoint should be developed also in the area of policy and regulation. A clear definition of the boundaries between the RES-E power plant, the grid infrastructure and overall system is indispensable. This will result in a transparent and fair allocation of grid connection costs among all players.

**Offshore Networks**

A large-scale development of offshore wind power will challenge the capability of the existent power systems to balance generation and demand and to transmit the power to the onshore consumption centres. Offshore networks, connecting new wind generation capacity and increasing the transmission capacity between different regions in the EU internal energy market, result in a more efficient and reliable use of the electricity infrastructure and (renewable) energy resources. Although this opportunity of interconnecting offshore projects and national transmission systems is not exploited at present, it should not be neglected in the future. Regulatory regimes and planning approaches within Europe should be harmonised for facilitating the development of such offshore projects. The first step was made by ETSO which proposed the creation of dedicated regional multinational offshore wind energy plans to coordinate the development and implementation of the necessary infrastructure on a European level. A strong European grid will offer the TSOs more flexibility and access to reserves from remote locations.

**Transmission planning approaches**

Transmission planning should be focused on two directions: a better coordination between national TSOs and an improvement of the transmission planning methods. The main keys to obtaining a reliable and effective European grid are integrated strategic planning and cross-border coordination. To this purpose Grid Codes, policies and regulations should be harmonised for facilitating trans-national projects. ENTSO-E will be an important player in this future process. Existing transmission planning methods commonly make use of a worst-case approach: power flow analysis is performed for a small number of cases selected by experienced network planners. However, this approach is not sufficient anymore, as the reduced number of cases analyzed limits the validity of the results. With the increased uncertainty and the many assumptions necessary for the analysis, the need of capturing more combinations of load, (renewable) generation and international exchange is becoming essential for gaining a robust planning under a variety of possible scenarios. A probabilistic approach to deal with such uncertainties should be developed. For each combination the risk for insufficient transmission capacity (e.g. line overloads, voltage limit violations) should be evaluated.
REFERENCES

A. European legislation, regulatory framework and initiatives


D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

Brussels, 23.1.2008

Brussels, 13.11.2008

European Commission: COM(2008) 782 final, Green Paper "Towards a secure, sustainable and competitive European energy network"
Brussels, 13.11.2008

Brussels, 13.11.2008

Brussels, 13.11.2008

Brussels, 26.11.2008

Council of the European Union:
European Economic Recovery Plan - Financing
9139/09 (Presse 105) Brussels, 27.04.2009

B. Main documents relevant for grid connection and planning

(MULTINATIONAL)

Grid Code for NORDEL (Denmark, Finland, Iceland, Norway and Sweden)
www.nordel.org/content/Default.asp?PageID=218

Luxembourg, 6 June 2007

Legal sources on renewable energy.
[22] Bublat, Tobias; Gehlhaar, Tobias: 
Comparison on high technical demands on grid connected wind turbines defined in international Grid Codes 
EWEC 2008

[23] Tsili, M.; Patsiouras, Ch.; Papathanassiou, S.: 
Grid code requirements for large wind farms: a review of technical regulations and available wind turbine 
technologies 
EWEC 2008

[24] Souto Perez, Paula; Van Hertem, Dirk et al: 
Wind power in the European Union: grid connection and regulatory issues 
IEEE 2006

[25] Iov, Florin; Hansen, Anca Daniela; Sørensen Poul; Cutululis, Nicolaos Antonio 
Mapping of grid faults and grid codes 
Riso-R-1617(EN), July 2007

[26] CIGRE Working Group 37.30: 
Network Planning in a Deregulated Environment 
February 2003

AUSTRIA

[27] Austrian Grid Code: 
Technische Regeln für Übertragungsnetze (Netze mit Nennspannung 110 kV) 
2000: 
www.e-control.at/portal/page/portal/ECONTROL_HOME/STROM/MARKTREGELN/TOR/TOR_B.PDF

BELGIUM

[28] Belgian Grid Code: 
Royal Decree of 19th December 2002 on the Introduction of Technical Provisions for the Operation of and 
the Access to the Electricity Transmission System (Arrêté royal établissant un règlement technique pour la 
gestion du réseau de transport de l'électricité et l'accès à celui-ci) 
December 2002 
www.juridat.be/cgi_loi/loi_a.pl?language=fr&caller=list&cn=2002121942&la=f&fromtab=loi&sql=dt='arrete%20royal'&tri=dd+as+rank&rech=1&numero=1

[29] Arrêté du Gouvernement wallon relatif à la révision du règlement technique pour la gestion du réseau de 
transport local d’électricité en Région wallonne et l’accès à celui-ci 
24.05.2007 
www.elia.be/repository/Lists/Library/Attachments/622/rt%20wallon%20transport%20local_mai%202007.pdf

BULGARIA

[30] Bulgarian Grid Code: 
04.06.2004 

[31] Whitford, Rob: 
Bulgaria’s burgeoning wind market, Energy in East Europe 
issue 141, June 6, 2008

CYPRUS
   Issue 2.0.0 (06.2006)
   www.dsm.org.cy/media/attachments/Transmission%20and%20Distribution%20Rules/TDR_ISSUE_2.0.0.en.pdf

CZECH REPUBLIC

[33] Czech Grid Code: Rules for transmission system operation
   (01.01.2006)
   www.ceps.cz/detail_eng.asp?cepsmenu=15&IDP=224&PDM2=0&PDM3=0&PDM4=0

DENMARK

(Danish Grid Code: see Nordic Grid Code)

[34] Energinet.dk
   Grid connection of wind turbines to networks with voltages above 100 kV
   Regulation TF 3.2.5, December 2004
   www.energinet.dk

[35] Energinet.dk
   Grid connection of wind turbines to networks with voltages below 100 kV
   Regulation TF 3.2.6, May 2004
   www.energinet.dk

ESTONIA

   26.06.2003
   www.mkm.ee/failid/The_Grid_Code.doc

FINLAND

(Finnish Grid Code: see Nordic Grid Code)

[37] FINGRID
   Specifications for the operational performance of power plants
   2008

FRANCE

[38] French Grid Code:
   Arrêté du 23 avril 2008 relatif aux prescriptions techniques de conception et de fonctionnement pour le
   raccordement au réseau public de transport d’électricité d’une installation de production d’énergie électrique
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

April 2008
www.journal-officiel.gouv.fr/frameset.html or www.droit.org/jo/20080425/DEVE0806640D.html

[39] RTE
Documentation technique de référence (Référentiel technique)
May 2008

[40] RTE planning methods Presentation
23-04-2009 REALISEGRID meeting, Vienna

[41] RTE

GERMANY

[42] German Grid Code:
(Common grid code for all German TSOs)
August 2007

[43] J. Boemer and K. Burges
Verbesserte Netzintegration von Windenergieanlagen im EEG 2009. Abschlussbericht
Ecofys Germany GmbH, June 2008.

GREECE

[44] Greek Grid Code:
Grid Control and Power Exchange Code For Electricity
May 2005
www.rae.gr/cases/C15/Code_eng.pdf

HUNGARY

[45] Hungarian Grid Code:
Územi Szabályzat (Operational Code)
2008

IRELAND

[46] Irish Grid Code:
EirGrid Grid Code
Version 3.2, December 2008

[47] EirGrid
Transmission Connection Agreement (TCA)

[48] General Conditions of Connection and Transmission use of System (GCTC)
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

[49] Electricity Regulation Act 1999 (ERA)

[50] ESB - Electricity Supply Board:
Transmission Planning Criteria

[51] EirGrid
GRID25
http://www.eirgrid.com/media/Grid%202025.pdf

ITALY

[52] Italian Grid Code:
Code for transmission, dispatching, development, and security of the grid
April 2007

[53] Allegato A.17 (Allegati al Codice di Trasmissione, Disperciamento, Sviluppo e Sicurezza della Rete) - Sistemi di controllo e protezione delle centrali eoliche, TERNA

[54] Carlini, Enrico Maria; Pericolo, Pietro Paolo; Di Cicco, Pierluigi:
Valutazioni tecniche ed economiche delle infrastrutture della RTN (in Italian)
L’Energia Elettrica, November.-December 2008

[55] Rebolini, Massimo; Fulli, Gianluca; Ferrante, Angelo:
GRTN's experience in developing the electricity transmission network in the framework of the European energy sector restructuring,
Première Conférence sur le transport d'électricité, Alger (Algeria), 19-20 September 2005

LATVIA

[56] Latvian Grid Code:
Grid Code
16.01.2008
www.latvenergo.lv/pls/portal/docs/PAGE/CORPORATEPAGES/AST/LATVIAN/FILES/ND_CITI/Tikla_ko dekss.doc

[57] JSC - High Voltage Network
Regulations on System Connection for Electricity Producers
Decision No. 303 of 14 December 2005
www.latvenergo.lv/pls/portal/docs/PAGE/CORPORATEPAGES/AST/LATVIAN/FILES/SPR_K_Piesl_noteik_el_en_razotajiem.doc

[58] Cabinet Regulations No. 476 “On Special Connection to the Electricity Transmission System”
Cabinet of Ministers on 13 June 2006
www.latvenergo.lv/pls/portal/docs/PAGE/CORPORATEPAGES/AST/LATVIAN/FILES/MK_NOTEIKUMI/MK_Noteik_par_spec_piesl_el_en_pary_sist.doc

LITHUANIA

[59] Lithuanian Grid Code:
Order No 398 of December 29, 2001 of the Minister of Economy of Republic of Lithuania
29.12.2001
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

LUXEMBOURG

[60] Dispositions générales de raccordement
Annexe II de la convention de concession du 11 novembre 1927, approuvée par la loi du 4 janvier 1928, et dispositions complémentaires/modifications
www.cegedelnet.lu/cegedel-net/produits/acces-reseaux/dispositions-generales.html

MALTA

[61] Maltese Grid Code:
Network Code
Version 1 - December 2007

THE NETHERLANDS

[62] Dutch Grid Code:
Netcode
September 2007
www.dte.nl/images/ENG_NETCODE%20per%202004%2009%202007%20def_tcm7-111134.pdf

[63] TenneT
Quality and Capacity Plan 2008-2014

[64] TenneT
Vision2030

[65] Electricity Act 1998
Providing Rules in Relation to the Production, Transmission and Supply of Electricity
2 July 1998

POLAND

[66] Polish Grid Code:
INSTRUKCJA RUCHU I EKSPLOATAJCJI SIECI PRZESYŁOWEJ
Wersja 1.0, Warszawa 2005

PORTUGAL

[67] Portuguese Grid Code:
Manual de Procedimentos do Gestor de Sistema
December 2008
[68] REN – Rede Eléctrica Nacional, SA
Plano de Desenvolvimento e Investimento da Rede de Tranporte 2009-2014 (2019)
www.ren.pt/vPT/Destaques/Pages/PDIRT.aspx
July 2008

ROMANIA

[69] Romanian Grid Code:
Technical Transmission Grid Code of the Romanian Power System
2004

[70] Proiect de Norma Tehnica: Conditii tehnice de racordare la retelele electrice de interes public pentru
centralele electrice eoliene. (December 2008)
www.anre.ro/documente.php?id=359

[71] Evaluarea cadrului de reglementare si actiuni necesare privind producerea energiei electrice din surse
regenerabile de energie, ANRE, Bucharest, January 2004

[72] Regulament privind racordarea utilizatorilor la retelele electrice de interes public” approved by the
government decision no. 867/2003

SLOVAKIA

[73] Slovakian Grid Code:
Transmission System Code
September 2002

SLOVENIA

[74] Slovenian Grid Code:
Grid Code Ur.l.RS 49/07
February 2007

SPAIN

[75] Royal Decree 1955/2000 on the regulation of transmission, distribution, trading, supply and authorisation
procedures for electricity facilities installation (Real Decreto 1955/2000 por el que se regulan las actividades
de transporte, distribución, comercialización, suministro y procedimientos de autorización de instalaciones de
energía eléctrica)
Official Gazette of December 27th, 2000
(The technical requirements are stipulated by different Decrees and Operating Procedures)
www.ree.es/operacion/procedimientos_operacion.asp

[76] P.O. 12.3 (October 4th, 2006) establishing the response requirements of wind power generation to network
voltage dips.

SWEDEN
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

(Swedish Grid Code: see Nordic Grid Code)


UK

[78] UK Grid Code:
The Grid Code
Issue 3 Revision 35 - 1st May 2009
www.nationalgrid.com/uk/Electricity/Codes/gridcode/

[79] GB Security and Quality of Supply Standard
Issue 1 - 22 September 2004
www.nationalgrid.com/uk/Electricity/Codes/gbsqsscode/DocLibrary/

[80] National Grid:
GB Seven Year Statement
May 2008
www.nationalgrid.com/uk/sys_08/default.asp?sNode=SYS&action=&Exp=Y

[81] OFGEM, UK Office of the Gas and Electricity Markets:
Offshore transmission
www.ofgem.gov.uk/Networks/offtrans/Pages/Offshorettransmission.aspx

[82] National Grid
Offshore Codes Workshop
Slides 19 June 2008
www.nationalgrid.com/uk/Electricity/offshoreProject/codes/

C. Technical studies, books, scientific papers and reports

[83] L’Abbate, Angelo; Fulli, Gianluca; Starr, Fred; Peteves, Stathis D.:
Distributed Power Generation in Europe: Technical Issues for Further Integration,

[84] EWIS Consortium,
The European Wind Integration Study (EWIS)
www.wind-integration.eu

[85] UCTE IPS/UPS Study,
Feasibility Study: Synchronous Interconnection of the IPS/UPS with the UCTE, Summary of Investigations and Conclusions, November 2008

[86] GreenNet-Europe:
Guiding Large Scale and Least Cost Grid and Market Integration of RES-Electricity in Europe (GreenNet-Europe incorporates a series of different projects having been supported in the Framework & IEE Programmes of the European Commission: GreenNet (2003-2004); GreenNet-EU27 (2005-2006); GreenNet-Incentives (2006-2009)).
http://greennet.i-generation.at/?site=100

[87] Dena Grid Study I:
Integration into the national grid of onshore and offshore wind energy generated in Germany by the year 2020
www.offshore-wind.de/page/index.php?id=2605&L=1

[88] MED2010 - Large scale integration of PV and wind power in Mediterranean countries
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

[89] ANEMOS - Development of a Next Generation Wind Resource Forecasting System for the Large-Scale Integration of Onshore and Offshore Wind Farms
http://anemos.cma.fr/

[90] TradeWind Project
www.trade-wind.eu

[91] Pignon, Virginie; Hermon, F.; Cepeda, Mauricio et al:
Investment criteria for generation capacity and interconnections in a regional electricity market

[92] Cepeda, Mauricio; Saguan, Marcelo; Pignon, Virginie:
Generation adequacy and transmission interconnection in regional electricity markets
Working Paper n°15, November 2008
www.grjm.net/documents/Paper_15_Larsen_nov08.pdf

www.energies-renouvelables.org/observ-er/stat_barobilan/barobilan7.pdf

[94] IEA WIND Task 25, Design and operation of power systems with large amounts of wind power - State-of-the-art report, October 2007

[95] Rechsteiner, Rudolf:
Wind Power in Context – A clean Revolution in the Energy Sector, December 2008:

[96] Ackermann, Thomas:
Wind power in power systems,
2005 John Wiley & Sons, Ltd

[97] Weissensteiner, Lukas; Obersteiner, Carlo; Pruggler, Wolfgang; Auer, Hans:
Grid infrastructure regulation incentivising large scale wind power integration,
European Wind Energy Conference & Exhibition, Milan, Italy, May 2007

[98] Jauch, Clemens; Matevosyan, Julija et al:
International comparison of requirements for connection of wind turbines to power systems,
2005, Wind Energy, Wiley Interscience, John Wiley & Sons Ltd

[99] de Dios, R.; Soto, F.; Conejo, A.J.:
Planning to Expand?,

[100] Conroy, J.F; Watson, R.:
Frequency Response Capability of Full Converter Wind Turbine Generators in Comparison to Conventional Generation,

[101] Kling, W; et al
Connection of generators and other customers - rules and practices,

D. Other documents from associations and platforms

[102] UCTE:
Transmission Development Plan 2008,
www.ucte.org/_library/otherreports/tdp08_report_ucte.pdf

[103] UCTE website,
www.ucte.org
[104] UCTE:
  System Adequacy Forecast 2009 – 2020,
  www.ucte.org/resources/publications/systemadequacy

[105] UCTE:
  System Adequacy Retrospect 2007
  www.ucte.org/resources/publications/systemadequacy

[106] UCTE:
  System Adequacy Methodology
  www.ucte.org/_library/systemadequacy/saf/UCTE_System_Adequacy_Methodology.pdf

[107] UCTE:
  Operation Handbook
  www.ucte.org/resources/publications/ophandbook/

[108] UCTE:
  Statistical Yearbook 2007,
  www.ucte.org/resources/publications/statsyearbook/

[109] ETSO:
  Response to the public consultation on "EU Action to promote Offshore Wind Energy",
  15 September 2008,
  www.etso-net.org/upload/documents/ETSO%20comments%20offshore%202015-09-08.pdf

[110] EWEA Working Group on Grid Code:
  Requirements – Position Paper, February 2008

[111] EWEA:
  Delivering Offshore Wind Power in Europe, 2007

[112] Greenpeace:
  A North Sea electricity grid [r]evolution,
  September 2008
  www.greenpeace.org/belgium/nl/press/reports/offshore
A. ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

A.1 BELGIUM

A.1.1 Grid access requirements for (wind) generators at transmission level

The network operator establishes the technical requirements adapted for the production units that use renewable energy sources and communicates them without delay to the Commission for Electricity and Gas Regulation (CREG - la commission de régulation de l'électricité et du gaz instituée par l'article 23 de la loi du 29 avril 1999).

Generally, when several production units are connected in a single connection point, the prescriptions of the grid code apply to each of these production units separately. For RES this has to be adapted.

a. Low voltage/Fault ride through capability

#1. One production unit must, unless contrary stipulated in the connection contract:
- Be able to operate synchronously with the system, on its whole operating domain, when the voltage at the connection point, expressed as a percentage of the nominal voltage in that point, remains in the shaded area illustrated in Figure 1, during a limited amplitude voltage dip.

b. Voltage/frequency operating limits

#1. A production unit must be able to function in synchronous mode with the network, on an unlimited period, in the shaded area of the diagram frequency-delta U from Figure 3, where delta U refers to the variation of the generator's output voltage and is expressed as a percentage of the generator's nominal voltage.

- Be able to operate synchronously with the system, on its whole operating domain, when the voltage at the connection point, expressed as a percentage of the nominal voltage in that point, remains in the shaded area illustrated in Figure 2, during a voltage dip of large amplitude or a network fault.

Figure 2 Limiting curves of voltage at the grid connection point for a generating facility in the event of a network fault / large voltage drop

#2. In exemption from what was stated at #1, the tension to be taken into account for the local production units is the tension at the exit of the local production unit.

#3. Specific regulations are specified in an objective, transparent and nondiscriminatory way by the network operator/manager for the asynchronous generators, in particular for the installations that use renewable energy sources and of cogeneration.

Figure 1 Limiting curves of voltage at the grid connection point for a generating facility at limited voltage drops
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

1. Any production unit whose active nominal power $P_{nom}$ is higher or equal to 25 MW is a regulating production unit independently of the connection point’s voltage level.

2. Independently of other specifications mentioned in the grid code, any regulating production unit must be able to adapt automatically and at the first request of the grid operator, without delay, its reactive power supply during slow (on a minute scale) and abrupt (on a fraction of a second scale) variations of voltage.

3. Any not regulating production unit must be able to adapt its reactive power supply according to the network’s needs, at least by a commutation of its reactive power production between two levels commonly agreed upon by the grid operator and the involved grid user.

4. For any value of the active power likely to be injected in the network, meaning between the technical minimum and the maximum connection capacity, with the normal operation voltage, the regulating production unit must respectively be able to absorb or to provide, at the connection point level, a reactive power ranging between a minimum of $-0.1P_{nom}$ and $0.45P_{nom}$.

5. For any voltage at the connection point, ranging between 0.9 and 1.05 times the normal operation voltage, the regulating production unit must have the same possibilities, unless there is a limitation due to the restrictions on the generator’s voltage or on the generator’s stator current. A possible limitation on the stator current cannot intervene in the rapid voltage control. The restrictions on the generator’s voltage must respect the rules previously described at 3.1.1 and 3.1.2.

6. Inside the operation range during slow variations of $U_{net}$ voltage at the connection point, each regulating production unit must be able to automatically adapt its reactive production $Q_{net}$ so that the relative sensitivity coefficient $\alpha_{eq}$ lies between 18 and 25,

$$\alpha_{eq} = \frac{\Delta Q_{net} / (0.45 \times P_{nom})}{\Delta U_{net} / U_{norm,op}}$$

where:

- $Q_{net}$ is the reactive power measured on the high voltage side of the step-up transformer;
- $P_{nom}$ is the maximum power that, according to the grid code, indicates the active power of a production unit defined in the connection contract and which determines the maximum continuous supply of active power authorized in the network;
- $U_{norm,op}$ is the normal operation voltage.

#2. A production unit must be able to function in synchronous mode with the network:
- unbounded in time if the frequency of the network lies between 48.5 Hz and 51 Hz;
- and during a time given by a mutual agreement between the network user and the network operator if the frequency of the network lies between 48 Hz and 48.5 Hz or between 51 Hz and 52.5 Hz.

#3. The frequency relays’ function that causes the islanding of a production unit, must not be activated as long as the grid’s frequency is equal or superior to 48 Hz, unless contrary stipulated in the connection contract.

#4. During an abrupt variation or of an important deviation of the frequency, no device of a production unit can thwart the action of the frequency primary control, as envisaged in the current grid code.

#5. The voltage regulator of a regulating production unit is equipped with an over-excitation limiting device and with an under-excitation a limiting. These regulators act automatically and only if the reactive power is outside the interval defined at #4.

#6. The voltage regulator of a regulating production unit is equipped with an over-excitation limiting device and with an under-excitation a limiting. These regulators act automatically and only if the reactive power is outside the interval defined at #4.

#7. For any value of the active power likely to be injected in the network, meaning between the technical minimum and the maximum connection capacity, with the normal operation voltage, the regulating production unit must respectively be able to absorb or to provide, at the connection point level, a reactive power ranging between a minimum of $-0.1P_{nom}$ and $0.45P_{nom}$.

#8. For any voltage at the connection point, ranging between 0.9 and 1.05 times the normal operation voltage, the regulating production unit must have the same possibilities, unless there is a limitation due to the restrictions on the generator’s voltage or on the generator’s stator current. A possible limitation on the stator current cannot intervene in the rapid voltage control. The restrictions on the generator’s voltage must respect the rules previously described at 3.1.1 and 3.1.2.

#9. Inside the operation range during slow variations of $U_{net}$ voltage at the connection point, each regulating production unit must be able to automatically adapt its reactive production $Q_{net}$ so that the relative sensitivity coefficient $\alpha_{eq}$ lies between 18 and 25,
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

Unet is the voltage measured on the high voltage side of the step-up transformer; Unorm, op is the normal operation voltage (the average voltage around the network is operated).

#7. If a non regulating production unit is provided with a regulation intended to respect an instruction of reactive power production of, this unit must be slow with respect to the voltage primary control of the regulating units (where the produced action takes effect on a second scale) and rapid with respect to the dynamics of the transformers’ tap-changers that are ordered by an automatic (acting on a scale often of seconds to minutes), in order to avoid oscillations in the electric system. The time-constant in closed loop of this regulation must be adjustable, at least, between 10 and 30 seconds.

A.1.2 Regulatory aspects of generation connection to the grid

Legal basis/ addressess

contractual basis

Under a contract, the plant operator is entitled to connection to the grid to be granted by the grid operator. The grid operator is obliged to conclude the contract (Art. 112 arrêté du 19. décembre 2002). The essential contents of the contract are stipulated by statutory law. Prior to the conclusion of the contract, the grid user has to apply to the grid operator for connection (demande de raccordement), requesting the grid operator to make an offer (Art. 94, §1 arrêté du 19. décembre 2002). A preliminary examination (demande d’étude d’orientation) shall be carried out prior to this application (Art. 79 ff. arrêté du 19. décembre 2002).

Entitled party: Every plant operator or grid user that meets the technical conditions of a so-called „utilisateur du réseau” is entitled (Art. 45-78 arrêté du 19. décembre 2002).

Obligated party: The obligated party is the grid operator (Art. 3-9 arrêté du 19. décembre 2002).

Priority to renewable energy

• Priority to renewable energy

Plants generating electricity from renewable energy sources whose capacity does not exceed 25 MW shall be granted priority connection with regard to the safety of the grid. This principle of priority shall be applied at all stages of the examination of a grid connection project (preliminary examination and application for connection Art. 79, 94, 100 arrêté du 19. décembre 2002).

Limitations/deadlines

The date of connection to the grid depends on the contractual terms. The conclusion of the contract on connection is subject to statutory deadlines (e.g. Art. 107, Art. 109 arrêté du 19. décembre 2002).

Realisation and connection adequacy (conformity): For the decentralised and standardised production units, using renewable energy sources or of cogeneration, of power lower or equal to 25 MW, a simplified procedure is developed for the adequacy (conformity) search.

The claim for grid connection arises at the date of the conclusion of the contract.

Funding

Plant operator: The costs of a grid connection are borne by the plant operator that submitted the application for connection. The costs arising from the mandatory examinations, the preliminary examination and the examination of the grid connection project are borne by the grid operator. They are subtracted from the costs of grid connection.

Orientation study request for a network connection: In the examination of the orientation study request, the network manager grants, taking into account as much as possible the security of necessary supply, a priority at the orientation study request relating to generating units which use renewable energy sources and to the cogeneration units whose nominal output is lower or equal to 25MW.

Connection request:

• During the examination of the connection request the network operator, taking into account the security of necessary supply, will give priority to the connection request made for renewable resources production units and cogeneration units.

• The network manager examines the orientation study request and, taking into account the security of necessary supply, evaluates it, in a nondiscriminatory way, considering in particular the priority to be given to the generating units using renewable energy sources and to the cogeneration units.

Arising/enforcement of a claim
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

A.2 CZECH REPUBLIC

A.2.1 Grid access requirements for (wind) generators at transmission level

The secure operation of the power system presupposes that the requirements of individual units be clearly specified and that such requirements comply with the needs of the TSO as a whole. These requirements in terms of voltage, frequency and power control concern the ability of all generation units (wind plants included) to work within the system including having to work at extraordinary voltage and frequency values.

Concerning the permitted values of voltage and frequency, whole generation units (i.e. including the consumption of the unit itself) must be capable of permanent operation with nominal generated active and reactive power in the frequency range 48.5 to 50.5 Hz and a terminal voltage in the range of 95% to 105% of nominal voltage; two frequency limits, \( f_{\text{min}} \) and \( f_{\text{max}} \), at which unit operation is not permitted, must be exactly defined by the unit’s operator for each unit. The frequency limits \( f_{\text{min}} \) and \( f_{\text{max}} \) are set out in a frequency plan. Values for permitted delivered active and reactive power or alternatively their time limitations must be defined by the unit for the frequency ranges \( f_{\text{min}} \) to 48.5 Hz and 50.5 Hz to \( f_{\text{max}} \) and simultaneously for terminal voltage ranges 80% to 95% and 105% to 110% of the nominal voltage. ČEPS must have these values at its disposal in the form of a set of tables or graphs.

Concerning the islanding operation, all newly constructed units should be capable of changing their output automatically depending on the frequency deviation from the reference (nominal) value. In addition, such units should be capable of changing their output upon receiving instructions from the transmission system dispatcher so to be able to participate in frequency regulation within the island at a level suitable for island re-synchronisation. This change should be either manual, for an instruction to change the output, or automatic, for switching to a static control mode – proportionately integrated speed control (following instructions from the dispatcher).

Concerning the fault ride through capability, all generation units must be resistant to network failure should the following be threatened:
- dynamic stability during and after short circuits
- static stability (upon loosing the ability to transfer active power over a weakened transmission profile)
- static stability (e.g. undampened swings, so-called ‘auto oscillations’).

Where dynamic stability is threatened (after discovery using calculations), units must be equipped with the appropriate protection. Loss of static stability can be avoided most effectively by the correct adjustment of the under excitation limiters. Power system excitation stabilisers (PSS) and suitability in terms of the size of increases in primary voltage control are the basic measures to be taken in order to avoid an increase in spontaneous swings.

Concerning the reactive power and voltage control, the generator must be able to supply nominal active power within a range of power factors from 0.85 inductive to 0.95 capacitive within a permitted terminal voltage range of ±5 % nominal voltage and with a frequency in the range between 48.5 and 50.5 Hz. At the lower values of active power, permitted reactive power values can be identified from unit operation diagrams which must form part of the unit’s operational-technical documentation. The basic required regulation range for reactive power herein stated may be modified, narrowed or extended respectively. Reasons for possible modification include for example differing (lower/higher) needs for reactive power at a given transmission system locality or special technological considerations. Such modifications require prior special agreement between ČEPS and the user.

The requirement for regulation power outlined above may be exchanged for the following: the generator must be able to supply nominal active power within a range of power factors from 0.85 inductive to 0.95 capacitive within a permitted terminal voltage range on the very high voltage side of the block transformer of 400kV±5%, 220kV ±10% and 110kV ±10%.

Special requirements in the Grid Code refer to:
- minimal frequency and voltage ranges for operation of wind generators
- possibility of power curtailment
- maximum allowed increase in power production
- rules for behaviour of wind generator in different situations in the system (short circuit, voltage and reactive power regulation, frequency deviations, protections, flicker etc.).

A.2.2 Regulatory aspects of generation connection to the grid

Legal basis/ addressees

- contractual basis

Plant operators are contractually entitled against the grid operator to the preferential connection of a system generating renewable-energy-sourced electricity to the grid. The grid operator is obliged to enter into the respective contracts (§ 4 par. 1 Act Nr.
180/2005 Sb., § 31 par. 2 in connection with § 50 par. 3 Act Nr. 458/2000 Sb.). Wind-power stations that cover an area of 1 km² and whose total capacity installed amounts to more than 20 MW are not eligible to this instrument (§ 3 par. 1 Act Nr. 180/2005 Sb.). However, they are contractually entitled to connection to the grid according to the principle of non-discrimination as stipulated by the general provisions of energy law (§ 31 par. 2 in connection with § 50 par. 3 Act Nr. 458/2000 Sb.).

Entitled party: The persons entitled are the producers of renewable-energy-sourced electricity. Entitlement is conditional upon the producer's having applied for connection of his plant and compliance with the conditions for connection, which are set out in a separate legal provision (Notice of the Ministry of Industry and Trade) and with the grid operator's terms and conditions on connection and transmission of electricity (§ 31 par. 2 Act Nr. 458/2000 Sb. in connection with § 4 par. 1 Act Nr. 180/2005 Sb.).

Obligated party The person obligated to grant connection is the grid operator. Both distribution and transmission grid operators are subject to this obligation. If a system is connected to the distribution grid, the distribution grid operator whose connection cost is lowest is obligated to connect the system. If he can provide evidence of a capacity shortage or of the connection threatening the reliable operation of the distribution grid, he is exempt from this obligation (§ 4 par. 2 Act Nr. 180/2005 Sb.). The transmission grid operator can not make use of this special provision, as he has a monopoly, excluding price differentiation for connection.

Priority to renewable energy

- Priority to renewable energy

Within the area they have a licence for, the transmission grid operator and the distribution grid operators are obligated to preferentially connect to the transmission grid or the distribution grids systems that generate renewable electricity and are specified as eligible by § 3 Act Nr. 180/2005, to transmit or distribute the electricity generated. In order for his system to be connected, the producer of renewable electricity shall apply for connection and comply with the conditions for connection and transmission of electricity laid down in Act Nr. 485/2000 (§ 4 par. 1 Act Nr. 180/2005 Sb.).

Capacity limits

In case of proven capacity shortage, the grid operator is exempt from his obligation to connect a system that generates renewable electricity (§ 4 par. 2 Act Nr. 180/2005 Sb.).

Limitations/deadlines

Statutory law does not provide any deadlines for connection to the grid, which may, however, be specified by the contractual terms.

Arising/enforcement of a claim

A claim for connection to the grid arises at the date on which the producer of renewable-energy-sourced electricity has applied for connection and complies with the conditions for the connection and transmission of electricity, which are specified by a separate provision (§ 4 par. 2 Act Nr. 180/2005 Sb.).

Funding

Plant operator: The cost of the connection of a system to the grid is borne by the plant operator (§ 23 par. 2 letter a) Act Nr. 458/2000 Sb.).

A.2.3 Regulatory and financial aspects of grid expansion

Legal basis/ addressees

- contractual basis

The plant operator is contractually entitled against the grid operator to an expansion of the grid, if the expansion is necessary to satisfy the connection agreement (§ 45 par. 1 Act Nr. 458/2000 Sb.).

Entitled party: The persons entitled are the producers of renewable-energy-sourced electricity. Entitlement is conditional upon the producer's holding an electricity production licence and compliance with the conditions for connection, which are set out in a separate legal provision (Notice of the Ministry of Industry and Trade) and with the grid operator's terms and conditions (§ 23 par. 1 letter a) Act Nr. 458/2000 Sb.).

Obligated party: The transmission and distribution operator whose cost of connection is lowest is obligated to connect a system that generates renewable electricity to his grid, unless he provides evidence for a capacity shortage or a threat to the reliable operation of the distribution system (§ 4 par. 2 Act Nr. 180/2005 Sb.).

Priority to renewable energy

- Non-discrimination
The grid operator is obliged to expand the grid without discriminating against certain plant operators. Renewable-energy-sourced electricity is not granted priority.

Capacity limits

In case of proven capacity shortage, the grid operator is exempt from his obligation to connect a system that generates renewable electricity (§ 4 par. 2 Act Nr. 180/2005 Sb.).

Limitations/deadlines

Statutory law does not provide any deadlines for an expansion of the grid, which may, however, be specified by the contractual terms.

Arising/enforcement of a claim

A claim for an expansion arises on the date of conclusion of the grid connection agreement between the grid operator and the plant operator.

Funding

**Grid operator:** The cost of an expansion of low-voltage lines is borne by the distribution grid operator unless the lines are more than 50m long and the expansion aims at supplying electricity to buildings other than private households.

**Plant operator:** In all other cases, the cost of a grid expansion is borne by the person that derives a benefit from the expansion. Thus, the plant operator generally bears the cost.

A.3 DENMARK

A.3.1 Grid access requirements for (wind) generators at transmission level

Two sets of technical requirements for wind turbines are in force. One for wind turbines connected to networks below 100 kV and a similar set of requirements for wind turbines connected to grids above 100 kV.

**Distribution**

According with the specifications from EnergyNet.dk [35] the wind turbines connected to grids with voltages below 100 kV must remain connected during grid faults as shown in Fig. 1.

![Fig. 1. Requirements for disconnection of wind turbines in the event of deviations in voltage in the distribution system (source [35]).](image)

Some special situations when a wind turbine, as well as the compensation equipment, must not be disconnected from the electrical network are specified also in [35] as follows:

- 3-phase short-circuit for 100 msec;
- 2-phase short-circuit with or without ground for 100 msec followed after 300-500 msec by a new short-circuit of 100 msec duration.

A summary of the voltage profile in these special conditions is given in Fig. 2.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

A wind turbine shall have sufficient capacity to fulfil the above mentioned requirements for the following sequences [35]:
- At least two 2-phase short-circuits within 2 min interval;
- At least two 3-phase short-circuit within 2 min interval.
Also, it shall be sufficient energy reserve (emergency, hydraulic and pneumatic) for the following sequences:
- At least six 2-phase short-circuits with 5 min interval;
- At least six 3-phase short-circuit with 5 min interval.

Transmission

The fault ride-through requirements for wind farms connected to grids with voltages above 100 kV are specified in [34].
A wind farm shall not disconnect in the following situations:
- 3-phase short-circuit – up to 100 msec;
- 2-phase short-circuit with/without ground for up to 100 msec followed by a new short-circuit of max 100 msec duration
- 1-phase short-circuit for up to 100 msec followed after 300-500 msec by a new short-circuit of max 100 msec duration

A wind farm shall not disconnect in the following situations:
- At least two 1-phase short-circuits with 2 min interval;
- At least two 2-phase short-circuits within 2 min interval;
- At least two 3-phase short-circuit within 2 min interval.

Also, it shall be sufficient energy reserve (emergency, hydraulic and pneumatic) for the following sequences:
- At least six 1-phase short-circuits with 5 min interval;
- At least six 2-phase short-circuits with 5 min interval;
- At least six 3-phase short-circuit with 5 min interval.

In [34] it is specified that the basic stability features which are incorporated in the design of a wind turbine shall be verified by means of a turbine test for all types of wind turbines included in the wind farm.
This turbine test “is carried out by simulation of the wind farm stability by applying a symmetric three-phase short circuit to the power grid” [34]. Additionally, the impact of asymmetrical faults, with unsuccessful automatic reclosure, on the wind farm must be documented. In this case the wind turbine shall not be disconnected from the grid.
Concerning the stability analysis during symmetric three-phase faults, according to [34] the wind farm owner must provide the TSO with a report detailing the simulation model and results for a voltage profile with a slowly recovering time as shown in Fig. 3.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

Simulation model shall have a structure as shown in Fig. 4.

![Fig. 4. Equivalent model of the power system used in stability analysis of symmetrical faults.](image)

The voltage source shall simulate the voltage profile given in Fig. 3 with a correction factor so that the voltage level in the Point of Common Coupling (PCC) is 1 pu before the fault. The grid impedance is characterized by a short-circuit power $S_k$ ten times bigger than the wind turbine’s rated power $P_n$ and an impedance ratio $R/X$ of 0.1. This impedance ratio corresponds to a grid angle of 84.3º. The report shall describe how the internal network is included in the model.

Rated wind speed, rated rotor speed and zero reactive power in the PCC are the initial conditions for the wind turbine.

In the report the simulation tool used in stability analysis shall be specified as well as a description of the wind farm model “to a level of detail that makes possible to repeat the calculation in the analysis tool of the system operator” [2].

The wind farm will meet the connection requirements when:
- The delivered power reaches the rated value no later than 10 sec after the voltage is above 0.9 pu:
- The active power in the PCC during the voltage dip meet the following condition:

$$P_{actual} \geq k_p * P_{r0} * \left( \frac{V_{actual}}{V_{r0}} \right)^2$$

where:
- $P_{actual}$ – active power in the PCC during the simulation
- $P_{r0}$ – active power measured in the PCC before the fault
- $V_{actual}$ – voltage in the PCC during simulation
- $V_{r0}$ – voltage measured in the PCC before fault
- $k_p$ – reduction factor considering any voltage dips to the generator terminals

- The reactive power exchange in the PCC shall be in the normal limits (see Fig. 5) no later than 10 sec after the voltage is above 0.9 pu. During the voltage dip the reactive current in the PCC shall not exceed the rated value.

![Fig. 5. Reactive power control range for normal operation of a wind turbine.](image)

Concerning the stability analysis during asymmetric faults and unsuccessful reclosure, the wind farm must be able to withstand the impacts from the asymmetric faults in the grid without requiring disconnection of wind turbines in the wind farm [34]. Two asymmetrical faults are considered here namely a two phase fault on the transmission line with unsuccessful reclosure and a single phase one in the same conditions. The voltage profile for these asymmetric faults are shown in Fig. 6.
D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

Plants shall be connected in line with the principle of non-discrimination (§ 24 Act on Electricity Supply).

Limitations/deadlines

The plant shall be connected to the grid without undue delay.

Arising/enforcement of a claim

The claim for connection to the grid is conditional upon compliance with the technical requirements established by the Ministry of Energy (§ 26 Act on Electricity Supply).

Funding

Plant operator: The costs arising from the connection to the grid are borne by the plant operator (§ 24 Act on Electricity Supply).

Distribution mechanism: The plant operator may not pass on the costs arising from the connection of plants to the grid.

A.3.2 Regulatory aspects of generation connection to the grid

a. Legal basis/ addressees

- statutory basis

Under statutory law, the plant operator is entitled to the connection of the plant generating renewable-energy-sourced electricity to the grid by the grid operator (§ 24 Act on Electricity Supply).

Entitled party: The entitled party is every plant operator whose plant complies with the technical requirements and who pays the charges for connection to the grid (§§ 24, 26 Act on Electricity Supply).

Obligated party: The obligated party is the grid operator (§ 24 Act on Electricity Supply).

Priority to renewable energy

- Non-discrimination
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

- Non-discrimination

The plant operator is not entitled to a grid expansion.

Limitations/deadlines

The plant operator is not entitled to a grid expansion.

Arising/enforcement of a claim

The plant operator is not entitled to a grid expansion.

Funding

**Grid operator**: The costs of a grid expansion are borne by the grid operator

**Distribution mechanism**

- **Grid operator – grid user.** The grid operator may pass on the costs of a grid expansion to the grid users (§§ 8, 67 Act on Electricity Supply).

- **Grid user - consumer.** The grid user may, in turn, pass on the costs to the consumers.

A.4 FRANCE

A.4.1 Grid access requirements for (wind) generators at transmission level

#1. Article 2 of the decree:

I. The reference voltage field mentioned in the decree of the 23rd April 2008, article 3 is given according to $P_{\text{max}}$ power in accordance with the limits illustrated in Table 1.

<table>
<thead>
<tr>
<th>Voltage Domain</th>
<th>Nominal Voltage $U_n$</th>
<th>$P_{\text{max}}$ Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTB1</td>
<td>63 kV</td>
<td>50 MW</td>
</tr>
<tr>
<td></td>
<td>90 kV</td>
<td></td>
</tr>
<tr>
<td>HTB2</td>
<td>225 kV</td>
<td>250 MW</td>
</tr>
<tr>
<td>HTB3</td>
<td>400 kV</td>
<td>$&gt; 250$ MW</td>
</tr>
</tbody>
</table>

II. Derogatory connections at the reference connection voltage levels from the table above can be carried respecting the conditions fixed at III to VI hereafter and other regulations of this decree.

III. A producer can ask, on a purely derogatory and exceptional basis, a connection in HTB1 for a power higher than 50 MW and lower or equal to 100 MW. The transmission system operator is held to take a favorable action pursuant to it only in the case where, within sight of the results of the study carried out in accordance with the provisions of article 6 of the decree of April 23, 2008 referred to above, connection proves to be possible by a direct connection with a HTB1 busbar exploited by the transmission grid operator taking into consideration this decree’s regulation. When such a connection is carried out in HTB1 within the framework of the regulations of this decree, this connection is known to be carried out at the connection voltage described as “lower than the reference connection voltage level” within the meaning of the dispositions of article 2 of the decree of August 28, 2007 referred to above.

IV. A producer can solicit, on a purely derogatory and exceptional basis, a connection in HTB2 for a power higher than 250 MW and lower or equal to 600 MW. The transmission grid operator is held to take a favorable action pursuant to it only in the case where, within sight of the results of the above-mentioned study, connection proves to be possible by a direct connection with a HTB2 busbar exploited by this operator taking into consideration regulation...
of this decree. When such a connection is carried out in HTB2 within the framework of the regulations of this decree, this connection is known to be carried out with the connection voltage described as “lower than the reference connection voltage level” within the meaning of the dispositions of article 2 of the decree of August 28, 2007.

V. No power plant generating a Pmax power higher than 100 MW can be connected in HTB1.

VI. No power plant generating a Pmax power higher than 600 MW can be connected in HTB2.

#2. Article 5: According to the results of the connection study, the dimensioning voltage ($U_{dim}$) which allows the optimization of the generating plant’s operation is fixed inside the normal domain of voltage variation. The limits of this domain are specified by Table 2 according to the connection level:

**Table 2 Voltage variation limits**

<table>
<thead>
<tr>
<th>Voltage Domain</th>
<th>Nominal Voltage</th>
<th>Normal Voltage Variation Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTB1</td>
<td>63 kV</td>
<td>55 kV – 72 kV</td>
</tr>
<tr>
<td></td>
<td>90 kV</td>
<td>78 kV – 100 kV</td>
</tr>
<tr>
<td>HTB2</td>
<td>225 kV</td>
<td>200 kV – 245 kV</td>
</tr>
<tr>
<td>HTB3</td>
<td>400 kV</td>
<td>380 kV – 420 kV</td>
</tr>
</tbody>
</table>

a. Low voltage/ Fault ride through capability

#1. Article 16: The frequency in the public transmission grid is considered to be inside its normal variation range, therefore situated between 49.5 Hz and 50.5 Hz. After the 30th of September 2009, all the wind power plants that are connected to the not meshed HTB1 or HTB2, must continue to operate according to the graph in **Figure 1** when a voltage dip appears at the delivery point of the generating facility. Similarly all wind power plants connected to the meshed HTB2 and HTB3 should operate according to **Figure 2**.

#2. Article 17: Any generating plant must keep operating when an important short circuit occurs of a maximum duration defined in the transmission grid operator’s technical documentation. The producer checks this aptitude during the connection study, by observing the installation’s behaviour. The checking takes into account
reference conditions specified in the technical reference documentation of the transmission grid operator.

**#3. Article 33.**
- The amendments in these “arrete” are available for all the production units that are the subject of a first transmission grid connection since the producer does not have a technical and financial proposal of the transmission grid operator for this valid connection at April 25, 2008. They also apply to the existing generating stations undergoing a substantial modification since the producer does has, for this modification, any technical and financial proposal valid on this same date.
- When the technical and financial proposal for the power plant’s connection was transmitted to the producer at the latest on September 30, 2009, the dispositions of #1 (of II of article 16 of this decree) are written as it follows:

When a voltage dip appears at the delivery point of the generating facility all the wind power plants must continue to operate by case according to one of the graphs in Figures 3 and 4.

**Figure 3 Voltage dip in the not meshed HTB1 and HTB2 networks (temporary measures until September 30, 2009 for the wind power plants)**

**Figure 4 Voltage dip in the meshed HTB3 and HTB2 networks (temporary measures until September 30, 2009 for the wind power plants)**

**b. Voltage/frequency operating limits**

**#3. Article 19:**

I. Any wind power plant must keep operating when the frequency of the public transmission grid takes exceptional values, under the conditions of duration and maximum power losses established in **Table 3:**

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Minimum operating duration</th>
<th>Maximum power losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>49.5 Hz – 49 Hz</td>
<td>5 hours</td>
<td>10 %</td>
</tr>
<tr>
<td>49 Hz – 48 Hz</td>
<td>3 minutes</td>
<td>10 %</td>
</tr>
<tr>
<td>48 Hz – 47.5 Hz</td>
<td>3 minutes</td>
<td>15 %</td>
</tr>
<tr>
<td>47.5 Hz – 47 Hz</td>
<td>20 seconds</td>
<td>20 %</td>
</tr>
<tr>
<td>50.5 Hz – 51 Hz</td>
<td>60 minutes</td>
<td>10 %</td>
</tr>
<tr>
<td>51 Hz – 51.5 Hz</td>
<td>15 minutes</td>
<td>According to II</td>
</tr>
<tr>
<td>51.5 Hz – 52 Hz</td>
<td>20 seconds</td>
<td>According to II</td>
</tr>
</tbody>
</table>

II. Any power plant mentioned in I must be equipped with a command–control system that allows reduce its power when the frequency exceeds
an adjustable threshold between 50.5 Hz and 52 Hz. The functional characteristics and the performances of this command-control are in conformity with the detailed regulations contained in the technical reference documentation transmission grid operator. The methods of its implementation are specified in the conventions of connection and exploitation. The provisions from this II are considered satisfied when the generating station is subjected to the amendments of article 14 (which is not for RES!!).

#2. Article 33:
For any power plant referred to in #1 (article 19), when the technical and financial proposal for the installation’s connection was transmitted to the producer at the latest on September 30, 2009, the table of this article is replaced by Table 4:

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Minimum operating duration</th>
<th>Maximum power losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>49.5 Hz – 49 Hz</td>
<td>5 hours</td>
<td>10 %</td>
</tr>
<tr>
<td>49 Hz – 48.5 Hz</td>
<td>3 minutes</td>
<td>10 %</td>
</tr>
<tr>
<td>48.5 Hz – 48 Hz</td>
<td>3 minutes</td>
<td>15 %</td>
</tr>
<tr>
<td>48 Hz – 47.5 Hz</td>
<td>3 minutes</td>
<td>20 %</td>
</tr>
<tr>
<td>50.5 Hz – 51 Hz</td>
<td>60 minutes</td>
<td>50 %</td>
</tr>
<tr>
<td>51 Hz – 51.5 Hz</td>
<td>15 minutes</td>
<td>According to II</td>
</tr>
</tbody>
</table>

Hence, for these installations, the value “52 Hz” mentioned at #1-II is replaced by the value “51.5 Hz”.

#3. Article 20:
a) In the event of simultaneity of the exceptional values of the transmission grid’s frequency and of the voltage at the power plant’s delivery point, the acceptable reduction of the power plant’s active power is the largest of those allowed for these two situations according to articles 15 and 19. The necessary operation duration is the shortest of the two.

b) However, in the event of an exceptional high voltage situation, the generating plant is subjected to the amendments of the preceding subparagraph (b) only as long as the ratio (U/Un)/(F/Fn) remains lower than 1.13, where “U” indicates the voltage noticed at the delivery point, “Un” the nominal voltage of HTB1 or HTB2 or HTB3 whose value is specified in article 2, “F” the frequency noticed on the transmission grid and “Fn” the rated frequency of the transmission grid, i.e. 50 Hz.

#4. Article 22:
a) Any power plant must be conceived so that its coupling with the transmission grid is possible when, simultaneously, the network’s frequency takes any value ranging between 49 Hz and 51 Hz and the voltage at the installation’s delivery point takes any value in a voltage range of amplitude of ±12% around the Un voltage.

b) Any power plant must be equipped with a device allowing its synchronous coupling to the transmission grid under conditions of voltages’ characteristics variation at the plant’s terminals and at the delivery point, which should not exceed the following values:
   - Maximum variation of frequency: 0.1 Hz.
   - Maximum variation of voltage: 10% of Un.
   - Maximum variation of phase: 10°.

However, transmission grid operator can accept an exemption from the amendments of the first subparagraph within sight of the results of the connection study which show that the absence of such a device’s implementation is not likely to endanger the safety and the reliability of the transmission grid nor the quality of its operation.

c. Reactive power control (power factor control, voltage regulation)

#5. Article 11:
I. For the application of the dispositions of this article, the frequency on the public transmission grid is considered inside its domain of normal variation, i.e. ranging between 49.5 Hz and 50.5 Hz. Moreover, Udim indicates the value of the dimensioning voltage which is established according to article 5 of this decree and U the value of the voltage at the delivery point.

II. The dispositions of present II are applicable in the general case.

1) At Pmax, the generating plant must be able to function under the following conditions:
   a) When U is equal to Udim, the reactive power of the installation must be able to take any value included in the interval [-0.35 × Pmax, +0.32 × Pmax];
   b) When U is equal to 0.9 × Udim, the installation must be able to provide a reactive power equal to 0.3 × Pmax;
   c) For any value of U between 0.9 × Udim and 1.1 × Udim, and in the limits of the normal voltage variation domain (which is fixed in Table 2 according to the voltage level), the generating plant must be able to modulate its production and its consumption of reactive power within the limits of the minimal operation range defined in the technical reference documentation of the public transmission grid operator in the shape of a [U, Q] diagram.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

2) Whatever the provided active power is, the installation must be able to operate under the following conditions:
   a) When \( U \) is equal to \( U_{\text{dim}} \), the reactive power of the installation must be able to take any value included in the interval \([-0.28 \times P_{\text{max}}, +0.30 \times P_{\text{max}}]\);
   b) When \( U \) is equal to \( 0.9 \times U_{\text{dim}} \), the installation must be able to provide a reactive power equal to \( 0.3 \times P_{\text{max}} \);
   c) For any value of \( U \) between \( 0.9 \times U_{\text{dim}} \) and \( 1.1 \times U_{\text{dim}} \), and in the limits of the normal voltage variation domain of the above-mentioned voltage, the generating station must be able to modulate its production and its consumption of reactive power within the limits of the minimal operation range defined in the technical reference documentation of the public transmission grid operator in the shape of a \([U, Q]\) diagram.

III. When the public transmission grid’s needs require it in the cases specified by its operator in the purpose of the connection study, this last can require a shift of the domain of reactive provided by the generating plant. The regulations of II are modified by an agreement between the transmission grid operator and the producer within the following limits:
   i. The intervals aimed to II-1-a and II-2-a are replaced, respectively, by the intervals \([D - 0.35 \times P_{\text{max}}, D + 0.32 \times P_{\text{max}}]\) and \([D - 0.28 \times P_{\text{max}}, D + 0.30 \times P_{\text{max}}]\), where “\( D \)” is a shift of the reactive power expressed as a percentage of \( P_{\text{max}} \) which takes a value defined by the transmission grid operator considering the connection study’s results and being able to be fixed between 0 and \(+0.13 \times P_{\text{max}}\);
   ii. The value “\( 0.3 \times P_{\text{max}} \)” aimed to II-1-b and II-2-b is replaced by the value: “\( D + 0.3 P_{\text{max}} \)”;
   iii. The diagrams \([U, Q]\) mentioned at II-1-c and II-2-c are shifted with the value \( d \), their form remaining unchanged.

IV. The dispositions of this paragraph apply only to the generating plants of a power \( P_{\text{max}} \) lower than 50 MW that use “fatal energy”. When a generating plant’s capacity to provide or to absorb reactive power (as mentioned at II or if necessary at III) is not acquired, because of technological limitations intrinsically related to the fatal energy recuperation process, than via the addition of accessory equipments inside the site of the generating plant the manager of the public network of electricity transmission can accept an exemption consisting in connecting initially the aforementioned installation in the absence of these accessory equipments since the study of connection shows that those are not immediately necessary. This exemption is subordinated to the engagement of the producer to provide later on for the addition with the above-mentioned accessory equipments to the request, matched for a notice, of the manager of the public network of electricity transmission. This engagement, the cases which can require its implementation as well as the above mentioned notice must appear in the convention of connection.

#5. Article 15:
I. For the application of this article’s dispositions, the public transmission grid’s frequency is considered to be in its normal variation domain, i.e. ranging between 49.5 Hz and 50.5 Hz. For any voltage value at the delivery point \( U \) found in one of the exceptional variation domains determined in Table 3 according to the voltage level, the generating plant must operate for limited periods under the conditions defined below:
   1. At least a 5-minute operation when \( U \) is equal to the higher limit of the high exceptional range. During such an operation, the active power that can be provided by the generating plant can be reduced to \( 0.95 \times P_{\text{max}} \). Moreover, the installation must be able to modulate the reactive power within the limits of the minimal operation range defined in the technical reference documentation of the public transmission grid operator, in the shape of a \([U, Q]\) diagram.
   2. At least a 90-minute operation when \( U \) is equal to \( 0.85 \times U_{\text{un}} \). Moreover, whatever the provided active power, the production unit must be able to provide a reactive power up to \( 0.3 \times P_{\text{max}} \) in the general case and of \( (D + 0.3 \times P_{\text{max}}) \) in the cases aimed at III of #1.
   3. Operation when \( U \) lies between \( 0.85 \times U_{\text{un}} \) and \( 0.8 \times U_{\text{un}} \) under the conditions consigned in the convention of exploitation with respect to the regulations of the transmission grid operator’s technical reference documentation.

II. The exceptional voltage variation domains in the public transmission grid are established according to the voltage range in the table hereafter:
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

Table 5

<table>
<thead>
<tr>
<th>Voltage Domain</th>
<th>Nominal Voltage $U_a$</th>
<th>Exceptional Variation Domains for the voltage at the delivery point</th>
<th>For memory (thresholds mentioned at I)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Superior limit of the high range $0.85^*U_a$ and the inferior limit of the low range $0.85^*U_a$</td>
<td></td>
</tr>
<tr>
<td>HTB1</td>
<td>63 kV</td>
<td>Low range: 50 kV – 55 kV</td>
<td>53.55 kV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High range: 72 kV – 74 kV</td>
<td>74 kV</td>
</tr>
<tr>
<td></td>
<td>90 kV</td>
<td>Low range: 72 kV – 78 kV</td>
<td>76.5 kV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High range: 100 kV – 102 kV</td>
<td>102 kV</td>
</tr>
<tr>
<td>HTB2</td>
<td>225 kV</td>
<td>Low range: 180 kV – 200 kV</td>
<td>191.25 kV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High range: 245 kV – 250 kV</td>
<td>250 kV</td>
</tr>
<tr>
<td>HTB3</td>
<td>400 kV</td>
<td>Low range: 320 kV – 380 kV</td>
<td>340 kV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High range: 420 kV – 440 kV</td>
<td>440 kV</td>
</tr>
</tbody>
</table>

A.4.2 Regulatory aspects of generation connection to the grid

Article 33, IV

Until April 25, 2018, it can be derogated from the amendments V and VI of article 2 from in the case of a substantial modification made to a generating station already connected at April 25, 2008 provided the aforementioned substantial modification does not require to engage an extension or a reinforcement of the works of the public network of electricity transmission and a limit of $P_{\text{max}}$ power determined by the transmission grid operator within the framework of the connection study referred to in article 4 of this decree.

Statutory provisions


<table>
<thead>
<tr>
<th>Type of law</th>
<th>Act of the national parliament</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Modernising and developing the public electricity supply (Loi n°2000-108, Art. 1).</td>
</tr>
</tbody>
</table>

Relation to renewable energy

This Act established the legal framework for the purchase and payment of renewable-energy-sourced electricity (Loi n°2000-108, Art. 10), the conditions regarding calls for applications (Loi n°2000-108, Art. 8) and provisions on the funding of the promotion system (Loi n°2000-108, Art. 5).

− Décret n°2001-365 du 26 avril 2001 relatif aux tarifs d'utilisation des réseaux publics de transport et de distribution d'électricité (Décret n°2001-365)

<table>
<thead>
<tr>
<th>Type of law</th>
<th>Ministerial decree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document structure</td>
<td>Articles ($)</td>
</tr>
<tr>
<td>Purpose</td>
<td>Establishing provisions regarding the grid usage fees.</td>
</tr>
<tr>
<td>Relation to renewable energy</td>
<td>The provisions also apply to the producers of renewable-energy-sourced electricity.</td>
</tr>
</tbody>
</table>

Electricity producers are contractually entitled against the grid operator to the connection of a system generating renewable-energy-sourced electricity to the grid (Art. 23 Loi n°2000-108). The grid operator is obliged to conclude this contract without discriminating against certain system operators. Systems generating electricity from renewable energy sources are not given priority. Legal basis/ addressees

− contractual basis

Electricity producers are contractually entitled against the grid operator to the connection of a system generating renewable-energy-sourced electricity to the grid (Art. 23 Loi n°2000-108). The term "accès au reseau" used in this Act refers to both access and connection to the grid.

High-voltage systems. According to experts, the exact terms regulating the connection of a plant generating high-voltage electricity to the grid are laid down in a grid connection agreement (convention de raccordement).

Low-voltage systems. The connection of systems that generate up to 36 kVA to a low-voltage grid requires the conclusion of an "all-in-one" agreement.

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants
(convention de raccordement, d'accès et d'exploitation) on connection to the grid, usage of the grid and system operation.

**Entitled party:** Authorised electricity producers are entitled to connection (Art. 23 Loi n°2000-108). Authorised producers shall be operators of a system generating renewable-energy-sourced electricity that hold the necessary licence issued by the Ministry for Energy (Art. 7 Loi n°2000-108).

**Obligated party:** The obligated party is the grid operator. Grid operators shall be operators of public transmission and distribution grids (Art.23 Loi n°2000-108).

**Priority to renewable energy**

- Non-discrimination

The grid operator is obligated to connect systems to the grid without discriminating against certain system operators (Art. 2 Loi n°2000-108). Renewable-energy-sourced electricity is not eligible for priority connection.

**Limitations/deadlines**

According to experts, the grid operator is obliged to submit to the applicant an offer on the technical implementation and the costs of connection (proposition technique et financière, PTF) within three months after having received the application for connection. The grid connection agreement (convention de raccordement) is based on the PTF and stipulates, among other things, a deadline for connection. The regulating authority CRE is entitled to intervene in case of connection delays caused by the grid operator.

**Arising/enforcement of a claim**

The claim for connection to the grid arises at the date of the conclusion of the connection agreement.

**Funding**

- **Plant operator:** The costs directly related to the connection of a system that generates renewable-energy-sourced electricity to the grid are borne by the system operator (Art. 18 Loi n°2000-108).

**A.4.3 Regulatory and financial aspects of grid expansion**

System operators may be contractually entitled to an expansion of the grid, if the connection of a system to the grid requires a grid expansion. In pursuance of the general provisions of the "service public de l'électricité", the grid operator is obligated to expand the grid (Art. 2 in connection with Art. 14 and Art. 18 Loi n°2000-108).

**Legal basis/ addressees:** contractual basis.

The system operator may be contractually entitled to an expansion of the grid, if the connection of the system requires a grid expansion. The grid connection agreement ("convention de raccordement") lays down terms on an expansion of the grid. The agreement is based on an offer on the costs and technical implementation (proposition technique et financière, PTF). In pursuance of the general provisions of the "service public de l'électricité", the grid operator is obligated to expand his grid (Art. 2 in connection with Art. 14 and Art. 18 Loi n°2000-108).

**Entitled party:** The agreement may entitle the system operator to an expansion of the grid.

**Obligated party:** The obligated party is the grid operator. Grid operators shall be operators of public transmission and distribution grids (Art.23 Loi n°2000-108).

**Priority to renewable energy:** Non-discrimination. Renewable energy is not entitled to any kind of priority regarding the expansion of the grid.

**Limitations/deadlines**

Limitations and deadlines regarding a possible expansion of the grid depend on the agreement.

**Arising/enforcement of a claim**

The claim for an expansion of the grid arises at the date of the conclusion of the agreement, unless access to the grid can be granted without a grid expansion.

**Funding**

- **Consumer:** The cost of a regular grid expansion is covered by the grid usage fees, which the grid operator charges to all users of the grid, including the final consumers (Art. 2f. Décret n°2001-365).

**Plant operator:** The costs arising from an expansion of the grid, which might become necessary in order to connect a system to the grid, are borne by the system operator (Art.18 Loi n°2000-108).
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

A.5 GERMANY

A.5.1 Grid access requirements for (wind) generators at transmission level

The nominal capacity of a generating unit within the meaning of these regulations is obtained from the sum of individual plants (generating units) combined in a grid connection point (network junction).

Behaviour in the event of network disturbances: there are two types of generating units:
- A type 1 generation unit if a synchronous generator is directly connected to the network;
- A type 2 generating unit exists where this condition is not fulfilled.

At transmission level type 2 is encountered.

a. Fault ride through capability

Type 2:

- Fault ride through capability

![Figure 1 Limiting curves of voltage at the grid connection point for a generating facility using renewable energy sources of type 2 in the event of a network fault](image)

b. Voltage/frequency operating limits

- If the voltage at the grid connection point decreases and remains at and below a value of 85 % of the reference voltage (380/220/110 kV, e.g. 110 kV x 0.85
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

= 93.5 kV) and if reactive power is simultaneously consumed at the grid connection point (under-excited operation) the generating facility must be disconnected from the network with a time delay of 0.5 seconds. The voltage value relates to the largest value of the three line-to-line network voltages. The disconnection must take place at the generator circuit breaker. This function performs the supervision of voltage support.

• If the voltage at the low-voltage side of each individual generator transformer decreases and remains at and below a value of 80 % of the lower value of the voltage range (e.g. 690 V \times 0.95 \times 0.8 = 525 V) one fourth of the generators must disconnect from the network after 1.5 s, after 1.8 s, after 2.1 s and after 2.4 s, respectively. The voltage value relates to the lowest value of the three line-to-line network voltages. A different time graduation can be agreed on a case-by-case basis.

• If the voltage at the low-voltage side of each individual generator transformer rises and remains at and above a value of 120 % of the upper value of the voltage range (e.g. 690 V \times 1.05 \times 1.2 = 870 V) the generator concerned must disconnect from the network with a time delay of 100 ms. The voltage value relates to the lowest value of the three line-to-line network voltages.

• The reset ratio of the measuring equipment for the under-voltage and over-voltage system automatics must be \( \leq 1.02 \) or \( \geq 0.98 \), respectively.

• At frequencies of between 47.5 Hz and 51.5 Hz, automatic disconnection from the network due to the frequency deviation from 50 Hz is not admissible. If the frequency falls below 47.5 Hz, automatic disconnection from the network must take place without delay; if the frequency rises above 51.5 Hz, automatic disconnection may be carried out.

• It is recommended implementing the functions of over-frequency and under frequency, over-voltage and under-voltage at the generators in one device each. In general, these functions, including the under-voltage function, shall be signaled at the grid connection point as system automatics.

• After disconnection of the generating facility from the network due to over-frequency, under-frequency, under-voltage, over-voltage or after termination of isolated operation, automatic synchronization of the different generators with the network is only permitted if the voltage at the grid connection point is higher than 105 kV in the 110 kV network, higher than 210 kV in the 220 kV network and higher than 370 kV in the 380 kV network. The voltage value is related to the lowest value of the three line-to-line network voltages. After this disconnection, the increase of the active power supplied to the network of the network operator concerned must not exceed a gradient of maximally 10 % of the network connection capacity per minute.

Figure 2 Principle of voltage support in the event of network faults with renewables-based generating facilities

- The generating facilities must support the network voltage during a voltage drop by means of additional reactive current. To this end, voltage control according to Figure 2 shall be activated in the event of a voltage drop of more than 10 % of the effective value of the generator voltage. This voltage control must ensure the supply of a reactive current at the low-voltage side of the generator transformer with a contribution of at least 2 % of the rated current per percent of the voltage drop. The facility must be capable of feeding the required reactive current within 20 ms into the network (control response time). If required, it must be possible to supply reactive current of at least 100 % of the rated current.

- After return of the voltage to the dead band range, voltage control must be maintained at least over additional 500 ms according to the given characteristic.

- In particular within the extra-high voltage grid, continuous voltage control without dead band may be required.

- If the distances from the generators of the generating facility to the grid connection point are too long and thus lead to ineffectiveness of voltage control, the network operator shall require that the voltage drop be measured at the grid connection point and that the voltage be controlled there as a function of this measured value.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

- The above mentioned modification proposal [43] suggests a changed principle of voltage support during faults by reactive current feed as shown in Figure 2'.

Figure 2' Proposed voltage support during faults by reactive current feed

c. Reactive power control (power factor control, voltage regulation)

- Reactive power supply at rated active power
  - Each new generating unit to be connected to the network must meet, within the rated operating point, the requirements illustrated in Figures 3, 4, 5 at the grid connection point.
  - The TSO shall select one of the possible variants shown in 3 to 5 on the basis of relevant network requirements. The generating unit must be able to pass repeatedly within a few minutes through the agreed reactive power range in the operating point $P = P_N$. It must be possible at any time to change the reactive power requirements within the agreed reactive power range. If required, the network operator may determine a different range.
  - If required, additional facilities must be provided on the generating unit, in agreement with the operator of the generating unit, in order to be able to carry out voltage and reactive power control within the area of the respective network operator.
  - The working point for steady-state reactive power exchange shall be determined in accordance with the need of the grid. The determination shall relate to one of the following three possibilities:
    - power factor ($\cos \varphi$)
    - reactive power value ($Q$ in Mvar)
    - voltage value ($U$ in kV), where necessary with tolerance band.

- The determination can be made by means of
  - an agreement on a value or, where possible, on a schedule
  - a characteristic dependent on the generating plant’s working point
  - online target-value specification.

- For online target-value specification, the new specifications for the working point of the reactive power exchange shall be realized after one minute, at the latest, at the grid connection point.

Figure 3 Basic requirement upon the network-side supply of reactive power from generating units to the network (Variant 1)
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

Figure 4 Basic requirement upon the network-side supply of reactive power from generating units to the network (Variant 2)

Figure 5 Basic requirement upon the network-side supply of reactive power from generating units to the network (Variant 3)

Table 1 Reactive power supply at rated active power (from = underexcited; to = overexcited)

<table>
<thead>
<tr>
<th>Variant</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>0.228</td>
<td>0.33</td>
<td>0.41</td>
</tr>
<tr>
<td>To</td>
<td>0.48</td>
<td>0.41</td>
<td>0.33</td>
</tr>
<tr>
<td>Q/Pn [p.u.] (network)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cos φ (network)</td>
<td>0.975</td>
<td>0.95</td>
<td>0.925</td>
</tr>
</tbody>
</table>

- Reactive power supply from generating units operating at less than full output
  - Apart from the requirements as to reactive power supply in the nominal design point of the generating unit (P=Pn) there are also requirements concerning operation at an active power output below the nominal active power (P<Pn).
  - In this case, it must be possible to operate the generator of the generating unit in every possible working point in accordance with the generator output diagram. Even at reduced active power output, reactive power supply at the grid connection point shall fully correspond to the generator output diagram taking the auxiliary service power and the losses at the generator transformer and the machine line into account.
  - The generating unit must be capable of immediately providing every reactive power supply resulting from the above. The relevant request can arise according to the situation on the network and imply that the provision of reactive power takes precedence over the supply of active power. The mode of operation is agreed between the operator of the generating unit and the TSO.

- Proposed changes in [43]:
  - The steady state reactive power provision can be a discrete and slow reactive power control with time constants of up to ten minutes.
• Consideration should be given to defining the steady-state reactive power provision for both nominal power and partial load operation of the power plant (Figure 6).

Figure 6 Example for proposed clarifying figure: the steady-state reactive power provision at partial load for the typical voltage range at the PCC (Variant 1)

• It is suggested that the implications that result from the PCC voltage dependence of the steady-state reactive power should be also illustrated for the partial load operation of the power plant (Figure 7).

Figure 7 Example for proposed clarifying figure: the steady-state reactive power provision at partial load for extreme voltages at the PCC (Variant 1)

d. Active power control (set-point, ramp rates, reserve, power curtailment capability, frequency regulation)

• Active power output - GENERAL

  • A deviation from the required generating unit’s output to the network in accordance with Figures 6 and 7 is permissible only after consultation with the TSO.
  • Each generating unit must be capable of operation at reduced power output. The level of minimum stable generation is agreed bilaterally between the operator of the generating unit and the TSO.
  • Rates of power changes of at least 1% PN/min related to the nominal capacity must be possible across the entire spectrum between the minimum stable generation power and the continuous output power. Power-station-specific particularities (e.g. for the consideration of mill switching points or inertia points) are taken into consideration. In the case of provision of ancillary services, these requirements may deviate from the above according to prequalification.
Figure 6 Requirements upon feed-in from generating units to the network to be guaranteed for specific periods as a function of the network frequency and the network voltage (quasi-steady consideration, e.g. frequency gradient $\leq 0.5 \%$/min; voltage gradient $5 \%$/min).

- **Active power output - RES**
  - Generating units using renewable energy sources must be controllable in terms of active power output according to the requirements of the TSOs with a view to counteracting a risk to or disturbance of the system balance pursuant to Article 13, paragraph 2 EnWG. It must then be possible to reduce the power output under any operating condition and from any working point to a maximum power value (target value) defined by the network operator. This target value is given by the network operator at the grid connection node and corresponds to a percentage value related to the network connection capacity. The reduction of the power output to the signalized value must take place with at least 10% of the network connection capacity per minute without disconnection of the plant from the network.
  - All renewables-based generating units must reduce, while in operation, at a frequency of more than 50.2 Hz the instantaneous active power with a gradient of 40% of the generator’s instantaneously available capacity per Hertz (Figure 8).

Figure 7 Requirements upon the output from generating units fed into the network within the dynamic short-time range.

- If the frequency returns to a value of $f \leq 50.05$ Hz, the active power output may be increased again as long as the actual frequency does not exceed 50.2

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

Hz. This control is realized in a decentralized manner (at each individual generator). The neutral zone must be below 10 mHz.

- A concept for resynchronization with the network is currently developed for wind energy plants which have been disconnected from the network due to over-frequency.

- **Other requirements**

  - **Exceptional rules for renewables-based generating facilities**
    - Generating units using renewable energy sources may be exempted from the requirement to be capable of operation under primary control.
    - In accordance with the capabilities of conventional generating units to interfere in the event of sudden power imbalances by means of network sectionalizing and islanding, and in order to contribute to network restoration, renewables-based generating facilities shall utilize control concepts which correspond to the latest state of the art.

  - **Special requirements for renewables-based offshore-generating facilities**
    - For the connection and operation of renewables-based generating facilities in the light of the implementation of the Act on the acceleration of infrastructures planning (2006), specific additional requirements resulting from the needs of transmission from offshore wind farms to the transmission grid are used a basis.

- **Protection equipment**
  
  (source REA* generating plants connected to the high- and extra-high voltage network, http://www.vdn-berlin.de/global/downloads/englisch/service/RL EEG HH EN 2004-08.pdf)

- Protection equipment is of considerable importance for secure and reliable operation of networks and of the connection facility with its generating units. Automatic installations need to be provided for short-circuit clearing in electric facilities.
- The responsibility for the concept, settings and operation of the protection equipment shall lie with the partner for whose operating facilities the protective installations represent the main protection. Concepts and protection settings at the interfaces between network operator and plant operator/connection holder are mutually agreed so that endangering of adjoining networks and plants can be excluded.

- To this end, the following installations are required:
  - protection equipment for the connection facility
  - protection equipment for the network operator’s network and
disconnection facilities at the generating units and at the point of connection.

- Figure 9 shows an overview of the rise-in-voltage and fall-in-voltage protection devices in connection facilities with generating units. Single overvoltage and undervoltage relays can be used if the transformer is equipped with a tap changer and the medium-voltage side is adjusted to a fixed voltage Uc.

![Figure 9 Rise-in-voltage and fall-in-voltage protection devices](http://www.vdn-berlin.de/global/downloads/englisch/service/RL EEG HH EN 2004-08.pdf)

Legend: U controller

Uc = agreed voltage in the medium-voltage network
A.5.2 Regulatory aspects of generation connection to the grid

Legal basis/addresses
- statutory basis
- contractual basis

The plant operator is entitled to the connection of a plant generating electricity from renewable energy sources to the grid by the grid operator. The grid operator shall not make the fulfilment of his obligation of connection to the grid conditional upon the conclusion of a contract (§ 12 Gesetz für den Vorrang Erneuerbarer Energien (EEG)).

Entitled party: Persons entitled to connection to the grid are the plant operators. A plant operator is one who uses a plant for the purpose of power generation from renewable energy sources. The matter of ownership is not relevant (§ 3 EEG).

Obligated party: Persons obliged to grant connection to the grid are the grid operators. In general, the claim is directed against the grid operator that is most closely located to the plant site and whose grid is technically suitable to receive electricity (§ 4 EEG). As an exception, the claim may be directed against a more distant operator of a grid whose connection point is technically and economically more suitable compared to the grid most closely located. If both grids are technically suitable, the more economical grid shall be given priority. A grid is deemed to be technically suitable even if feeding in the electricity requires the grid operator to expand his grid at an economically reasonable expense.

Priority to renewable energy
- Priority to renewable energy
- Non-discrimination

In general, the connection of plants generating electricity from renewable energy sources to the grid must be given priority compared to the connection of traditional power plants („principle of priority“, § 4 EEG). If the capacity of the grid is temporarily entirely taken up by electricity generated from renewable energy sources or mine gas, the plant operator is entitled to priority connection of his plant by the grid operator only if the plant has a technical facility for reducing the feed-in in the event of a grid overload (§ 4 EEG). Grid overloads resulting from feed-ins of electricity generated from traditional energy sources do not justify a limitation of the preferential treatment.

Limitations/deadlines

The plant must be connected to the grid immediately, i.e. without undue delay (§ 4 EEG in connection with § 121 BGB).

Arising/enforcement of a claim

The claim for connection to the grid does not arise until the construction of the plant is completed in so far as it is ready for connection. Under German law, the plant operators have the possibility to prove that they are entitled to connection to the grid before the plant is completed („declaratory action“). This legislation considers the fact that the banks grant loans for investments into plants generating electricity from renewable energy sources only if the plant operators can prove that they are entitled to connection to the grid. For this reason, in practice the grid operators promise guaranteed connection to the grid or electricity purchase. In general, this promise is conditional upon the submission of a definitive plant licence.

Funding

Consumer: The consumer bears the costs of a grid expansion necessary for the connection to the grid (link, if necessary), if the grid operator makes use of the possibility to add the costs of the grid expansion when calculating the charges for use of the grid. The charges for use of the grid are reflected by the electricity prices, which enables the costs to be borne by the consumer.

Grid operator: The grid operator bears the costs associated with a potentially necessary grid expansion (§ 13 par. 2 EEG)

Plant operator: The plant operator bears the costs of connecting the plant to the technically and economically most suitable grid connection point as well as the costs of the necessary measuring devices for recording the electricity transmitted and received (§ 13 par. 1 EEG).

ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

UNS = Uc/ü with ü = transformation ratio of low-voltage transformers

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants
A.6 IRELAND

A.6.1 Grid access requirements for (wind) generators at transmission level

All generators connecting to the transmission system are required to comply with the grid code. The grid code was originally developed with synchronous generators in mind. Since wind turbine generators (WTG) do not have the same characteristics as synchronous generators, it was considered appropriate to develop a new set of grid code provisions specifically for Controllable WFPSs. This section of the grid code gives the specific requirements for Controllable WFPSs.

a. Low voltage/ Fault ride through capability

A Controllable WFPS shall remain connected to the Transmission System for Transmission System Voltage dips on any or all phases, where the Transmission System Phase Voltage measured at the HV terminals of the Grid Connected Transformer remains above the heavy black line in Figure 1.

![Fault Ride Through Capability of Wind Farm Power Stations](image)

**Figure 1: Fault Ride-Through Capability of Controllable WFPSs**

In addition to remaining connected to the Transmission System, the Controllable WFPS shall have the technical capability to provide the following functions:

- **Active power management**
  A Wind Farm Control System shall be installed by the Controllable WFPS to allow for the provision of Active Power Control and Frequency Response from the Controllable WFPS.
  - **Active power control**
    The Wind Farm Control System shall be capable of operating each WTG at a reduced level if the Controllable WFPS’s Active Power output has been restricted by the TSO. The Wind Farm Control System shall be capable of receiving an on-line Active Power Control Set-point sent by the TSO and shall commence implementation of the set-point within 10 seconds of receipt of the signal from the TSO. The rate of change of output to achieve the Active Power Control Set-point should be no less than the maximum ramp rate settings of the Wind Farm Control System, as advised by the TSO.
  - **Frequency response**

- **Transmission system frequency ranges**
  Controllable WFPSs shall have the capability to:
  - a) operate continuously at normal rated output at Transmission System Frequencies in the range 49.5 Hz to 50.5 Hz;
  - b) remain connected to the Transmission System at Transmission System Frequencies within the range 47.5 Hz to 52.0 Hz for a duration of 60 minutes;
  - c) remain connected to the Transmission System at Transmission System Frequencies within the range 47.0 Hz to 47.5 Hz for a duration of 20 seconds required each time the Transmission System Frequency is below 47.5 Hz;
  - d) remain connected to the Transmission System during rate of change of Transmission System Frequency of values up to and including 0.5 Hz per second.

No additional WTG shall be started while the Transmission System Frequency is above 50.2 Hz.
The Frequency Response System shall have the capabilities as displayed in the Power-Frequency Response Curve in Figure 2 where the power and frequency ranges required for points A, B, C, D, E are defined below in Table WFPS1.1 and Table WFPS1.2.

**Figure 2: Example of Power-Frequency Response Curve.**

Under normal Transmission System Frequency ranges, the Controllable WFPS shall operate with an Active Power output as set by the line ‘B’ - ‘C’. If the Transmission System Frequency falls below point ‘B’, then the Frequency Response System shall act to ramp up the Controllable WFPS’s Active Power output, in accordance with the Frequency/Active Power characteristic defined by the line ‘B’ - ‘A’.

Where the Transmission System Frequency is below the normal range and is recovering back towards the normal range, the Frequency Response System shall act to ramp down the Controllable WFPS’s Active Power output in accordance with the Frequency/Active Power characteristic defined by the line ‘A’ - ‘B’.

A Frequency dead-band shall be applied between the Transmission System Frequencies corresponding to points ‘B’ and ‘C’, where no change in the Controllable WFPS’s Active Power output shall be required.

Once the Transmission System Frequency rises to a level above point ‘C’, the Frequency Response System shall act to ramp down the Controllable WFPS’s Active Power output in accordance with the Frequency/Active Power characteristic defined by the line ‘C’ - ‘D’ - ‘E’. At Transmission System Frequencies greater than or equal to ‘D’ - ‘E’, there shall be no Active Power output from the Controllable WFPS.

Points ‘A’, ‘B’, ‘C’, ‘D’ and ‘E’ shall depend on a combination of the Transmission System Frequency, Active Power and Active Power Control Set-point settings. These settings may be different for each Controllable WFPS depending on system conditions and Controllable WFPS location. These settings are defined in Table 1 below.

**Table 1: Transmission System Frequency and % Available Active Power Settings for the Points ‘A’, ‘B’, ‘C’, ‘D’ and ‘E’ illustrated in Figure 2.**

<table>
<thead>
<tr>
<th>Point</th>
<th>Transmission System Frequency (Hz)</th>
<th>Controllable WFPS Active Power Output (% of Available Active Power)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$F_A$</td>
<td>$P_A$</td>
</tr>
<tr>
<td>B</td>
<td>$F_B$</td>
<td>Minimum of: $P_B$ or Active Power Control Set-point (converted to a % of Available Active Power)</td>
</tr>
<tr>
<td>C</td>
<td>$F_C$</td>
<td>Minimum of: $P_C$ or Active Power Control Set-point (converted to a % of Available Active Power)</td>
</tr>
<tr>
<td>D</td>
<td>$F_D$</td>
<td>Minimum of: $P_D$ or Active Power Control Set-point (converted to a % of Available Active Power)</td>
</tr>
<tr>
<td>E</td>
<td>$F_E$</td>
<td>$P_E = 0$ %</td>
</tr>
</tbody>
</table>

Two settings for each of $F_A$, $F_B$, $F_C$, $F_D$, $F_E$, $P_A$, $P_B$, $P_C$, $P_D$ and $P_E$ shall be specified by the TSO at least 120 Business Days prior to the Controllable WFPS’s scheduled Operational Date. The Controllable WFPS shall be responsible for implementing the appropriate settings during Commissioning.

Alterations to the Active Power Control Set-point may be requested in real-time by the TSO and the implementation of the set-point shall commence within 10 seconds of receipt of the signal from the TSO. The rate of change of output to achieve the Active Power Control Set-point should be no less than the maximum ramp rate settings of the Wind Farm Control System, as advised by the TSO.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

The table below, Table 2, shows the Transmission System Frequency and Active Power ranges for FA, FB, FC, FD, FE, PA, PB, PC, PD and PE.

Table 2: Transmission System Frequency & Active Power ranges appropriate to Figure 2.

<table>
<thead>
<tr>
<th>Transmission System Frequency (Hz)</th>
<th>Available Active Power (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEC &gt; 10 MW</td>
</tr>
<tr>
<td>F_A 47.0-51.0</td>
<td>P_A 50-100</td>
</tr>
<tr>
<td>F_B 49.5-51.0</td>
<td>P_B 50-100</td>
</tr>
<tr>
<td>F_C 49.5-51.0</td>
<td>P_C 20-100</td>
</tr>
<tr>
<td>F_D 50.5-52.0</td>
<td>P_D 0</td>
</tr>
</tbody>
</table>

For the Transmission System Frequency values in Table 2 above, FA ≤ FB ≤ FC ≤ FD = FE.

Alterations to the Controllable WFPS’s Active Power output, triggered by Transmission System Frequency changes, shall be achieved by proportionately altering the Active Power output of all available WTGs as opposed to switching individual WTGs on or off, insofar as possible.

No time delay other than those necessarily inherent in the design of the Frequency Response System shall be introduced. The response rate of each available online WTG shall be a minimum of 1 % of WTG rated capacity per second (MW/second). The Frequency Response System shall continuously monitor the Transmission System Frequency in order to continuously determine the Controllable WFPS’s appropriate Active Power output by taking account of the Controllable WFPS’s Available Active Power or Controlled Active Power.

If the Transmission System Frequency rises to a level above ‘D’-‘E’, as defined by the Power-Frequency Response Curve in Figure 2, the TSO accepts that WTGs may disconnect. Any WTG which has disconnected shall be brought back on load as fast as technically feasible (provided the Transmission System Frequency has fallen below 50.2 Hz).

Procedure for Setting and Changing the Power-Frequency Response Curves

Two Power-Frequency Response Curves (Curve 1 and Curve 2) shall be specified by the TSO at least 120 Business Days prior to the Controllable WFPS’s scheduled Operational Date. The Controllable WFPS shall be responsible for implementing the appropriate settings during Commissioning. The Frequency Response System shall be required to change between the two curves within one minute from receipt of the appropriate signal from the TSO. The TSO shall give the Controllable WFPS a minimum of 2 weeks notice if changes to either of the curve’s parameters (i.e. FA, FB, FC, FD, FE, PA, PB, PC, PD or PE), are required. The Controllable WFPS shall formally confirm that any requested changes have been implemented within two weeks of receiving the TSO’s formal request.

Transmission system voltage ranges

Controllable WFPSs shall remain continuously connected to the Transmission System at maximum Available Active Power or Controlled Active Power output for normal and disturbed system conditions and for step changes in Transmission System Voltage of up to 10 %. The following are the ranges which may arise during Transmission System disturbances or following transmission faults:

(a) 400 kV system: 350 kV to 420 kV;
(b) 220 kV system: 200 kV to 245 kV;
(c) 110 kV system: 99 kV to 123 kV.

Automatic voltage regulation

Controllable WFPSs shall have a continuously-variable and continuously-acting Voltage Regulation System with similar response characteristics to a conventional Automatic Voltage Regulator and shall perform generally as described in BS4999 part 140, or equivalent European Standards.

The Voltage Regulation System shall be capable of receiving a Voltage Regulation Setting-point for the Voltage at the Connection Point. The Voltage Regulation System shall act to regulate the Voltage at this point by continuous modulation of the Controllable WFPS’s Reactive Power output, within its Reactive Power range and without violating the Voltage Step Emissions limits as set out in the IEC standard 61000-3-7:1996 Assessment of Emission limits for fluctuating loads in MV and HV power systems. A change to the Voltage Regulation Setting-point shall be implemented by the Controllable WFPS within 20 seconds of receipt of the appropriate signal from the TSO.

The Voltage Regulation System Slope Setting shall be capable of being set to any value between 1 % and 10 %. The setting shall be specified by the TSO at least 120 Business Days prior to the Controllable WFPS’s scheduled Operational Date. The Controllable WFPS shall be responsible for implementing the appropriate settings during Commissioning. The slope setting may be varied from time to time depending on Transmission System needs. The TSO shall give the Controllable WFPS a minimum of two weeks notice if a change is required. The Controllable WFPS shall formally confirm that any requested changes have been implemented within two weeks of receiving the TSO’s formal request.
The speed of response of the Voltage Regulation System shall be such that, following a step change in Voltage at the Connection Point the Controllable WFPS shall achieve 90% of its steady-state Reactive Power response within 1 second. The response may require a transition from maximum Mvar production to maximum Mvar absorption or vice versa.

Figure 3 shows the relevant points appropriate to the Voltage Regulation System for a Controllable WFPS. X is the HV side of the WTG transformer, Y is the lower voltage side of the Grid Connected Transformer and Z is the Connection Point.

Figure 3: Locations for Voltage Regulation set-point (Z) and the Power Factor range (Y). The HV side of the WTG transformer is (X).

c. Reactive power control (power factor control, voltage regulation)

Controllable WFPSs shall be capable of operating at any point within the Power Factor ranges illustrated in Figure WFPS1.4, as measured at the lower voltage side of the Grid Connected Transformer (point Y in Figure 3). The design reference voltage for the Reactive Power capability shall be the nominal voltage at point Y. The Grid Connected Transformer tap changing range must be capable of ensuring nominal voltage at point Y for any Voltage at the Connection Point (Point Z) within the ranges of transmission system voltage. For Controllable WFPSs where the Connection Point is remote from the Grid Connected Transformer, any supplementary Reactive Power compensation required to offset the Reactive Power demand of the HV line, or cable, between the Connection Point and the Controllable WFPS shall be identified during the TSO’s Connection Offer process.

Figure 4: Reactive Power Capability of Controllable WFPS

For operation below 10% of the Controllable WFPS’s MEC, the Controllable WFPS shall operate within the shaded triangle in Figure 4. However, if this cannot be
achieved, then the total charging of the Controllable WFPS network during low load operation (below 10%) shall be examined during the TSO’s Connection Offer process. If during this examination it is identified that this charging may cause the voltage on the Transmission System to be outside the Transmission System Voltage ranges, then the Reactive Power requirements will need to be altered.

A.6.2 Regulatory aspects of generation connection to the grid

Legal basis/ addressees

- contractual basis

Under a contract, every operator of a power plant is entitled to the connection of this plant to the grid on the part of the grid operator (Sec. 33 (1), 34 (1), 35 ERA in connection with PC 4.1 b) GC 3.0 in connection with 4.1 TCA).

Entitled party: The party entitled to connection to the grid is the plant operator as a contracting party to the connection agreement. Only those who have a licence to generate electricity (Sec. 14 (1) b) ERA) and are authorised to construct or reconstruct a generating station (Sec. 16(1) ERA) may become a contracting party.

Obligated party: The obligated party is Eirgrid

Priority to renewable energy

- Non-discrimination

Non-discriminative connection. Plants generating electricity from renewable energy sources shall be connected according to non-discriminative criteria (Sec. 34 (8) in connection with PC 7.2 GC). The regulative authority may decide that the connection of plants generating renewable energy shall be given priority (Sec. 9 (5) (e) ERA). So far, the regulative authority has not taken such a decision.

Group Processing. However, plants generating renewable energy sourced electricity are connected under the system of group processing. Group processing aims at speeding up the connection of plants generating electricity from renewable energy sources through the standardisation of the procedural steps and increasing connection security (CER /05/049). This especially applies to wind power plants. Plants generating a maximum capacity of 0,5 MW are exempt from “group processing”. Plant operators that prove that a selective procedure not being part of group processing is faster and in the public interest, may be exempt from group processing. The respective plant operators require a special permit by the CER.

Limitations/deadlines

The grid connection offer shall specify a term for connection (GC/PC 4.3.1 c), PC A 2.1.2). The term depends on when the system tests necessary to connect the plant can be carried out.

Arising/enforcement of a claim

The claim for connection arises according to the terms specified in the contractual agreement.

Funding

Plant operator: The plant operator bears the costs of connection to the respective grid entry point and the costs of the metering devices necessary to record the electric power furnished and received (Sec. 35 (1) b), 36 ERA in connection with 7.8 GCTC). The grid operator bears the costs of a potentially necessary grid expansion, which he may, however, pass on to the plant operator through the connection charge.

A.6.3 Regulatory and financial aspects of grid expansion

Legal basis/ addressees

- contractual basis

Under a contract, the plant operator is entitled to the expansion of the grid on the part of the grid operator, if the expansion is necessary to satisfy the claim for connection to the grid (Sec. 34 (1) ERA in connection with 2.1 GCTC in connection with TCA).

Entitled party: The entitled party is the plant operator (Sec 34 (1) in connection with Preamble TCA).

Obligated party: The obligated party is Eirgrid (Sec. 34 (1) in connection with Preamble TCA).

Priority to renewable energy

- Non-discrimination
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

The connection agreement may oblige the grid operator to expand the grid in such a way as to enable the plant to be connected to the nearest, technically and economically most suitable connection point (Preamble (C) TCA, Art. 9.7 TCA).

Limitations/deadlines

If the plant operator accepts the connection offer, the plant operator and the grid operator shall, within 20 days, agree upon the date on which the connection works of both parties, including the grid expansion works, shall be completed (Connection Works Completion Date, Art. 2.7.4, 2.10, 2.11 schedule 10 GCTC).

Arising/enforcement of a claim

The claim for a grid expansion arises at the date of the conclusion of the connection agreement. The grid operator’s connection offer shall specify the conditions of the grid expansion.

Funding

Grid operator: The costs of a grid expansion to the grid entry point are borne by the grid operator.

Plant operator: According to the general principles of electricity law, the grid operator may pass on the costs to the plant operators and electricity vendors through the grid usage charges. (SoC Vers. 1).

Consumer: According to the general principles of energy law, the electricity vendors may in turn pass on these costs to the final consumers.

A.7 ITALY

A.7.1 Grid access requirements for (wind) generators at transmission level

a. Low voltage/ Fault ride through capability

1B.5.4.1 The generation plant, along with the related facilities and devices, must be designed, built and operated to remain synchronously connected to the system also in emergency and power system recovery conditions.

In these situations, the generation plant must guarantee, in compliance with what set out in the Grid Code and the related documents:

(a) the planned active power production:

(b) the possible contribution to frequency regulation, depending upon the inherent characteristics of the generation groups;

(c) the possible contribution to voltage regulation, depending upon the inherent characteristics of the generation groups;

The regulator must guarantee the stable operation of the group for an indefinite period of time, for each and every frequency spanning from 47.5 Hz and 51.5 Hz, and with each and every load included between the auxiliary services load and the maximum generating power. Additionally, the regulator must guarantee the proper operation up to 46 Hz for limited time spans (a few seconds).

Insensitivity to voltage dips

During a short circuit on the power grid, a general reduction of the voltage levels in all the system’s nodes is unavoidable. In case of a fault external to the power plant, the generating plant must be able to remain connected to the network. It is also required that the wind power plants keep their operating state and the wind turbines remain connected to the network when duration and amplitude of the voltage reductions, typical of network faults and measured at the plant’s connection point, are above the curve depicted in Figure 1. It is noted that the area below this discontinuous line does not represent the voltage-time couples of values where the disconnection is required, but simply the couples of values where the disconnection is allowed.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

Active power control

The wind power plant, in order to control the frequency of the national power system, must be at least able not to decrease the output power in case of under-frequency events within the foreseen limits and must be able to swiftly and automatically reduce the output power in case of over-frequency events, without disconnecting from the network. To this end, the wind power generators must be equipped with an automatic system regulating the power injected into the network, compatibly with the wind conditions, in function of the power-frequency characteristic curve depicted in Figure 2. In particular, the central regulating system must:

a) allow the continuous injection of the efficient instantaneous power of the wind power plant, for frequencies included between 47.5 and 50.3 Hz;
b) permit the reduction of the power injected into the network in function of the amplitude of the positive frequency error, with a droop included between 2% and 5% for frequencies higher than 50.3 Hz and up to 51.5 Hz (Maximum value admitted). Generally the droop shall be equal to 2.4%;
c) guarantee a response time allowing the reduction of half of the available regulation power within max 15 s and of the whole reserve power within 30 s from the beginning of the frequency variation. Additionally, the regulator shall have an adjustable dead band comprised between 0 mHz and 200 mHz.

Figure 2: Regulating conditions for wind power plants, in function of the power system frequency, in the region of admissible operation.
In order to ensure what laid down in bullet b) of this paragraph, those wind power plants which are not equipped with the prescribed regulation systems for justified technical reasons, must still deploy an automatic system which progressively disconnects the wind generating units (individually or in groups) in function of the frequency increase. As an example, the following table provides a possible breakdown of the disconnection values, thresholds and delays.

<table>
<thead>
<tr>
<th>Wind power generators</th>
<th>Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disconnected power</td>
<td>Threshold Delay</td>
</tr>
<tr>
<td>25% of efficient power</td>
<td>50.6 Hz 1.0 s</td>
</tr>
<tr>
<td>25% of efficient power</td>
<td>50.9 Hz 0.8 s</td>
</tr>
<tr>
<td>25% of efficient power</td>
<td>51.2 Hz 0.6 s</td>
</tr>
<tr>
<td>25% of efficient power</td>
<td>51.5 Hz 0.4 s</td>
</tr>
</tbody>
</table>

The gradual reconnection of the wind power plants, in function of the wind resource availability, is expected when the normal operating frequency is restored.

c. **Reactive power control (power factor control, voltage regulation)**

To comply with the provisions of reactive power regulation, each wind power generator must be capable to regulate the power factor measured at the generator’s terminals from 0.95 lagging to 0.95 leading. The power factor can be kept at a fixed value agreed upon by the system operator and the producer. Generally, the power factor at the connection point of the generator with network shall be kept at a value equal to 1.

1B.5.3 Generation groups performances

1B.5.3.1 The generators must be capable to operate in a continuous way within the following limits:
(a) the active power (Pc) shall be any value comprised between the efficient power (Pe) and the technical minimum declared;
(b) the reactive power, required by the network, shall be comprised between the minimum value (Qc,min) and the maximum value (Qc,max), drawn from the capability curve (Figure 1), in correspondence with the active power produced and with frequency and voltage values falling in the Area A of Figure 3.

1B.5.3.2 Additionally, the generators must be capable to keep, for no more than 15 minutes and in compliance with the Italian standards (CEI) for the electrical machinery, the following operation mode:
(a) the active power (Pc) shall be any value comprised between the efficient power (Pe) and the technical minimum declared;
(b) the reactive power, required by the network, shall be comprised between the minimum value (Qc,min) and the maximum value (Qc,max), drawn from the capability curve (Figure 4), in correspondence with the active power produced and with frequency and voltage values falling in:
(i) the Area B, for the non-salient pole generators with rated power equal or higher than 10 MVA;
(ii) the Area C, for the non-salient pole generators with rated power lower than 10 MVA and for the salient pole generators.

The system operator and the producer can agree upon operating areas wider than those reported in Figure 3.

Figure 3: Frequency-voltage operating areas of power generators.

1B.5.3.3 The rated power factor (in overexcitation mode) at the generator’s terminals shall be:
(a) for non-salient pole generators, no higher than:
(i) 0.85 for a rated power up to 200 MVA;
(ii) 0.9 for a rated power higher than 200 MVA;
(b) for salient pole generators, no higher than:
(i) 0.85 for a rated power up to 70 MVA;
(ii) 0.9 for a rated power higher than 70 MVA.

The power factor at the generator’s terminals shall be 0.95 in underexcitation mode. The presence of limiters shall not reduce, in a significant way, the boundary for the reactive power. The limiters setting shall in any case be consented with the system operator.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

Figure 4: Typical capability curve of a generating group.

A.7.2 Regulatory aspects of generation connection to the grid

a. Legal basis/addressess

- contractual basis

The plant operator is entitled to be connected to the national electricity grid upon request (Art. 3 DL 79/99). To this aim, the grid operator and the electricity producer conclude a contract (contratto di connessione), (Section 1A.5.9.1 TERNA 2007).

Entitled party The person entitled to connection to the grid is the producer of renewable-energy-sourced electricity (Section 1A.5 TERNA 2007).

Obligated party The obligated party is the operator of the transmission grid RTN (RETE di Trasmissione Nazionale). He assesses the applications and checks the technical possibilities (Section 1A.3.1 TERNA 2007).

b. Priority to renewable energy

- Non-discrimination

All plant operators have the same right to the connection of their plant to the national grid. Renewable energy is not given priority.

c. Limitations/deadlines

Applications for connection of a plant to the grid and for access to the grid are answered by TERNA within a period of 90 days. The reply includes the draft of a technical solution (soluzione tecnica minima generale, STMG), (Section 1A.5.2 TERNA 2007).

d. Arising/enforcement of a claim

The claim for connection to the grid arises at the date of the conclusion of the contract.

e. Funding

The costs arising from the connection of a plant to the grid are borne by the plant operator. As he is the producer of renewable-energy-sourced electricity, he shall pay to the grid operator a fee of 1,250€ instead of 2,500€, which is a 50% reduction. Furthermore, he shall pay 50% of the quota, i.e. 0.5 €/kWh. All plant operators bear the costs of the acceptance test and the subsequent approval by the grid operator as specified in the contract (Section 1A.5.10 TERNA 2007).

A.7.3 Regulatory and financial aspects of grid expansion

a. Legal basis/addressess

contractual basis

The grid user is entitled against the grid operator to a grid expansion, if the expansion is necessary to satisfy the claim for connection to the grid. The grid operator prepares the technical draft (soluzione tecnica minima generale) on connection to the grid, which is the legal basis.

b. Priority to renewable energy

Non-discrimination

Renewable energy is not given priority.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

c. **Limitations/deadlines**

Limitations and deadlines regarding the claim for expansion of the grid are specified by the draft technical solution for the connection to the grid (Section 1A.5.2.1 TERNA 2007).

d. **Arising/enforcement of a claim**

The claim for an expansion of the grid arises if the draft technical solution (STMG) is accepted.

e. **Funding**

The distribution of the cost of a grid expansion is subject to the general provisions of energy law. For further information please see the grid code TERNA (Section 1A.5.2 TERNA 2007).

**Entitled party** The entitled party are those plant operators that have applied for connection to the grid.

**Obligated party** The obligated party is the grid operator.

**Grid operator.** The applicant bears the cost of the connection of a plant generating renewable-energy sourced electricity. The grid operator refunds part of the costs according to the following calculation (AEEG 281/05, Art. 13): The costs refunded depend on the transmission distance.

---

A.8 **THE NETHERLANDS**

A.8.1 **Grid access requirements for (wind) generators at transmission level**

For connection capacities bigger than 100 MVA the nominal connection voltage is bigger than 50 kV.

Low-voltage generation units connected via a machine transformer to the high-voltage network shall be deemed to be connected to this high-voltage network.

When several generation units are placed at one and the same location, the conditions stated in this section shall apply to each individual generation unit.

Generation units dependent solely upon one or more energy sources that cannot be regulated shall be exempted from the obligation to provide reserve power and reactive power.

a. **Voltage/frequency operating limits**

**Operational situations in which the generator must remain connected to the network operator’s network (general)**

---

![Figure 1](image-url)
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

b. Reactive power control (power factor control, voltage regulation)

Generation units dependent solely upon one or more energy sources that cannot be regulated shall be exempted from the obligation to provide reserve power and reactive power.

Voltage control

All generation units with synchronous generator(s) or power electronic network coupling shall be equipped with and operated by a primary voltage control of which the voltage droop is adjustable between 0% and 10%. Depending on the local situation the network operator may require or allow a cos φ control for generation units. If a generation unit is not connected directly to the network operator's network, the voltage allocated during design to the generator or machine transformer shall be appropriate to the expected average operating voltage at the connecting point and the average voltage loss between the generator and the connecting point. The voltage variation at the generator location shall be derived from the voltage variation at the connecting point.

Power factor control

All generation units connected to networks at a voltage of 50 kV and higher shall be capable of operating at a power factor between 1.0 and 0.8 (lagging) measured at the generator terminals.

c. Other requirements

A.8.2 Regulatory aspects of generation connection to the grid

Overview of access to the grid

Electricity generated from renewable energy sources is granted access to the grid according to the general provisions of energy law and according to non-discriminatory principles. There aren’t any special regulations for renewable energy sources. A preferential access or transmission of electricity from renewable energy sources does not exist.

Statutory provisions

- Elektriciteitswet 1998
- Netcode Voorwaarden als bedoeld in artikel 31, lid 1, sub a van de Elektriciteitswet 1998 (Netcode)
- TarievenCode Elektriciteit. Gewijzigd vastgesteld door de Raad van Bestuur van de NMa bij besluit van 10 juli 2007, nr. 102674/6 (TarievenCode Elektriciteit)

These provisions are of a general nature. There aren’t any special regulations for electricity generated from renewable energy sources.

<table>
<thead>
<tr>
<th>Elektriciteitswet 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Created: 30.11.2007 Name (English)</td>
</tr>
<tr>
<td>Type of law</td>
</tr>
<tr>
<td>Future amendments</td>
</tr>
<tr>
<td>Purpose</td>
</tr>
<tr>
<td>Relation to renewable energy</td>
</tr>
</tbody>
</table>

Netcode Voorwaarden als bedoeld in artikel 31, lid 1, sub a van de Elektriciteitswet 1998 (Netcode)

<table>
<thead>
<tr>
<th>Created: 30.11.2007 Name (English)</th>
<th>Gridcode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviated form</td>
<td>Netcode</td>
</tr>
<tr>
<td>Type of law</td>
<td>Legal provision subject to Art. 31 Elektriciteitswet, enacted by the regulative authority.</td>
</tr>
<tr>
<td>Purpose</td>
<td>Regulating connection and access to the grid</td>
</tr>
</tbody>
</table>

Link to full text of legal source (Dutch)
http://www.dte.nl/images/NETCODE%20per%2020070205%20def_tcm7-106161.pdf
Link to English version
http://www.dte.nl/images/ENG_NETCODE%20per%2004092007%20def_tcm7-111134.pdf

TarievenCode Elektriciteit. Gewijzigd vastgesteld door de Raad van Bestuur van de NMa bij besluit van 10 juli 2007, nr. 102674/6 (TarievenCode Elektriciteit)
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

| Created: | Tariffcode electricity |
| 30.11.2007 | (English) |
| TarievenCode Elektriciteit |
| Type of law | Legal provision subject to Art. 31 Elektriciteitswet, enacted by the regulative authority. |
| Future amendments | The code is subject to a review at least once a year. |
| Purpose | Regulating grid usage fees. |

Link to full text of legal source (Dutch)
http://www.dte.nl/images/Tarievencode%2C%20versie%20juli%202007_tcm7-104736.pdf

The plant operator is entitled to connection to the grid on the part of the grid operator by contract. The grid operator is obliged to enter this contract (Art. 23 Abs.1 Elektriciteitswet). There aren’t any privileges for plants generating electricity from renewable energy sources, e.g. in terms of a priority connection.

Legal basis/addresses: contractual basis.

The plant operator is entitled to connection to the grid on the part of the grid operator by contract. The grid operator is obliged to conclude the contract according to non-discriminative criteria (§ 23 Abs.1 Elektriciteitswet).

Entitled party: Every one, though as a rule the plant operator, is entitled to connection to the grid, if he/she has concluded a contract on connection to the grid with the grid operator. The grid operator is obliged to conclude the contract on request (Art. 23 par.1 Elektriciteitswet).

Obligated party: The party obligated to connection to the grid is the grid operator who has concluded a contract with the plant operator. The grid operator is obliged to conclude the contract on request (Art. 23 par.1 Elektriciteitswet).

Priority to renewable energy: Non-discrimination.

The grid operator is obliged to expand his grid according to general principles (Art. 16 Elektriciteitswet). Plants generating electricity from renewable energy sources are not given priority.

Legal basis/addresses
A specific claim for grid expansion does not exist. The grid operator is rather obliged to expand his grid according to general principles (Art. 16 Elektriciteitswet). The regulative authority may inform the Minister of Economic Affairs if it suspects the grid operator to be unable or become unable to provide the grid capacity necessary for granting access to the grid. The Ministry of Economic Affairs can subsequently request the grid operator to satisfy his duties (Art. 22 Elektriciteitswet).

Priority to renewable energy: Non-discrimination.

A specific claim for grid expansion does not exist.

Arising/enforcement of a claim
A specific claim for grid expansion does not exist.

Funding
The costs of expansion of the grid are proportionally borne by the fees which the national grid operator charges for usage of the grid (Art. 27 ff. Elektriciteitswet). The grid operators, electricity producers and big industrial electricity consumers are obliged to pay these costs.

**Plant operator:** The costs of connection to the grid are borne by the plant operator. For this reason, the grid operator charges the plant operator a lump sum for establishing a grid connection. The amount of this charge is determined by the Tarievencode (Art. 23 Abs.1 i.V.m. Art. 27 ff. Elektriciteitswet).

**A.8.3 Regulatory and financial aspects of grid expansion**

The contract on access to the grid and grid usage may also include the plant operator’s entitlement to grid expansion, if this is necessary to guarantee access to or usage of the grid. However, apart from rights deriving from the contract, the plant operator is not entitled to grid expansion on the part of the grid operator. The grid operator is obliged to expand his grid according to general principles (Art. 16 Elektriciteitswet). Plants generating electricity from renewable energy sources are not given priority.

**Legal basis/addresses**
A specific claim for grid expansion does not exist. The grid operator is rather obliged to expand his grid according to general principles (Art. 16 Elektriciteitswet). The regulative authority may inform the Minister of Economic Affairs if it suspects the grid operator to be unable or become unable to provide the grid capacity necessary for granting access to the grid. The Ministry of Economic Affairs can subsequently request the grid operator to satisfy his duties (Art. 22 Elektriciteitswet).

**Priority to renewable energy:** Non-discrimination.

A specific claim for grid expansion does not exist.

**Arising/enforcement of a claim**
A specific claim for grid expansion does not exist.

**Funding**
The costs of expansion of the grid are proportionally borne by the fees which the national grid operator charges for usage of the grid (Art. 27 ff. Elektriciteitswet). The grid operators, electricity producers and big industrial electricity consumers are obliged to pay these costs.

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

A.9 POLAND

A.9.1 Grid access requirements for (wind) generators at transmission level

a. Low voltage/ Fault ride through capability

A wind power generator shall remain connected to the Transmission System for Transmission System voltage dips and voltage variations on one or all phases, at the PCC, as shown in figure 1.

![Figure 1: Fault Ride-Through Capability of Wind Power Generators](image)

b. Voltage/frequency operating limits

A WPP must have the capability to:

a) operate continuously for frequencies within the range of 49.5 Hz to 50.5 Hz, and for voltages between 95…111% \(U_r\);

b) remain connected to the Transmission System for a duration of minimum 30 minutes at Transmission System Frequencies within the range 48.5 Hz to 49.5 Hz and for an output power \(P>90\% P_{\text{available}}\);

c) remain connected to the Transmission System for a duration of minimum 20 minutes at Transmission System Frequencies within the range 48.5 Hz to 48.5 Hz and for an output power \(P>85\% P_{\text{available}}\);

d) remain connected to the Transmission System for a duration of minimum 10 minutes at Transmission System Frequencies within the range 47.5 Hz to 48 Hz and for an output power \(P>80\% P_{\text{available}}\);

e) reduce its output active power for frequencies between 50.5 Hz and 51.5 Hz;

f) required to disconnect within \(t<300\) ms when the frequency is over 51.5 Hz.

At frequency below 47.5 Hz disconnection is permitted.

Constant power reduction rate down to \(P=0\% P_r\) at 50.5 Hz and a rise up to 51.5 Hz or by disconnection of single wind turbine.

c. Reactive power control

The WPP must be able to provide reactive power control for an active power \(0<P<P_{\text{rated}}\). Inside this interval it should be able to adjust its power factor between \(0.975_{\text{inductive}}\) and \(0.975_{\text{capacitive}}\).
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

A.10 PORTUGAL

A.10.1 Grid access requirements for (wind) generators at transmission level
Information only available in Portuguese.

a. Low voltage/ Fault ride through capability

b. Voltage/frequency operating limits

c. Reactive power control (power factor control, voltage regulation)

d. Other requirements

A.10.2 Regulatory aspects of generation connection to the grid

Legal basis/ addressees

- contractual basis

Operators of plants generating renewable-energy-sourced electricity are contractually entitled against the grid operator to connection of their system to the grid. The grid operator is obligated to enter into a contract on connection to the grid ("obligation to enter into a contract", Item 4 and 5 DL 312/2001).

Entitled party: The person entitled is the plant operator (Item 4 DL 312/2001).

Obligated party: The person obligated is the grid operator (Item 5 DL 312/2001).

Priority to renewable energy

- Non-discrimination

As a rule, connection to the grid shall be granted according to the principle of non-discrimination. Renewable-energy-sourced electricity is not granted priority connection. However, besides acting according to the principle of equal treatment, the grid operator shall take into account the aims of the national energy policy, among them the use of renewable energy, when deciding on which system to connect to the grid (Item 6, 13 DL 312/2001).

Capacity limits

Capacity limits may be imposed only in case of capacity overload. In such a case, one of the following measures shall be taken (Art. 6 DL 312/2001):

- General expansion of the grid. If the grid capacity is overloaded, the grid operator shall implement a plan for the expansion of the grid (Items 7 and 8 DL 312/2001). To this aim, the grid operator and all plant operators interested shall draft an investment plan and submit it to the Minister of Economics, who is responsible for authorising this plan. The plan shall comply with the National Energy Plan, especially with its provisions on renewable energy, and help develop the electricity grid in Portugal.

- Early expansion of the grid. A plant operator may apply for an early expansion of the grid, if the connection of his system requires an expansion.

- Selection of several applicants for connection. If several operators apply for connection to the same connection point without the number of receive lines being sufficient, the grid operator shall select the plant operator to be connected according to the criteria of Item 13 DL 312/2001. This Order provides for a hierarchy of criteria for decision-making to be applied by the grid operator, who shall respect the principle of equal treatment when making a decision. Environmentally sustainable generation of electricity through the use of renewable energy is among the most important criteria to be taken into account.

Limitations/deadlines

The connection of the system shall commence within 18 months after the grid operator's consent to connect the system. The parties in question agree on the start of connection works in the contract (Item 17f. DL 312/2001).

Arising/enforcement of a claim

The circumstances in which a claim arises depend on the contractual terms. Violations of the contract carry a penalty (Art. 20 DL 312/2001).

Funding
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

Plant operator: The plant operator whose plant is to be connected to the grid shall establish an additional connection to the grid. This additional connection is deemed a part of the entire grid; yet, the plant operator shall bear the cost in full (Item 3 DL 189/88).

Distribution mechanism: Statutory law does not provide for a mechanism allowing for the cost of connection to the grid to be passed on.

A.10.3 Regulatory and financial aspects of grid expansion

Legal basis/ addressees

- contractual basis

The contract may give rise to a claim for expansion of the grid, if the plant operator applies for an early expansion of the grid in order to be able to connect his plant (Item 6 DL 312/2001). In general, plant operators are not entitled to an expansion of the grid. Yet, the grid operator has the obligation to expand his grid to comply with general standards. The plan of expansion shall be in line with the National Energy Plan and shall be authorised by the Minister of Economics (Items 7, 8 DL 312/2001).

Entitled party: The contract may give rise to a claim for expansion of the grid, if the plant operator applies for an early expansion of the grid in order to be able to connect his plant (Item 6 DL 312/2001). The grid operator is obligated to expand the grid to comply with general standards, without the plant operator being entitled to it.

Obligated party: The grid operator that has submitted a detailed investment plan to the Minister of Economics is obligated to expand his grids (Items 7, 8 DL 12/2001).

Priority to renewable energy

- Non-discrimination

As regards the expansion of the grid, renewable-energy-sourced electricity is not granted priority (Items 6, 13 DL 312/2001).

Limitations/deadlines

The contractual terms may specify deadlines for an early expansion of the grid.

Arising/enforcement of a claim

The circumstances in which a claim arises depend on the contractual terms.

Funding

Grid operator: In general, the grid operator shall bear the cost of a grid expansion (Items 7, 8 DL 312/2001).

Plant operator: The cost of a grid expansion shall be borne by the plant operator, if he has applied for an early expansion of the grid to be able to connect his plant to the grid (Item 6 DL 312).

Distribution mechanism: Statutory law does not provide for a distribution mechanism.
A.11 ROMANIA

A.11.1 Grid access requirements for (wind) generators at transmission level

All generators connecting to the transmission system are required to comply with the grid code. The grid code was originally developed with synchronous generators in mind. Since wind turbine generators (WTG) do not have the same characteristics as synchronous generators, it was considered appropriate to develop a new set of grid code provisions specifically for the wind power plants connected to the grid in order to create a set of minimum criteria that ensure both the well functioning of the electrical power system and also the conditions for installing a total capacity as high as possible in such power plants. The technical regulation project (which is on its way of being approved) cited previously represents a completion brought to Chapter 5 of the TECHNICAL TRANSMISSION GRID CODE: Transmission Grid Connection Requirements. This Technical Regulation Project applies to the interactions between the Grid Operator and the users that ask to interconnect wind power plants to the electrical grids of public interest.

For wind power plants with an installed capacity above 10 MW the requirements are as it follows.

a. Low voltage/Fault ride through capability

A wind power generator shall remain connected to the Transmission System for Transmission System voltage dips and voltage variations on one or all phases, at the grid interconnection point, as shown in figure 1.

![Fault Ride Through Capability of Wind Farm Power Stations](image)

**Figure 1: Fault Ride-Through Capability of Wind Power Generators**

Also, during the voltage dips the Wind Power Plant (WPP) must provide Active Power in proportion to the retained voltage and must maximise the reactive current injected to the Transmission System without exceeding the WPP limits. The WPP must be able to provide the maximum reactive current shall continue for at least 3 s.

From the moment of transmission system voltage recovery within the normal operating limits, the WPP must produce its whole available active power as quickly as possible and with a variation gradient of minimum 20% of the installed capacity per second (MW/s).

b. Voltage/frequency operating limits

A WPP must be able to produce continuously, in the interconnection point, simultaneously the maximum active power and maximum reactive power that correspond to the weather conditions, and according to the equivalent P-Q diagram for which the WPP received its authorization, within the frequency range of 49.5-50.5 Hz and in the allowed voltage range.

A WPP must have the capability to:

a) operate continuously for frequencies within the range of 47.5 Hz to 52.0 Hz;
b) remain connected to the Transmission System at Transmission System Frequencies within the range 47.0 Hz to 47.5 Hz for a duration of minimum 20 seconds;
c) remain connected to the Transmission System during rate of change of Transmission System Frequency of values up to and including 0.5 Hz per second;
d) operate continuously at a voltage at the grid interconnection point comprised in the interval 0.90 ÷ 1.10 U_n.

A WPP must remain in operation at:

a) frequency variations within the range of 49.5 ÷ 47.5 Hz. At the decrease of the frequency below 49.5 Hz, a linear diminishment of the available active power is allowed, proportional to the frequency deviation;
b) frequency variations with a speed of up to 0.5 Hz per second and/or voltage variations between 0.90 ÷ 1.10 U_n.

Also, the operation at abnormal voltages or frequencies must not lead to a reduction of the WPP’s available active power with more than 20%.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

c. **Active power control**

A WPP shall be provided with an Active Power Control System with Frequency Response (automatic f/P control). This control system will act according to a frequency/active power response curve that is shown in Figure 2, where \( P_d \) represents the available active power. Points ‘A’, ‘B’, ‘C’, ‘D’ and ‘E’ depend on a combination of the Transmission System frequency, the active power that can be produced by the WPP and Active Power Control Set-point settings that limit the active power within the intervals: A (50-47 Hz), B (50-47 Hz), C (50-52 Hz), DE (50-52 Hz). The position of these points must be controllable according to the grid operator’s requirements with an error of maximum ±10 mHz. The frequency measurement error must not exceed ±10 mHz.

If the frequency’s value reaches a higher value than the one of the “D-E” segment on the characteristic curve illustrated in figure 2, it is allowed to disconnect the WPP. The way the WPP is put again into operation is decided by the TSO.

At the frequency variations from the National Electrical Power System, the WPP must have the capability to:

- a) ensure the reduction of the active power with at least 40% of the installed capacity per Hz at the rise of the frequency above 50.2 Hz;
- b) ensure the rise of the active power up to the maximum limit of the available active power, at the frequency drop below 49.8 Hz.

There must be the possibility to limit the active power produced by a WPP must at a reference value. The size of the reference value must be set locally or automatically received from distance, within the interval between the technical minimum power and the installed capacity of the WPP. The WPP must ensure the active power control at the connection point with a precision of ±5% of the installed capacity (as a 10-minute average power).

During normal operation the WPP must have the ability to:

- a) set the linear growth/reduction ramp rates of the produced active power at the value asked by the grid operator (MW/min);
- b) reduce, at the grid operator’s request, the active power output at the requested value (including a shut-down) while respecting the load/unload ramp rate. The active power ramp rate must be respected both for natural power variation (the intensification of the wind speed) and for variations of the reference power.

The power ramp rate setting must be done in a range between 10% of the installed capacity per minute and the maximum allowed ramp rate, given by the manufacturer.

If a wind power generator has tripped due to the wind speed exceeding the limits given by the manufacturer, the generator must be able to reconnect when the wind speed enters again the normal range.

---

d. **Reactive power control**

At values of the voltage in the connection point, within the allowed voltage range, the reactive power produced/absorbed by a WPP must be continuously controlled according to a power factor situated at least within the range of 0.95 capacitive and 0.95 inductive.

The WPP must be able to perform the automatic voltage-reactive power control at the Point of Common Coupling (PCC) in all of the following ways:

- a) voltage control;

---

**Figure 2: The WPP’s active power variation with the frequency**

The modification of the produced active power due to frequency variations, will be made as much as possible by proportionally modifying the produced active power by each group of the WPP, and not by starting and stopping groups. The response speed of each operating wind power generator must be at least 60% of the nominal power per minute (MW/min).
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

b) control of the reactive power exchanged with the National Electric Power System;

c) power factor control.

The detailed terms regarding the voltage and reactive power control are decided by the grid operator through the technical connection notice.

The voltage control system’s response speed must be of minimum 95% of the available reactive power per second.

During normal operation of the grid, the WPP must not produce at the connection point fast voltage variations higher than ±5% of the nominal voltage.

The connection solution of the WPP must consider ways of avoiding the islanding of the WPP, inclusive by using protections that disconnect the WPP in such a situation.

A.12 SPAIN

A.12.1 Grid access requirements for (wind) generators at transmission level

In Spain the Grid Code is divided in different parts, all of them approved by the Government (Royal Decree or Ministerial Order). These are the ones related to wind generation:

- R.D. 436/2004 (March 12th, 2004) establishing the juridical and economical regime for renewable power generation and cogeneration

- P.O. 12.1 (February 11th, 2005) concerning the access requests for the connection of new power generation (all types of generation)

- P.O. 12.2 (February 11th, 2005) concerning the minimum requirements on design, equipment, operation, security and commissioning of new power generation (all types of generation)

- R.D. 1454/2005 (December 2nd, 2005) establishing that wind power installations whose power is higher than 10 MW shall be associated to a control centre that will be its interlocutor to the TSO

- P.O. 12.3 (October 4th, 2006) establishing the response requirements of wind power generation to network voltage dips

- P.O. 3.7 (October 4th, 2006) establishing how the non manageable Renewable Generation Programs are to be made

The R.D. 436/2004 establishes that authorisations for renewable power generation will be governed from the general norms that apply to all electric power generation installations. The R.D. 436/2004 establishes specifically for wind power installations:

- if they include equipment to contribute to continuity of supply the wind power operators will be entitled to receive a special retribution

- their protective systems must respect the minimum requirements established by the TSO

The Royal Decree 436/2004 states that operators of older machines will receive the market price for their power plus a bonus based on whether and how well the machines
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

support the grid. In recent years the additional payment was capped at 2.6548 euro cents per kilowatt-hour.

This is then developed in P.O. 12.3.

The P.O. 12.1 regulates the access and connection requirements of new installations (all types):

- access right will be restricted only because of the lack of necessary capacity justified for criteria of security, regularity or quality of supply
- TSO will establish the access capacity in a point as the maximum simultaneous total production that can be injected on that point, according to established criteria

In other terms, access cannot be denied by the TSO.

The P.O. 12.2 establishes the minimum design requirements, equipment, operation security and commissioning for generators which have:

- to respect conditions of frequency and voltage in permanent state
- to respect regulation about quality levels
- to bear without damage and without disconnection the values established in the previous regulation
- to bear without disconnection the voltage dips associated to short circuits correctly cleared, voltage imbalances and short interruptions of supply

The R.D. 1454/2005 establishes that all renewable power generation units having a capacity over 10 MW must be associated to a control centre that will be its interlocutor with the TSO. In this way, the TSO will be able to control directly wind power generation installations sending orders from its control system to the control system of the generator, if these installations satisfy the TSO requirements. Generation control by the TSO (REE) involves:

- wind plant to REE - capability of wind plants for receiving real time info from all wind plants (production, voltage, connectivity, wind speed, and so on)
- REE to wind plant - capability of wind plants for receiving and executing TSO’s instructions (production control, provision of system services)

For security and efficiency, this interaction between the TSO and wind plants cannot be individual but via control dispatch centres with control over a number of plants. Due to the large number of plants, agents and nodes involved, as well as specific technical requirements, there has been the need to create a general wind generation control centre supervising the different control dispatch centres. This is the CECRE generation control centre.

The P.O. 12.3 addresses fault ride-through capabilities and reactive power/voltage control during faults and it applies to wind power plants connected to the main transmission grid. Concerning the fault ride-through capability, the P.O. 12.3 establishes the minimum requirements of the response to voltage dips of wind power plants. The wind turbines shall remain connected to the system in case of faults in the network (3/2/1 phase short circuits), allowing the protection system to clear the fault, for a voltage profile as shown in Fig. 1. There is no specification regarding the procedure for calculation of voltages during the fault.

Fig. 1. Fault ride-through requirement for wind turbines in the Spanish transmission grid.

Concerning the design, the P.O 12.3 requires generators and equipment to be able to carry currents during the fault. Concerning the operation, the P.O. 12.3 requires an appropriate protection adjustment.
The wind power plants are required to stop drawing the reactive power within 100 msec of a drop voltage and to be able to inject reactive power within 150 msec of grid recovery as shown in Fig. 2.

Fig. 2. Grid support during faults by reactive current injection as specified in the P.O. 12.3.

ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

A.12.2 Regulatory aspects of generation connection to the grid

a. Legal basis/addressers

• statutory basis

Plant operators are contractually entitled against the grid operator to the connection of a system generating renewable-energy-sourced electricity to the grid (art. 17 Loi n°2000-108). The plant operator and the grid operator shall lay down the technical conditions for connection in a contract, which shall comply with the model contract provided by the Ministry of Energy and Mining (art. 16 RD 661/2007). Before the contract may be concluded, the plant operator shall submit to the grid operator the official authorisation of the power system and, if the operation of the system requires special devices, of the connection devices that link the system to the point of connection of the transmission and distribution grid (art. 16 par. 2 RD 661/2007).

Entitled party: The persons entitled are operators of plants that come under the so-called special regulation ("Régimen Especial"), (art. 17 RD 661/2007 in connection with art. 2 par. 2 nr. 2 b RD 661/2007). The following power systems have a special status:

• Technologies. The systems’ primary source of energy shall be a renewable source of energy like solar or wind energy as defined by statutory law (art. 2 par. 1 nr. 2 b RD 661/2007).

• Classification by the authorities. Systems shall be classified as coming under the special regulation by official notice (art. 6, 8, 14 par. 1 RD 661/2007).

• Connection to a central control system. All systems that generate electricity as specified by the special regulation and whose capacity exceeds 10 MW shall be connected to a central control system, which shall be the interface to the plant operator. The control system shall provide real-time system information and make sure that the plant operator's instructions are implemented in such a way as to guarantee the reliability of the electric system.

Systems need not be listed in the register of systems (art. 9 RD 661/2007) in order to be awarded the status of system under the special regulation.

Obligated party: The person obligated is the grid operator (art. 17 RD 661/2007).

Priority to renewable energy

• Priority to renewable energy

Renewable energy systems shall be connected at a priority, i.e. prior to conventional power systems (art. 17.e, Annex XI RD 661/2007).

Limitations/deadlines

Systems shall be connected to the grid after the contract on the technical conditions has been concluded (art. 16 RD 661/2007), the bank guarantee has been put and the Ministry of Energy and Mining has authorised the application for connection to the grid (art. 53, 59 RD 1955/2000).

Arising/enforcement of a claim

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

The claim arises at the date on which the construction of the system is completed and the system has been classified as system under the special regulation (art. 17 par. 1 RD 661/2007). The status of system under the special regulation enters into force on the date on which the notice on classification is issued by the authority in charge (art. 14 par. 1 RD 661/2007).

**Funding**

**Plant operator:** The plant operator shall bear the costs of connection to and a possible expansion of the grid (Annex XI nr. 8, 9 RD 661/2007). Furthermore, operators of plants whose capacity exceeds 10 MW and which shall be connected to a control system shall bear the costs of installation and maintenance of the control systems, including installation and maintenance of the communication lines to the grid operator (art. 18 RD 661/2007).

**Distribution mechanism:** Plant operators may not pass on the cost of connection to the grid.

**A.12.3 Regulatory and financial aspects of grid expansion**

The plant operator may be contractually entitled against the grid operator to an expansion of the grid, if the connection of his system to the grid requires an expansion (entitlement arises from the obligation to bear the cost as specified by Annex XI nr. 9 RD 661/2007). However, the grid operator is not directly obligated to expand the grid. Yet, the grid operator has the obligation to expand his grid according to general criteria specified by energy law (art. 8, -16 RD 1955/2000). Possible individual claims for an expansion may arise if the connection of a system to the grid requires an expansion (Annex XI nr. 9 RD 661/2007).

**Entitled party:** A plant operator may be entitled to an expansion, if the expansion is necessary to connect his system and this claim has been laid down in the contract.

**Obligated party:** The contract concluded with the plant operator may oblige the grid operator to expand his grid. As far as the grid operator's general obligation to expand the grids is concerned, he shall elaborate a grid expansion plan in co-operation with the Ministry of Economy every four years. The plan shall take into account the number of existing and new systems and the opinions of interested persons (art. 11 RD 1955/2000).

**Priority to renewable energy**

- Non-discrimination

The grid shall be expanded according to the principle of non-discrimination. Renewable-energy-sourced electricity is not given priority.

**Limitations/deadlines**

Time limitations and deadlines of an expansion of the grid depend on the terms of the contract.

**Arising/enforcement of a claim**

The circumstances in which an individual claim arises depend on the conditions of the contract.

**Funding**

**Grid operator:** The cost of a general expansion of the grid is borne by the grid operator (Annex XI RD 661/2007).

**Plant operator:** If the expansion is to the benefit of the plant operator only, he shall bear the cost of the expansion (Annex XI RD 661/2007).

**Distribution mechanism:** Statutory law does not provide for distribution mechanisms.
A.13 UK

A.13.1 Grid access requirements for (wind) generators at transmission level

It is defined as Intermittent Power Source the primary source of power for a Generating Unit that can not be considered as controllable, e.g. wind, wave or solar. Special rules apply to the Scottish generators.

a. Low voltage / Fault ride through capability

CC.6.3.15 Fault Ride Through
(a) Short circuit faults at Supergrid Voltage up to 140ms in duration
(i) Each Generating Unit, DC Converter, or Power Park Module and any constituent Power Park Unit thereof shall remain transiently stable and connected to the System without tripping of any Generating Unit, DC Converter or Power Park Module and / or any constituent Power Park Unit, for a close-up solid three-phase short circuit fault or any unbalanced short circuit fault on the GB Transmission System operating at Supergrid Voltages for a total fault clearance time of up to 140 ms.
(ii) Each Generating Unit or Power Park Module shall be designed such that upon both clearance of the fault on the GB Transmission System as detailed in CC.6.3.15 (a) (i) and within 0.5 seconds of the restoration of the voltage at the Grid Entry Point to the minimum levels, Active Power output shall be restored to at least 90% of the level available immediately before the fault. Once the Active Power output has been restored to the required level, some Active Power oscillations may be acceptable.

During the period of the fault as detailed in CC.6.3.15 (a) (i) each Generating Unit or Power Park Module shall generate maximum reactive current without exceeding the transient rating limit of the Generating Unit or Power Park Module and / or any constituent Power Park Unit.
(iii) Each DC Converter shall be designed to meet the Active Power recovery characteristics as specified in the Bilateral Agreement upon clearance of the fault on the GB Transmission System as detailed in CC.6.3.15 (a) (i).
(b) Supergrid Voltage dips greater than 140ms in duration

In addition to the requirements of CC.6.3.15 (a) each Generating Unit or Power Park Module and / or any constituent Power Park Unit, each with a Completion Date on or after the 1 April 2005 shall:
(i) remain transiently stable and connected to the System without tripping of any Generating Unit or Power Park Module and / or any constituent Power Park Unit, for balanced Supergrid Voltage dips and associated durations anywhere on or above the heavy black line shown in Figure 5.
(ii) provide Active Power output, during Supergrid Voltage dips as described in Figure 5, at least in proportion to the retained balanced voltage at the Grid Entry Point (or the retained balanced voltage at the User System Entry Point if Embedded) except in the case of a Non- Synchronous Generating Unit or Power Park Module where there has been a reduction in the Intermittent Power Source in the time range in Figure 5 that restricts the Active Power output below this level and shall generate maximum reactive current without exceeding the transient rating limits of the Generating Unit or Power Park Module and any constituent Power Park Unit; and,
(iii) restore Active Power output, following Supergrid Voltage dips as described in Figure 5, within 1 second of restoration of the voltage at the Grid Entry Point to the minimum levels, to at least 90% of the level available immediately before the occurrence of the dip except in the case of a Non-Synchronous Generating Unit or Power Park Module where there has been a reduction in the Intermittent Power Source in the time range in Figure 5 that restricts the Active Power output below this level. Once the Active Power output has been restored to the required level, some Active Power oscillations may be acceptable.

(c) Other Requirements
(i) In the case of a Power Park Module (comprising of wind-turbine generator units), the requirements in CC.6.3.15(a) and CC.6.3.15(b) do not apply when the Power Park Module is operating at less than 5% of its Rated MW or during very high wind speed conditions when more than 50% of the wind turbine generator units in a Power Park
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

Module have been shut down or disconnected under an emergency shutdown sequence to protect User’s Plant and Apparatus.

(ii) In addition to meeting the conditions specified in CC.6.1.5(b) and CC.6.1.6, each Non-Synchronous Generating Unit or Power Park Module with a Completion Date after 1 April 2005 and any constituent Power Park Unit thereof will be required to withstand, without tripping, the negative phase sequence loading incurred by clearance of a close-up phase-to-phase fault, by System Back-Up Protection on the GB Transmission System operating at Supergrid Voltage.

b. Voltage/frequency operating limits

CC.6.3.3 Each Generating Unit, DC Converter, Power Park Module and/or CCGT Module must be capable of
(a) continuously maintaining constant Active Power output for System Frequency changes within the range 50.5 to 49.5 Hz; and
(b) (subject to the provisions of CC.6.1.3) maintaining its Active Power output at a level not lower than the figure determined by the linear relationship shown in Figure 2 for System Frequency changes within the range 49.5 to 47 Hz, such that if the System Frequency drops to 47 Hz the Active Power output does not decrease by more than 5%. In the case of a CCGT Module, the above requirement shall be retained down to the Low Frequency Relay trip setting of 48.8 Hz, which reflects the first stage of the Automatic Low Frequency Demand Disconnection scheme notified to Network Operators under OC6.6.2. For System Frequency below that setting, the existing requirement shall be retained for a minimum period of 5 minutes while System Frequency remains below that setting, and special measure(s) that may be required to meet this requirement shall be kept in service during this period. After that 5 minutes period, if System Frequency remains below that setting, the special measure(s) must be discontinued if there is a materially increased risk of the Gas Turbine tripping. The need for special measure(s) is linked to the inherent Gas Turbine Active Power output reduction caused by reduced shaft speed due to falling System Frequency.

(c) For the avoidance of doubt in the case of a Generating Unit or Power Park Module using an Intermittent Power Source where the mechanical power input will not be constant over time, the requirement is that the Active Power output shall be independent of System Frequency under (a) above and should not drop with System Frequency by greater than the amount specified in (b) above.

(d) A DC Converter Station must be capable of maintaining its Active Power input (i.e. when operating in a mode analogous to Demand) from the GB Transmission System (or User System in the case of an Embedded DC Converter Station) at a level not greater than the figure determined by the linear relationship shown in Figure 3 for System Frequency changes within the range 49.5 to 47 Hz, such that if the System Frequency drops to 47.8 Hz the Active Power input decreases by more than 60%.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

D3.1.1 Review of existing methods for transmission planning and for grid connection of wind power plants

CC.6.3.4 At the Grid Entry Point the Active Power output under steady state conditions of any Generating Unit, DC Converter or Power Park Module directly connected to the GB Transmission System should not be affected by voltage changes in the normal operating range specified in paragraph CC.6.1.4 by more than the change in Active Power losses at reduced or increased voltage. The Reactive Power output under steady state conditions should be fully available within the voltage range ±5% at 400kV, 275kV and 132kV and lower voltages.

c. Reactive power control (power factor control, voltage regulation)

CC.6.3.2 (a) All Synchronous Generating Units must be capable of supplying Rated MW at any point between the limits 0.85 Power Factor lagging and 0.95 Power Factor leading at the Synchronous Generating Unit terminals. The short circuit ratio of Synchronous Generating Units shall be not less than 0.5.
(b) Subject to paragraph (c) below, all Non-Synchronous Generating Units, DC Converters and Power Park Modules must be capable of maintaining zero transfer of Reactive Power at the Grid Entry Point (or User System Entry Point if Embedded) at all Active Power output levels under steady state voltage conditions. For Non-Synchronous Generating Units and Power Park Modules the steady state tolerance on Reactive Power transfer to and from the GB Transmission System shall be specified in the Bilateral Agreement.
(c) Subject to the provisions of CC.6.3.2(d) below, all Non-Synchronous Generating Units, DC Converters (excluding current source technology) and Power Park Modules (excluding those connected to the Total System by a current source DC Converter) with a Completion Date on or after 1 January 2006 must be capable of supplying Rated MW output at any point between the limits 0.95 Power Factor lagging and 0.95 Power Factor leading at the Grid Entry Point in England and Wales or at the HV side of the 33/132kV or 33/275kV or 33/400kV transformer for Generators directly connected to the GB Transmission System in Scotland (or User System Entry Point if Embedded). With all Plant in service, the Reactive Power limits defined at Rated MW at Leading Power Factor will apply at all Active Power output levels above 50% of the Rated MW output as defined in Figure 1. With all Plant in service, the Reactive Power limits defined at Rated MW at Leading Power Factor will apply at all Active Power output levels above 50% of the Rated MW output as defined in Figure 1. With all Plant in service, the Reactive Power limits will reduce linearly below 50% Active Power output as shown in Figure 1 unless the requirement to maintain the Reactive Power limits defined at Rated MW at Leading Power Factor down to 20% Active Power output is specified in the Bilateral Agreement. These Reactive Power limits will be reduced pro rata to the amount of Plant in service.

Figure 3

CC.6.3.4 At the Grid Entry Point the Active Power output under steady state conditions of any Generating Unit, DC Converter or Power Park Module directly connected to the GB Transmission System should not be affected by voltage changes in the normal operating range specified in paragraph CC.6.1.4 by more than the change in Active Power losses at reduced or increased voltage. The Reactive Power output under steady state conditions should be fully available within the voltage range ±5% at 400kV, 275kV and 132kV and lower voltages.

CC.6.3.2 (a) All Synchronous Generating Units must be capable of supplying Rated MW at any point between the limits 0.85 Power Factor lagging and 0.95 Power Factor leading at the Synchronous Generating Unit terminals. The short circuit ratio of Synchronous Generating Units shall be not less than 0.5.
(b) Subject to paragraph (c) below, all Non-Synchronous Generating Units, DC Converters and Power Park Modules must be capable of maintaining zero transfer of Reactive Power at the Grid Entry Point (or User System Entry Point if Embedded) at all Active Power output levels under steady state voltage conditions. For Non-Synchronous Generating Units and Power Park Modules the steady state tolerance on Reactive Power transfer to and from the GB Transmission System shall be specified in the Bilateral Agreement.
(c) Subject to the provisions of CC.6.3.2(d) below, all Non-Synchronous Generating Units, DC Converters (excluding current source technology) and Power Park Modules (excluding those connected to the Total System by a current source DC Converter) with a Completion Date on or after 1 January 2006 must be capable of supplying Rated MW output at any point between the limits 0.95 Power Factor lagging and 0.95 Power Factor leading at the Grid Entry Point in England and Wales or at the HV side of the 33/132kV or 33/275kV or 33/400kV transformer for Generators directly connected to the GB Transmission System in Scotland (or User System Entry Point if Embedded). With all Plant in service, the Reactive Power limits defined at Rated MW at Leading Power Factor will apply at all Active Power output levels above 50% of the Rated MW output as defined in Figure 1. With all Plant in service, the Reactive Power limits defined at Rated MW at Leading Power Factor will apply at all Active Power output levels above 50% of the Rated MW output as defined in Figure 1. With all Plant in service, the Reactive Power limits will reduce linearly below 50% Active Power output as shown in Figure 1 unless the requirement to maintain the Reactive Power limits defined at Rated MW at Leading Power Factor down to 20% Active Power output is specified in the Bilateral Agreement. These Reactive Power limits will be reduced pro rata to the amount of Plant in service.

Figure 3

CC.6.3.4 At the Grid Entry Point the Active Power output under steady state conditions of any Generating Unit, DC Converter or Power Park Module directly connected to the GB Transmission System should not be affected by voltage changes in the normal operating range specified in paragraph CC.6.1.4 by more than the change in Active Power losses at reduced or increased voltage. The Reactive Power output under steady state conditions should be fully available within the voltage range ±5% at 400kV, 275kV and 132kV and lower voltages.

c. Reactive power control (power factor control, voltage regulation)

CC.6.3.2 (a) All Synchronous Generating Units must be capable of supplying Rated MW at any point between the limits 0.85 Power Factor lagging and 0.95 Power Factor leading at the Synchronous Generating Unit terminals. The short circuit ratio of Synchronous Generating Units shall be not less than 0.5.
(b) Subject to paragraph (c) below, all Non-Synchronous Generating Units, DC Converters and Power Park Modules must be capable of maintaining zero transfer of Reactive Power at the Grid Entry Point (or User System Entry Point if Embedded) at all Active Power output levels under steady state voltage conditions. For Non-Synchronous Generating Units and Power Park Modules the steady state tolerance on Reactive Power transfer to and from the GB Transmission System shall be specified in the Bilateral Agreement.
(c) Subject to the provisions of CC.6.3.2(d) below, all Non-Synchronous Generating Units, DC Converters (excluding current source technology) and Power Park Modules (excluding those connected to the Total System by a current source DC Converter) with a Completion Date on or after 1 January 2006 must be capable of supplying Rated MW output at any point between the limits 0.95 Power Factor lagging and 0.95 Power Factor leading at the Grid Entry Point in England and Wales or at the HV side of the 33/132kV or 33/275kV or 33/400kV transformer for Generators directly connected to the GB Transmission System in Scotland (or User System Entry Point if Embedded). With all Plant in service, the Reactive Power limits defined at Rated MW at Leading Power Factor will apply at all Active Power output levels above 50% of the Rated MW output as defined in Figure 1. With all Plant in service, the Reactive Power limits defined at Rated MW at Leading Power Factor will apply at all Active Power output levels above 50% of the Rated MW output as defined in Figure 1. With all Plant in service, the Reactive Power limits will reduce linearly below 50% Active Power output as shown in Figure 1 unless the requirement to maintain the Reactive Power limits defined at Rated MW at Leading Power Factor down to 20% Active Power output is specified in the Bilateral Agreement. These Reactive Power limits will be reduced pro rata to the amount of Plant in service.
ANNEX: CONNECTION PRACTICES IN SELECTED EU COUNTRIES

A.13.2 Regulatory aspects of generation connection to the grid

Entitled party: Every operator of a plant generating electricity is entitled to connection to the grid, if he has concluded an agreement with the grid operator.

Obligated party: The person obliged to grant connection to the grid is the grid operator who supplies energy to the respective region and who has concluded an agreement with the plant operator.

Priority to renewable energy
- Non-discrimination

The grid operator is obliged to connect plants to his grid according to non-discriminative criteria. Electricity generated from renewable energy sources is not given priority.

Limitations/deadlines

Time requirements depend on the respective agreement. The grid operator may impose time limitations as long as he respects the principle of non-discrimination.

Arising/enforcement of a claim

The claim for connection to the grid arises at the date of the agreement. The plant operator can apply for the conclusion of this agreement even before the plant has been licensed and before its construction has been completed.

Funding

Plant operator: The costs resulting from the connection of a plant to the grid are borne by the plant operator. The latter is charged for these costs by the grid operator.

A.13.3 Regulatory and financial aspects of grid expansion

Legal basis/ addressees

The agreement between the grid operator and the plant operator may give cause for a claim if access to the grid can be granted through a grid expansion only. In addition, the grid operators are generally obliged to expand their grids in a sufficient way without the plant operators being entitled to it.

Entitled party: The persons entitled to a grid expansion are those operators of a power plant, who have concluded an agreement with the grid operator.
**Obligated party:** The person obliged to grant connection to the grid is the grid operator who supplies energy to the respective region and who has concluded an agreement with the grid operator.

**Priority to renewable energy**
- Non-discrimination

The grid operators are generally obliged to expand their grids. Renewable energy sources are not given priority.

**Capacity limits**

The scope and the limits of the claim for grid expansion depend on the provisions set out in the agreement.

**Limitations/deadlines**

Time limitations on the claim for grid expansion depend on the terms agreed upon. Delayed expansion of the grid generally constitutes a breach of contract and carries a penalty.

**Arising/enforcement of a claim**

The claim for a grid expansion arises at the date of agreement, unless access to the grid cannot be granted by other means.

**Funding**

The costs of a grid expansion are generally included in the costs of access to the grid. 73% of these costs are borne by the electricity consumers, while 27% are borne by the plant operators. In this manner, the grid operator can make financial provisions for a future grid expansion that might become necessary.