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The Impact of Renewable Energy Sources and Distributed Generation on Substation Protection and Automation

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Symbols and Abbreviations

AC: Alternating Current
ATP: Alternating Transient Program
AVR: Automatic Voltage Regulator
BCH: British Columbia Hydro
BOP: Blocking Overreach Protection
CARE: Clean Air Renewable Energy Coalition
CEA: Canadian Electricity Board
CCGT: Combined Cycle Generator Turbine
CHP: Combined Heat and Power
CML: Customer Minutes Lost
CRISP: Critical Infrastructure for Sustainable Power
DC: Direct Current
DER: Dispersed Energy Resources
DFIG: Doubly Fed Induction Generator
DG: Distributed generation/generator
DGCG: Distributed Generation Co-ordinating Group
DN: Distribution Network
DR: Distributed Resource
DNO: Distribution Network Operator
DSO: Distribution System Operator
DSM: Demand Side Management
DTI : Department of Trade and Energy (UK)
DTT: Direct Transfer Trip
EDF: Electricité de France
EDP: Distribuição Energia SA
EJP: Peak Day Load Shedding in France
EHV: Extra High Voltage
ENSG: Electricity Networks Strategy Group (UK)
EPS: Electricity Power Supply
ETR: Engineering Technical Report
EU: European Union
FRT: Fault Ride Through
GDEG: General Directorate for Energy and Geology
GDP: Gross Domestic Product
GHG: Green House Gases
HV: High Voltage
HVAC High voltage AC
HVDC High voltage DC
ICT: Information and Communication Technologies
IEC: International Electrotechnical Commission
IEEE: Institute for Electrical and Electronics Engineers
IPP: Independent Power Producer
LOM: Loss Of Mains
LNG: Liquid Natural Gas
LV: Low voltage
MEI: Ministry of Economy and Innovation
MTC: Million Tonnes of Carbon
MV: Medium Voltage

NEB: National Energy Board (Canada)
NEM: National Electricity Market (Australia)
NEMMCO: NEM Management Company (Australia)
NER: Australian National Electricity Rules (Australia)
NGET: National Grid Electricity Transmission
NVD: Neutral Voltage Displacement
PCC: Point of Common Coupling
PLL: Phase Locked Loop
PSS: Power System Stabilizer
POTT: Permissive Overreach Transfer Trip
PQ: Power Quality
PUTT: Permissive Underreach Transfer Trip
PV: Photovoltaic
PVI: Pre-Viability Information
R&D: Research and Development
RAS: Remedial Action Scheme
RES: Renewable Energy Resources
REN: Rede Eléctrica Nacional SA
RMS: Root Mean Square
ROCOF: Rate Of Change Of Frequency
RSCAD: Proprietary software from RTDS
RTE: Réseau de Transport Electricité
RTDS : Real Time Digital Simulator
RTU: Remote Terminal Unit
SAPS: Standalone Power Systems
SAS: Substation Automation System
SCADA: Supervisory Control and Data Acquisition
SCIG: Squirrel Cage Induction Generator
SDC: Sustainable Development Commission
SIPS: System Integrity Protection Schemes
SM: Synchronous Machine
SMES: Superconducting Magnetic Energy Storage
SN: Rated apparent power
SPS: Special Protection Scheme or System Protection Scheme
STATCOM: Static Synchronous Compensator
SVC: Static VAR Compensator
TN: Transmission Network
TSO: Transmission System Operator
UCTE: Union for the Co-ordination of Transmission of Electricity
UK: United Kingdom
UKGDS: United Kingdom Generic Distribution System
UTE: Standardisation Bureau of electric and Electronic systems in France
VDEW: German Electricity Association, trade association of the electricity supply
VHV: Very High Voltage
VS: Vector Shift
VT: Voltage Transformer
WAP: Wide Area Protection
WF: Wind Farms
WPP: Wind Power Producer
WT: Wind Turbines
WTG: Wind Turbine Generator

1 Executive Summary

There is evidence that power system infrastructure needs better planning. The urgent need for power grid management to allow more renewable sources has received huge media attention. The power grid is a complex dynamic system with a lot of uncertainties. The integration of renewable energy such as wind farms further adds complexity and challenges to the existing protection and automation at all voltage levels. A lot of efforts have gone into the advancement of protection and automation in distributed generation based on renewables to promote the interests of the electric power utilities, consumers, politicians and environmentalists.

In this report, guidelines, codes, regulations and practices with protection of DG in different countries will be covered. Future trends in islanding detection, intelligent power systems, wide-area protection applications, substation communications & automation and wind farm for network stability will also be considered.

1.1 Drivers for Change

Following the political drivers to mitigate the effects of climate change on a global scale and the international trend towards privatisation of the electricity supply industry, power systems are under immense scrutiny to enable the use of renewable energy sources while reducing the effects of centralised fossil fuel generation on carbon dioxide and toxic emissions. In Europe mandatory targets could mean that an increase of 34% of renewable energy sources are connected to the power networks of Europe leading up to the 2020 deadline. The increase of two-way power flows at sub-transmission and distribution level, the impact of intermittency and the freedom to connect to less than suitable parts of networks could all contribute to major instability and operational challenges for electrical network operators around Europe.

The impact of these regulated changes on the power network in general and substation protection and automation specifically will be profound. This is compounded by end users requirements for dependable, reliable and high quality power delivery to power ever increasing electronic lifestyles. This scenario is driving such initiatives as the European Technology Platform SmartGrids which has developed a holistic vision and road map to deliver a distributed architecture that is highly automated and driven by customer choices. Likewise, these drivers have also provided strong motivation for the work of this group.

1.2 Current Status of Distributed Generation

As the pressures of climate change issues combine with the concerns over security of supply, the level of penetration of Renewable Energy Sources (RES) and Distributed Generation[1] (DG) is set to increase dramatically over the next 30 years. The impact for power networks in general is already manifesting itself in the design and operation of both transmission and distribution systems. In particular, the effect on substation protection and automation has been profound, requiring new and innovative solutions to evolve in order to enable the connection of uncontrollable and predominantly intermittent sources of energy at various voltage levels.

Up until recently the existence of DG was very limited, and therefore, had little impact on the operation of the system as a whole. Consequently, the regulatory framework and the connection

[1] Different terms are used for distributed generation: embedded generation, cogeneration, dispersed energy sources, renewable energy sources, independent producers, etc. The common characteristic is that the output of these generators is not dispatchable or fully controllable. DG will be used throughout the document for simplicity.

requirements have been restrictive to protect the integrity of passive radial distribution systems. However, in the past few years a gradual change of attitudes has been observed and in many countries more supportive regulations have already been implemented or currently are under revision. Although the situation is generally improving, it is still far from being resolved as the majority of the proposed changes are not coordinated internationally.

One of the key factors influencing the speed of DG expansion is the global economy. Although, the international trend towards privatisation of the electricity supply industry has resulted in a fast, uninhibited expansion of privately owned DG in both distribution and transmission networks, this is not happening without consequences. There is potentially a conflict between the requirements of the power utility, whose primary concern is that of the security of its network, and the requirements of the DG whose primary objective is profit via the commercial production of electrical energy. Additionally, under deregulation, new plants are being built on more short-term, cost-based decisions. Long-term investments such as large-scale expensive power plants or advanced communication based protection and automation infrastructures are not favoured in deregulated markets where customers cannot be secured. As it is often difficult to resolve such conflicting interests, apart from the utilities and DG owners, this report is also aimed at the policy makers and legislative bodies whose decisions can make a fundamental impact on the future of DG and active networks. The restructured electricity market is not projected to stimulate renewable energy technologies unless required by government policies as it is foreseen that renewable resources will remain more costly than fossil fuel alternatives to at least 2015.[1]

The progressive increase in penetration levels and generator sizes, as well as the fluctuating nature of power and its dispersed locations, pose a number of technical challenges for the DNO/TSO relating to:

- Stability
- Voltage profile and voltage transients
- Congestion
- Balancing of active and reactive power (reserve requirements)
- Losses
- Fault Ride Through (FRT) capability
- Short circuit levels
- Power Quality
- Control and monitoring
- Protection co-ordination
- Islanding Detection
- Synchronisation

Specifically, those issues concerning protection, such as islanding detection, FRT, stability, etc. are dealt with in this report.

Additionally, special attention needs to be paid to the additional benefits which the presence of DG can potentially bring to the network operators. These benefits include enhanced load profile management, provision of reactive power to support voltage regulation, contribution to frequency control, improvement of the supply reliability to customers, to name but a few. Most of these valuable services and opportunities unfortunately come at high initial cost. However, the benefits can be substantial if the changes are introduced in a coordinated manner and according to the best practice. Additionally, the increased presence of power electronic based DGs will provide a natural asset for better control and stability of such networks through advanced control capabilities. Supported by the development of the communication infrastructure, intelligent power electronic devices can offer interesting opportunities to improve flexibility and response time to changing network conditions facilitating more real-time automation and adaptive protection to maintain system integrity.

The purpose of this report is to present guidelines on the requirements for protection, control and monitoring of DG which can address the primary concerns of both the utilities and the generators.

1.3 Aim, Objectives and Scope

This report primarily aims to identify the impact of renewable and distributed energy sources on the substation protection and automation. The best practice from around the globe is highlighted through the international review of DG connection solutions. This review forms a basis for identifying the future trends and possible solutions which will need to be adopted if power networks are to remain robust and resilient to the increasing consumer and environmental demands. The report seeks to improve the DG connection practices by contributing to the process of international standardisation, specifically in the area of power system protection and automation associated with DG.

As an initial basis, the best practice from around the globe has been collected to form an informative compendium of current methods and solutions for the connection of DG at transmission and distribution levels. Both protection and automation aspects are discussed and analysed leading to the conclusions and recommendations put forward to the readers by the working group. The intended audience includes primarily utility companies and generators but also, and possibly more importantly, the policy makers and regulatory bodies which can make a decisive contribution to the integration of DG.

The scope of the project covers particularly the connection of the large renewable generation (excluding nuclear) associated with the subtransmission and transmission (above 35 kV) power networks, although producers connected to Local Medium Voltage (MV) network (35 kV and below) are also considered in the report as reference because of the unclear limits in regulations and practices in some countries and due to the possible impact of their increasing penetration on the transmission system performance..

From the outset of this work it has become apparent that the vocabulary used to describe system voltage levels (EHV, HV, LV, etc.) is different in each country, and also differs from many of the defined standards including CIGRÉ. For instance in the UK distribution level is generally referred to as including what would be considered sub-transmission level in continental Europe. It is important that the reader understands these differences when reviewing the submissions from different countries. For ease of reference the definitions of the voltage levels in a number of countries are grouped together in section A.4 of Appendix A.

This report focuses on medium and large power plants because of their greater influence on the network performance, which include the following technologies and sources: synchronous rotating machines from diverse sources (hydro, gas, steam, CHP, CCGT, reciprocating engines, etc.), asynchronous wind turbines and converter based generators, such as full converter wind turbines and large PV installations. Microgeneration and energy storage systems (fuel-cells, batteries, flywheels, etc.) are not covered in this report.

Although, many other considerations associated with DG connection are also included, the report does not cover in detail the following aspects:

- control and stability
- protection practices for small-scale DG connected to the LV distribution system
- power quality
- voltage and frequency regulation
- economical considerations

1.4 Summary of Chapters

The report is structured to enable the reader to understand the various processes that were followed to arrive at the recommendations and conclusions within the scope of the project.

Chapter 2 considers the protection requirements in relation to the connection of DG's. The different aspects of the power systems influencing protection requirements are analysed, the protection functions commonly used for the connection of DG to network (interface protection and line protection) are the possible implications on utility protections (selectivity and sensitivity issues, reclosing co-ordination, etc.) are described. Finally, general country regulations for DG interconnection, specifically for wind power plants are presented. Finally, the chapter includes a comparative analysis of fault ride-through capability required in various countries.

Chapter 3 concentrates on the additional requirements for DG with respect to their control capabilities, monitoring and SCADA supervisory functions. The first part of the chapter presents a general overview of the current situation and state of the art in voltage and frequency control capabilities of wind farms. The second part describes some implementations and requirements in a few selected countries, including monitoring and control functions.

Chapter 4 considers power system islanding both inadvertent and intentional. In the first part a review of anti-islanding methods is presented together with the methodology for the protection performance assessment and the risk based approach to inadvertent sustained islanded operation. In the second part the requirements for intentional islanding are outlined and a number of the international projects and initiatives exploring potential benefits of intentional islanding are summarised.

Chapter 5 presents a comparative analysis under a protection perspective of the different practices and guidelines for the protection schemes and protection settings used in the connection of DG's in several countries. Some recommendations, derived from this comparison, are also outlined. Appendix D collects the specific practices of each country. The following aspects are described: prevailing generation technologies, main challenges and potential benefits and examples of typical connections. Appendix E includes a template that allows the reader to easily identify the salient differences of approach between each of the examples.

Chapter 6 identifies future trends and considers the challenges both technical and non technical for substation protection and automation with large scale integration of DG into the electricity network. New smart grid structures which address the barriers to large scale integration of DG are discussed. Some of the future protection trends considered include new trends in islanding detection, intelligent protection systems, special protection schemes and WAP applications, substation communications, interaction of protection and automation, future extensions of

SCADA functionality, standards and protocols, and trends in the requirements and capabilities of new generation technologies.

1.5 Main Findings

Based on the review of the protection practices in different countries and the available technical literature the main findings of the working group can be summarised as follows:

- In the recent years, a spectacular growth of DG/RES has been happening widely in all countries and this is expected to continue over the next few decades.
- The increase of the DG penetration in distribution networks with the emergence of large DG power plants connected to sub-transmission network has pushed recently some countries to develop new requirements or revise the existing codes to cope with the new scenario. However, this process is has not been co-ordinated internationally. This work highlights the pressing need for better international co-ordination of these requirements.
- In view of the different connection arrangements analysed for each country it is commonly acceptable to establish different DG connection criteria for distribution networks generally radial up to 69kV networks, and for (sub)transmission meshed 100kV and above networks. In transmission networks, the DG is normally connected to a dedicated or existing substation, directly or through a dedicated line. Also, tapped connection to an existing two ended line is acceptable in transmission networks in some countries.
- All countries use practically the same set of interface protections, which are under-/over-voltage protection, under-/over-frequency protection, phase and ground overcurrent protection complemented with transformer differential protection. For more detailed recommendations and best practice in generator interface protection refer to chapter 5.
- The impact of reduced short circuit current contribution from new generation technologies on the performance of the current line protection needs to be assessed, especially for those connections where current detected by the relays is exclusively supplied by the DG, i.e. direct line connections, tapped connections or connections to a substation with a few lines.
- With growing DG penetration levels of all sizes and connection voltages there is an increased need for high performance anti-islanding protection. Taking into account current relay offerings the implementation of anti-islanding protection is always a question of compromise between sensitivity and stability as well as between the performance and cost. Traditionally, the stability aspect was of lesser importance as the network operation did not depend on the presence of DG. This situation is gradually changing and reliable islanding detection is becoming increasingly more important. New solutions are needed as the limitations of the existing methods may eventually pose a barrier to further integration of DG. The use of active methods and alternative communication technologies to improve performance should be considered.
- With low levels of DG penetration or small units, system operation does not depend significantly on the generated power from DG sources and in case of abnormal situations all DG units are required to trip. In these cases conventional philosophies for protection

and restoration are valid and few implications or adaptations in the existing network protections are required.

- As the penetration increases the units are considered more important for the security of the power system. Also, the implications in the network protection and the need for co-ordination becomes greater. System operators are demanding more capabilities from generators to stay connected under certain voltage disturbances (defined by FRT curves) or frequency excursions, even contributing to support the system parameters during these conditions. Classical frequency settings can result in significant tripping of DG for disturbances in the transmission network, so settings should be adapted to those of conventional generation for proper co-ordination. There is also a noted lack of co-ordination between undervoltage interface relays and FRT capabilities.

- The FRT requirements for wind generation in some networks are unnecessarily demanding. The reactive consumption and time responses are not appropriate for system stability. Therefore, the harmonization in FRT requirements is highly recommended.

- New generation technologies, such as inverter based generators, can offer capabilities to steady state voltage, power factor and frequency control. In the future, the technology will evolve to provide new capabilities that maximize the output of non-synchronous generators, allow increased integration of new generation technologies and provide better system security.

- Current automation, monitoring and control practices are not sufficient for the needs of DG integration. Regional control centres for DG/RES should be extended and integrated. Also, more control capabilities (voltage and frequency) and contribution to ancillary services should be added. Local automation functions and the development of communication networks to control the operation of DG by the transmission system dispatch together with more advanced forecast applications will permit, especially for renewable sources, the integration of DG into the network and exploit their control capabilities similar to conventional generation. In the future, new control technologies such as pitch control and the development of new power management tools will allow more flexible operation of windfarms and a greater integration into the market mechanisms.

- There is a trend for more standardised communications between protection relays of different manufacturers. The recent IEC 61850 communications standard aims to facilitate efficient communication, interoperability, and interchangeability between the IEDs, between the IEDs and the station bus, and between instrument transformers and the IEDs on the process bus. The standardisation of these communications will help promote more use of WAP/SPS and adaptive protection schemes in the future, required for DG protection applications. Cybersecurity is a growing issue in the power industry and more secure communication networks are required in the future to keep data confidentiality and integrity and promote wider use of standardised communications in protection schemes, especially wide area protection schemes.

- Streamlining, simplification and harmonisation of existing permission procedures and standardisation of the grid codes for the connection of DG is also required to encourage large scale integration of DG. The standardization in the connection requirements of DG, particularly of the protection equipment and settings criteria, will be very positive for the development of the DG, especially in highly interconnected networks to avoid nuisance tripping and obtain more generation availability and so network stability.

- In order to further increase the security of supply DG units could be allowed to operate in an islanded mode in a meshed distribution network. Currently the view of many countries concerning intentional islanding is that the cost of additional infrastructure outweighs the benefits. However, with increased levels of DG penetration in the future and the tendency of connecting these generators at higher voltage levels, it is expected that the benefits of islanded operation will be more significant and the additional cost relatively lower. Intelligent protection schemes which can adapt their protection settings will play an important role to enable stable operation and protection of these power islands.

2 Protection Requirements

2.1 Introduction

This chapter aims to describe the different aspects concerning protection as a consequence of the connection of DG to the network. Aspects, such as protection requirements of DG, the system aspects that determine the different protection implementations, the implications of the presence of DG on the network protection and finally, the capabilities recently included in almost all grid codes for the wind generation regarding voltage and frequency tolerances and response to voltage dips are analysed.

2.2 System Considerations

2.2.1 Introduction

A proper understanding of the characteristics of the power system, including steady state and dynamic system performance, is essential in ensuring the correct arrangement of protection and control of the DG/Utility interface. A selection of appropriate protection and control philosophy is determined by factors such as:

- Electrical characteristics of the network at the connection point (fault level, network structure, etc.).
- Voltage profile and power transfer capability at the connection point.
- Type of connection to the network (radial/tapped, dedicated or non dedicated line, etc.).
- The prospective fault current contribution from the DG to the utility network and vice versa.
- The dynamic response of the DG units to the utility network faults and disturbances and the ability of the DG units to maintain stability on loss of the utility connection.
- Backup protection policy of the utility network at connection point (clearance time requirements).
- Auto-reclosing policy on the utility network.
- Co-ordination requirements with the utility protection.
- Grounding arrangement of the DG when operated in an islanded mode.
- DG connection arrangement to the utility network, e.g. direct connection, via generator-transformer unit, connection via step-up transformer.

The characteristics of the power system, the type of connection and the type of power generation technology are the most determinant factors for the protection system. These factors and their influence are analysed in the next sections.

2.2.2 Dynamic response of different generation technologies

2.2.2.1 Dynamic response of synchronous generators

The protection and control arrangements at the interface between the DG and utility network must be suitable to protect the DG equipment in the event of a major system disturbance and to protect the utility network against abnormal operating conditions resulting from a maloperation of the DG governor and/or Automatic Voltage Regulator (AVR). Generally a detailed assessment of the dynamic response of the generator is recommended to provide a full understanding of the response to system disturbances to enable the correct determination of control equipment and interface protection relay settings.

The interface protection relays must be provided with settings that ensure correct tripping for genuine disturbance conditions but prevent tripping under transient conditions from which the overall system will recover to stable operation. It is particularly relevant to examine the dynamic frequency response of the DG generators to faults, loss of load or generation when operating in parallel with the utility network.

For the proper assessment of the overall system performance, steady state and transient stability studies should normally be carried out for the connection of synchronous generating plant. Other aspects such as voltage stability, oscillatory stability or frequency stability, which are as important as transient stability, must also be analysed.

The generating plant is defined as stable in steady state if, following a small disturbance, the system returns to the stable steady state operating condition. Small disturbances arise frequently as a result of normal operating conditions such as load fluctuation and switching operations. Undamped power oscillations which result in sustained voltage and power swings, and in the extreme case the loss of synchronism between generating units can arise following a small disturbance if:

- The transfer capability of the interconnecting network is insufficient or
- The control and load characteristics either singly or in combination are such that negative damping or reduced synchronizing torque occurs.

Generating units are transiently stable if, following a large system disturbance, each generating unit settles to a new steady state operating condition. Large system disturbances arise following severe or close up electrical faults or as a result of major load or generation loss. During severe electrical faults the output of the generating unit can be substantially smaller than the mechanical input from the prime mover and the rotor will accelerate and start to swing against the system. Provided the fault is cleared quickly, the generating unit controllers respond rapidly and adequate network connections are maintained following the fault, the oscillations are damped and the stability can be maintained. If the swing is not contained, large cyclic power exchanges will occur between generating units and the network, potentially resulting in damage to the generating units, maloperation of protection systems and unacceptable voltage depressions in the utility supply network.

It has to be appreciated that the DG generating plant should be considered an integral part of the overall transmission or distribution system to which it is connected. The design of the system should aim to maintain system stability and prevent the loss of synchronism of generating plant under all operating conditions. Generating plant which does become unstable should be rapidly disconnected from the network. Protection equipment provided for the disconnection of generating plant should, however, be designed to ensure that unnecessary tripping does not occur for conditions of transiently stable operation.

In the event that system stability studies show a risk of instability, suitable protection should be provided to detect the condition and disconnect the DG generating unit(s) from the utility network. This may be achieved either by tripping the generating plant, or by tripping the interface circuit breaker(s) and retaining islanded operation of the DG plant. Alternatively, the following measures could be considered to maintain transiently stable operation:

- Reducing fault clearance times
- Improving generator excitation systems
- Improving governor and/or prime mover response
- Improving voltages and/or installing reactive compensation
- Changing the machine parameters, if possible, to provide higher inertia and/or lower synchronous and transient impedance
- Fitting breaking resistors

2.2.2.2 Dynamic performance of wind turbines

Particularly in the case of wind power, the impact on the dynamics and stability of the power system is mainly determined by the fact that, due to the specific technology, the wind turbines do not contribute to the same extent towards the grid frequency and voltage stabilisation as it is in the case of traditional power plants, which are actively involved in grid stability control.

The main factors potentially having an impact on transient stability are:

- Wind power plants can only be constructed at locations with a good wind resource and are usually integrated through radial connections, which is not necessarily favourable from the perspective of grid voltage control.
- Power flows are considerably different in the presence of a high amount of wind power and power system is typically not optimized for wind power transport, so when large amounts of power have to be transported over long distances, congestion on existing networks can occur. Limited capacity of interconnectors can also lead to the transmission systems being very much closer to small signal stability limits and in extreme circumstances close to transient instability limits.
- Wind turbines are relatively weakly coupled to the system because they are usually connected to lower voltage levels (subtransmission and distribution systems) compared to the conventional power plants, which are connected to the transmission level via large step-up transformers. This reduces their contribution towards voltage and reactive power control.
- The intermittent nature of wind power is not seen to be relevant to transient stability, but because of limited predictability of wind speed, systems with high amounts of wind power usually require higher spinning reserve than conventional power systems.

- Wind generators do not contribute to the system inertia as conventional generators so the frequency fluctuations after disturbances or with loss of generation are greater when there is a high proportion of wind power generation. On the other hand, the control action from these generators may be faster than conventional generators, which tends to improve stability.
- It is possible to assess the impact of the three main wind turbine types on power system dynamics and stability in a qualitative sense by analysing their properties:
- Squirrel-cage induction generators used in constant-speed turbines cause significant power and torque fluctuations, but offer good inertial contribution. They can lead to voltage and rotor-speed instability. During a fault, they accelerate due to the unbalance between mechanical power extracted from the wind and electrical power supplied to the grid. During voltage restoration, they consume high amounts of reactive power, impeding voltage restoration. When the voltage does not return quickly enough, the wind turbines continue to accelerate and draw reactive power from the grid. This eventually leads to voltage and rotor-speed instability. Opposite to what applies to synchronous generators, whose exciters increase reactive power output at low voltage and thus support voltage recovery process, squirrel-cage induction generators tend to slow down voltage restoration. In such cases capacitor banks are normally used for reactive power control.
- Doubly-fed induction generators (DFIG) have little impact on the transient stability performance of the system. They are capable of providing sufficient reactive power support and voltage control.
- Full converter generators have even less impact on the transient stability performance of the system than the DFIG. The converter's fast control of active and reactive power or of the AC voltage at the generator terminals can provide reactive power to the network both during steady-state conditions as well as during disturbances. Although full converter generators can potentially be beneficial for system operation and stability (for example contributing to system frequency regulation), the full extent of the added benefits is not sufficiently understood at the moment.

With variable-speed turbines, the sensitivity of the power electronic devices to overcurrents caused by system faults can have serious consequences for the stability of the power system. When the penetration level of variable-speed turbines in the system is high and they are all set to disconnect at relatively small voltage drops, this could lead to a large generation deficit. To prevent this, some grid companies and transmission system operators facing a high contribution of wind power in their control area are currently proposing more demanding connection requirements (see 2.5.2) and manufacturers are implementing new solutions to reduce the sensitivity of variable-speed wind turbines to grid voltage variations.

The lack of wind power contribution to frequency control and load balancing is caused by the fact that the prime mover is uncontrollable. Therefore, wind power rarely contributes to primary system frequency regulation, although some TSOs are including this requirement in their grid codes (refer to section 3.2). The impact of wind power on frequency control and load balancing becomes more severe the higher the wind power penetration level is. Additionally, the high wind power penetration level will have an impact on the demand profile faced by the remaining conventional units. Thus, the requirements on the ramping capabilities of these units will be stricter in order to match the remaining demand curve and to keep the fluctuations of the system frequency within acceptable limits.

As a consequence the protection systems have to be designed and set depending on the overall state of the power system. There will always have to be a certain amount of conventional generation in order to ensure that transient stability is maintained during system faults.

2.2.3 Power flow, short-circuit power and fault current

In distribution networks, DG leads to fundamental changes in power flows, which may trigger problems such as overloading, voltage profile and voltage stability. Under certain circumstances the power flow may change quite suddenly, for instance due to wind shifts or due to tripping of DG during systems disturbances. Additionally, the direction of short-circuit currents may change causing non-selective tripping and different transient phenomena can be observed.

At transmission level less problems regarding power flow and short-circuit current patterns are expected as transmission grids are predominantly used to connect large generators. Short-circuit currents are normally much higher and faults are cleared much faster than in distribution networks. Nevertheless, the capability of the existing grid to accommodate the connection of a new DG is generally dependent on the local transmission system network conditions concerning:

- Short circuit fault rating
- Required fault clearance time of the protection and switchgear for the maintenance of system stability
- Power distribution to the grid supply and consumption
- Restoration of the network after loss of supply

The location of DG connection to the transmission network is usually beyond the utility's control, and therefore, the DG may be connected at a point where it adds to the system complexity and the resulting network performance may change significantly. System studies are thus necessary to determine the performance of the DG and the associated transmission network in order to ensure the correct specification for the circuit breakers and associated protection and control equipment.

Studies are particularly necessary when the generator rated power is not in proportion to the short circuit level of the utility grid at the point of connection. For this reason not only transient conditions, but also subtransient contributions should be taken into account.

Knowledge of the prospective fault current has an important impact on the behaviour of protection and materials.

Regarding generators with a voltage controlled exciting source, we have to make a difference between:

- Excitation with an independent permanent source.
- Excitation from the voltage on the generator terminals.

Both methods of excitation give the same contribution to fault current during the subtransient period (50 to 100 ms). However, the first excitation system gives a continuously high level of short circuit current during the subsequent transient period.

The second method depends on the voltage on the generator terminals and the short circuit current may quickly decay (depending on the transient time constant of the generator). It can even decrease below the rated current of the generator and close to zero when the short circuit is on the generator's terminals.

Regarding wind turbines, they are usually required to supply short circuit current in order to support the voltage during faults. It is also important to ensure correct operation of the network protection. The behaviour under external faults and the current contribution differs between the three main wind turbine types:

- Constant-speed turbines are based on a directly grid-coupled squirrel-cage induction generator (SCIG). They contribute to the fault current in the first 50 ms in a similar way to the synchronous generator and they rely on the conventional protection schemes (overcurrent, overspeed, over- and undervoltage).
- Turbines based on the doubly fed induction generator (DFIG) also contribute to the fault current. However, due to the sensitivity of power electronics to rotor overcurrents, they are quickly disconnected when a fault is detected. The ability to support the grid in case of voltage dips is an area that is still under development but in several countries it is a requirement that is already being incorporated in the grid codes (see 2.5.2.3). The protection method is often based on the so-called crowbar protection. During severe voltage dips due to grid faults, the rotor side power electronic converter is quickly disconnected from the grid in order to protect it against possible large current peaks during such events. In order to achieve this, the three-phase rotor winding is short-circuited via the crowbar switch and consequently the DFIG generator behaves like a normal SCIG generator. For limiting the rotor current and for influencing the speed-torque characteristic of the machine, the rotor can preferably be bypassed through an impedance. The crowbar is released in a short time usually before the fault clearance. The units have thus the capability to provide reactive power support to the system during sustained faults and contribute to the voltage recovery of the system. Detailed information about the behaviour of DFIG under external faults with and without crow-bar protection is explained in the document [2].
- Wind turbines with a direct-drive generator (full converter) and other converter based generation such as PV have a limited capacity to contribute to the fault current because the power electronic components of the converter are normally not capable of supplying a fault current. The short-circuit current is usually limited to 10-20% above the rated current and converters are normally equipped with under-voltage relays and over-current limiting in case of disturbances on the distribution system. Therefore, they are quickly disconnected in case of a fault. However, recent designs offer ride through capability, which is achieved by applying specific control strategies to the inverter so that the converter fault current can be limited in a controlled way [3].

This particular behaviour of recent generation technologies regarding fault current contribution poses a challenge to the network protection performance. A proper understanding of the current and voltage transients during faults is necessary to assess the protection performance and select the appropriate settings. In 2.4.9 the impact of the reduced short-circuit currents on the protection system is analysed.

2.2.4 System grounding

In most utility networks, the HV transmission system is solidly grounded. Accordingly, DG connections to the system are generally grounded. This ensures that the transmission system remains grounded even if the utility line terminals are opened.

Occasionally, an ungrounded DG connection to the transmission system may present itself by virtue of:

- MV embedded generation connected via a utility substation
- Existing Industrial Plant (which was a load) which now has connected generation

In the evaluation of the DG installation, the consequences of ungrounded operation must be evaluated. A determination must be made as to whether or not the transmission system can be temporarily ungrounded. The classic situation where this can occur is when the utility end of the transmission line has tripped but the DG units remains connected through a power transformer with an HV delta connection.

It is well known for this situation, that for a ground fault on an ungrounded network, the voltage on the unfaulted phases will rise to $\sqrt{3}$ times the phase-to-neutral value. However, in some instances, where transmission lines are long and lightly loaded, the voltages in the healthy phases can rise considerably above the $\sqrt{3}$ value. This can make the resizing of equipment, to accommodate the overvoltages, too expensive or impractical.

<u>*Solidly Grounded Connection*</u>
With a grounded transformer connection (for example: HV grounded star, LV delta which is discussed in detail in section 2.2.5) the transmission system remains grounded if the utility end of the transmission system is opened. This is appropriate considering that transmission equipment ratings (e.g.: surge arresters) are sized for grounded operation.

Often, there can be a conflict between the system requirement for grounded operation and protection requirements. A solidly grounded connection depending upon the size of the DG, the network topology and the connection point along the transmission line may present problems with ground relaying sensitivity at the utility terminals. This is discussed in section 2.4.1 “Implications of tapped connections of DG”.

<u>*Ungrounded Connection*</u>
An ungrounded DG connection to the transmission system may manifest itself in two ways: as an LV connection to an existing industrial load or utility substation installation. In many instances the installations will be HV delta, LV grounded star. This connection may be satisfactory for loads but may present overvoltage problems as discussed above.

If ungrounded operation is to be considered, studies need to be performed to determine whether resizing of surge arresters or other equipment needs to be made.

2.2.5 DG transformer connection

The DG transformer connects the generator to the point of interconnection/common coupling with the utility grid and provides the appropriate voltage transformation.

Only two transformer connections are discussed, HV star – LV delta and HV delta – LV star. The discussion is restricted to these two types (even though there are considerable variants) because these represent the two extreme cases of either a strong source of zero sequence current to the HV system (for the former) and a connection with no zero sequence source of current to the HV system (for the latter).

HV star connected - LV delta
This connection is typical for most DG installations as well as generator facilities owned and operated by the utility. The connections offer the advantage of:

a) Zero sequence isolation between the HV and LV windings, ensures that the HV system is not a source of ground fault current for generator winding faults.

b) Trapping of third harmonic currents (and multiples thereof) in the delta winding is beneficial.

c) An HV grounded connection (with LV delta) ensures grounded transmission line operation if the remote utility bus breakers open for any reason.

Although this is a standard connection for most installations, it can cause problems if the proponent of the DG project proposes taps into an existing transmission line with a single breaker. The DG installation will reduce the reach and sensitivity of relays at the utility buses. These aspects are covered in 2.4.1.

HV delta - LV star grounded connected
Though this is not the preferred approach, this connection can manifest itself in several ways. When an existing industrial complex proposes to add self-generation for export to the utility the existing HV customer transformer connection may be a delta connection.

The second instance is for the case where a DG is added to the distribution system, and the transformer in the utility substation imposes an HV delta source to the transmission system. Note: though distribution level DG connections are beyond the remittance of this report, the impacts on the HV system must always be assessed.

2.3 Protection of the DG interconnection

2.3.1 Introduction

This section describes the protection requirements imposed by the grid. It focuses on the protection at the utility/DG interface to detect faults within the DG plant that can be fed by the utility system or abnormal operating conditions that lead to voltage or frequency excursion out of statutory limits. Line protection is only briefly covered as there are many pertinent guides available covering this subject. Potential impact of DG connection on the utility protection is also discussed in 2.4. The issues include the reduction of protection reach and sensitivity, co-ordination problems, automatic reclosing (with an emphasis on those considerations applicable when reclosing onto an isolated source of generation), voltage supervision, check synchronizing and out of step protection.

Regarding the strategy for DG protection, small power units are traditionally operated in such a way that for any disturbance in the network, they are immediately switched off by very sensitive instantaneous relays in order to prevent islanded operation. For large power plants, and in many cases also for medium size power plants, utilities have put forward requirements that the generating plants contribute to the stability of the network by remaining connected during external disturbances. This requirement termed as "fault ride through" capability is achieved by co-ordinating (delaying) the relays with the network protection. Due to the increasing penetration of distributed generation in recent years, in a number of countries utilities tend to put forward similar requirements even for the smaller power generating plants. However, it can sometimes be in conflict with the need of the owner to protect the unit from damage.

The greater capability to withstand faults should not affect the sensitivity for the islanding detection, so a compromise between sensitivity for islanding detection and stability under external disturbances is needed. In chapter 4 some comparative test results of the typical anti-islanding relays regarding this compromise are included.

2.3.2 Interface protection

Firstly, interface protection considers those protection elements which are applied for a DG installation at the utility/DG interface to provide coverage for DG faults that may be fed by the utility system. In fact, such protection has to be provided not only for DGs but for any load connected to the utility grid. Secondly, the interface protection also includes detection of abnormal voltage or frequency conditions caused either by the utility or by an out of range operation of the DG, for example during islanded operation.

According to the scheme presented in Figure 2-1, in order to guarantee the supply to the embedded loads of the DG installation, the interface protection can trip the generator breaker (A) when the DG is designed for parallel operation only, or the interface breaker (B) if it is also designed to operate independently in an islanded mode.

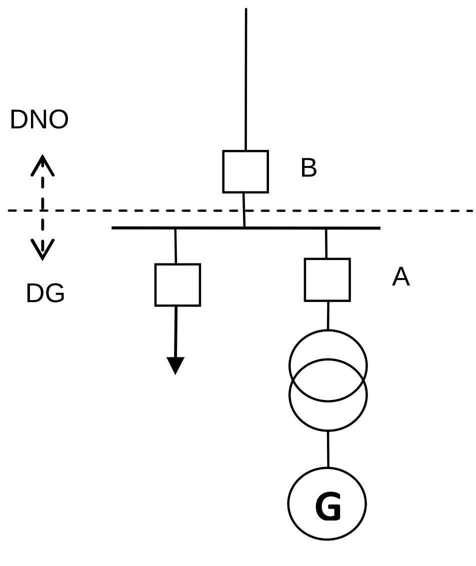


Figure 2-1: DG with embedded loads

Most DG interfaces include the following protection functions:

- Overcurrent relays (51-51N) to protect against overloads and short-circuits inside the DG installation. Depending on the size of the transformer, short-circuit protection may be assumed by a transformer differential relay.

- Over and Under-frequency relays (81O-81U), which disconnect the plant under unstable conditions of the network and prevent undesirable islanded operation and self-excitation of the generator.
- Over and Under-voltage relays (59, 27), which prevent the islanded operation of the generator with an abnormal voltage or a malfunction of the exciter.

Under-voltage protection prevents also overcurrents as a reduced voltage leads to an increased current and it also reacts to faults inside the generator or within the nearby network. In some cases two stage settings are used for both over and under-voltage relays. The fast over-voltage setting serves to prevent self-excitation.

For small units, the voltage and frequency protection are normally sufficient to act as anti-islanding protection because of a sudden transition to island operation typically involves large excursions in voltage and frequency due to the imbalance of real and reactive power. The problem is the lack of stability to faults in adjacent circuits due to the required high sensitivity and speed of operation. These requirements are particularly important when automatic reclosing exists which could potentially lead to out of phase re-connection of the unit. For that reason and for more reliable detection of the islanded operation when no faults exist, in addition to these functions, a dedicated anti-islanding protection or transfer trip facility is used in some countries to prevent the islanded operation. Due to the special considerations for this type of protection Chapter 4 includes a detailed description and analysis of the operation principles and performance of various anti-islanding protection methods.

An example of the interface protection scheme is shown in Figure 2-2.

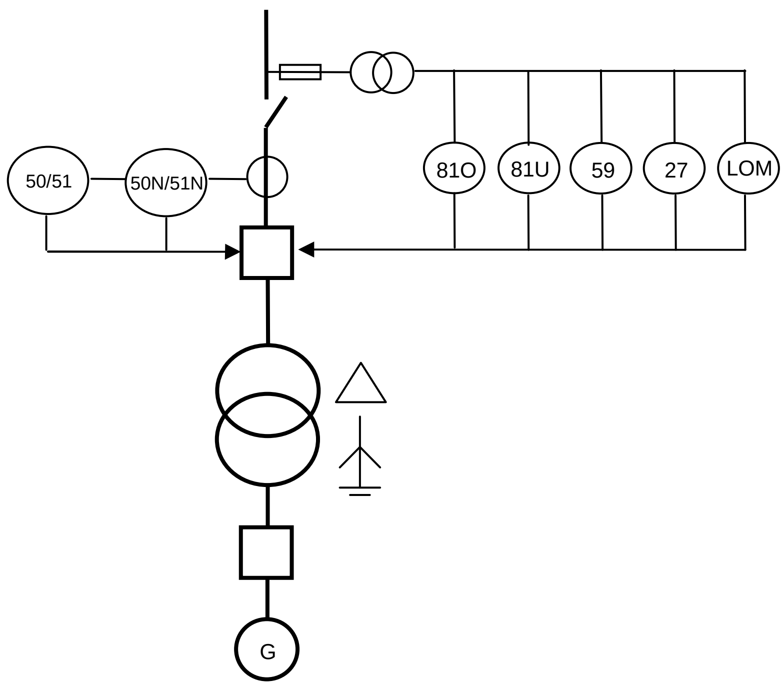


Figure 2-2: Example of interface protection scheme

One important aspect of including as much of the DGs HV equipment in the interface protection zone is that it ensures the detection and clearance of such a fault by the DG protection rather than by the remote utility protection.

Another important issue is that the interface protection must be coordinated with the remote utility protection. Co-ordination means:

- Fully selective clearing – the DG's protection will clear all faults in the DG's installation before the utility's relaying initiates tripping for such faults.
- Simultaneous clearing – the DG's protection will clear all faults in the DG's installation coincidentally with utility clearing of such faults.

Additionally, for faults in the network but external to the line, utility protection must clear the fault before interface protection trips. Therefore, depending on the relation between the fault current contributions for the different fault locations, it may be necessary to use directional overcurrent relays to accomplish the co-ordination requirements.

Frequency relays have been traditionally used as anti-islanding detectors with very sensitive settings (i.e. 49/51 Hz and 0.2 sec.). However, this can be highly undesirable in case of transient network frequency excursions because the spurious DG disconnection contributes in a negative way to the system frequency recovery. Consequently, it creates a negative impact on system stability, especially in networks with high DG penetration (see section 2.4.6).

2.3.3 Line protection

Line protection is required to remove the DG infeed to transmission line faults. Line protection requirements are driven by:

- transformer connections of the DG
- transmission line relaying practises for the utility grid
- critical fault clearance time
- form of connection to the DG (tapped connection or radial circuit)
- size of connected DG and main transformer

<u>*Transformer Connections*</u>
Transformer connections were discussed from a system perspective in section 2.2.5. From a line protection perspective, the primary consideration is whether the main power transformer is a source of zero sequence current or not.

As described in section 2.2.5 the HV star – LV delta connection delivers ground fault current to the utility for transmission phase-to-ground faults.

The logical protection choices with this transformer connection would include residually connected ground overcurrent relays and ground distance protection.

Occasionally, an HV delta – LV grounded star connection is used. For this situation neither ground overcurrent detection nor ground distance protection will work. Typically, the HV VT open delta secondary voltage is measured. This will detect the zero sequence voltage for a single phase to ground fault on the transmission system.

Transmission Line Relaying Practices
The utility line protection practises will have a major influence on the application of the transmission line relaying. Fristly (ignoring DG size and other aspects for the moment), the DG line protection in many instances will be similar to the remote line protection and it should ease co-ordination requirements. For example it is easier to coordinate two distance relays with each other than an overcurrent relay with a distance relay. Secondly, it is likely that the protection clearance speed requirements for faults fed from the DG will be similar to those for the utility line relaying.

Other considerations are: the need for two sets of protection, redundancy policy and teleprotection aided scheme. Generally, whatever requirements the utility has (for example Main 1 plus Main 2) will also apply to the DG.

Form of DG Connection to the gird - radial or tapped
DGs will generally be connected as a tap to an existing transmission circuit, at the end of a radial transmission circuit or to a dedicated substation. For reasons of economy (to the DG proponent) the tap connection is preferred but this can introduce protection complications as well as system problems for the utility which are explained in more detail in section 2.4.1.

For a radial connection, the protection problems will not be so onerous, since there are only two terminals proving infeeds to transmission line faults.

Size of connected DG and main transformer
The preceding considerations are important for the line protection issues related to a DG. The final consideration discussed, relates to the size of the connecting transformer and the generator.

For small generators/transformers connected to MV the line protection applied may not be very sophisticated for economic reasons related to the total cost of the DG project, and more importantly, the ability of the DG to deliver fault current to the HV transmission system. Figure 2-3 illustrates such a protection installation where phase-to-phase voltage detectors, normally the same under-voltage relay is used for interface protection, are provided for detecting multi-phase line faults and zero sequence voltage detection is used to detect line-to-ground faults. Comparing with distance protection, one drawback is that the operation of these relays must be delayed for all faults in the line to achieve co-ordination with the remote utility protection.

Furthermore, as discussed in 2.5.2.3, when fault ride-through capability for wind turbines is required by some TSOs, the backup relays used to detect faults external to the line must be delayed accordingly permitting the generators to remain connected during voltage dips. This applies, for example, to undervoltage relays (27 and 59N) or time delayed distance relays.

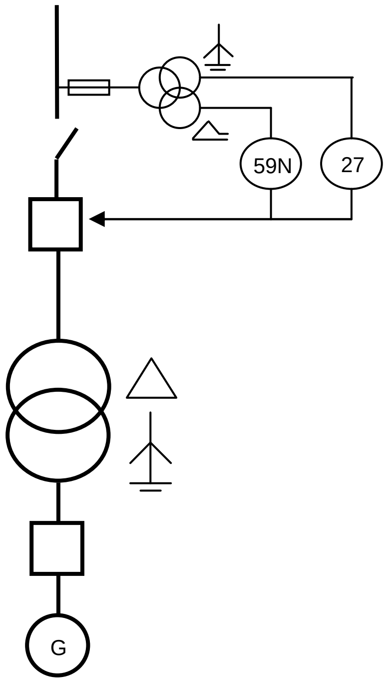


Figure 2-3: Example of a simple line protection scheme

2.4 Protection Implications of DG Connection

Connection of DG to power networks has various effects on the performance of the existing protection system. Most of them mainly concern the distribution and radial networks and their importance depends on the penetration and size of the DG units:

- Reduction of fault detection sensitivity and speed in tapped connections (blinding of protection)
- Increased fault levels may exceed the capacity of the existing switchgear
- Reduced reach of impedance relays
- Unnecessary tripping of utility breaker for faults in adjacent lines due to fault contribution of the DG (sympathetic tripping)
- Changes in the value and direction of short circuit currents, depending whether the generator is connected or not, which affect the co-ordination and operation time of the overcurrent relays
- Unintended islanding which can prevent automatic reclosure, unsynchronized reclosure and in some cases operation of the parts of the system without effective grounding
- Out-of-step conditions
- Over-voltages due to resonance conditions
- System protection performance issues (load shedding protection, WAP, SPS, etc.)
- Impact of the reduced fault contribution of converter based generators on protection performance

It is important to notice that the high penetration of DG could imply substantial changes of the utility protection system and even of the network topology.

Next sections give a detailed explanation of some of these impacts.

2.4.1 Implications of tapped connections of DG

For economic reasons, tapped connection of DG to an existing line is one of the most often utilised connection types, but it can introduce some protection complications.

One consequence is the reduction of sensitivity of the overcurrent relays. Fault current contributions during a fault are shown in Figure 2-4 and Figure 2-5 and equations (2.1) and (2.2) can be formulated, respectively. The conclusion is that the fault current contribution from the utility will decrease depending on the DG and utility source impedances and line impedances between each one and the fault location. This can lead to protection not operating for faults in certain parts of the network. In some cases, the relay will not operate until the protection of the DG unit trips. In the worst case scenario, the fault will go undetected until it burns into a larger fault.

There is an increased risk of non-detection especially for high impedance ground faults. However, in case of tapped line DG connection with HV delta connected transformer, the sensitivity to ground faults will not be diminished. This is one reason why this form of connection may be preferred if there are requirements to cover high resistive ground faults.

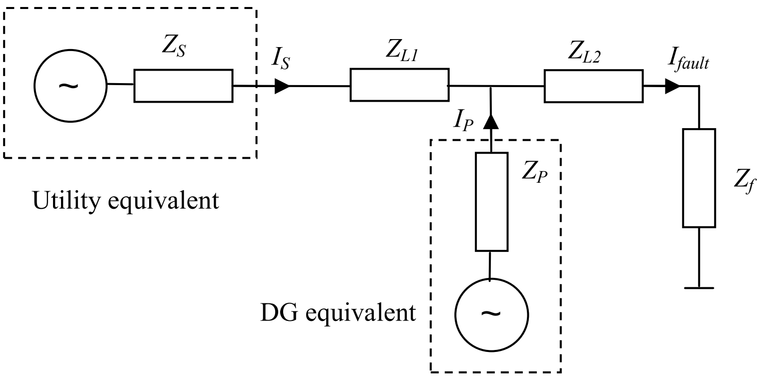


Figure 2-4: Fault current contributions for a fault downstream the DG

$$\frac{I_s}{I_p} = \frac{Z_p}{Z_s + Z_{L1}} \tag{2.1}$$

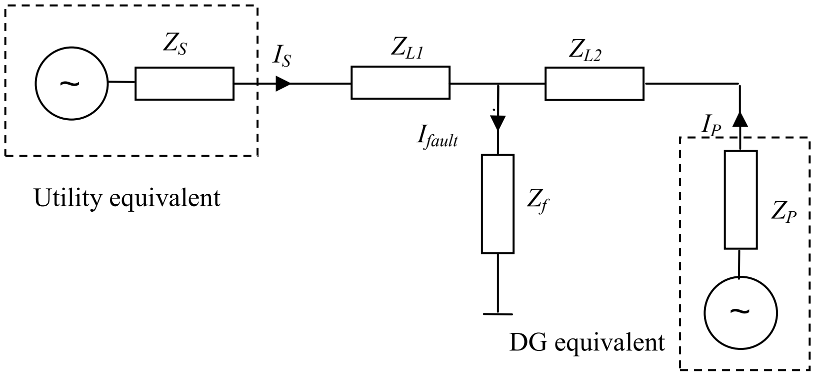


Figure 2-5: Fault current contributions for a fault between utility substation and DG

$$\frac{I_S}{I_P} = \frac{Z_P + Z_{L2}}{Z_S + Z_{L1}} \tag{2.2}$$

Another consequence is the effective reduction of the reach of the utility distance relays due to the positive sequence current infeed for multi-phase faults. According to Figure 2-4 and equation (2.3), the impedance measured by the distance relay located at the utility end Z_r is higher than the real fault impedance (Z_{L1}+ Z_{L2}) which corresponds to the increased measurement of the distance to fault. Consequently, the relay may trip with longer time delay, corresponding to another distance zone.

$$Z_r = Z_{L1} + Z_{L2} + \frac{I_P}{I_S} Z_{L2} \tag{2.3}$$

When a DG is connected by a tapped circuit to a two-ended line, the typical problems of multi-ended feeders with distance protection arise [4], which can be:

- Under-reaching effect for internal faults due to current infeed at the T point, as mentioned above
- Effect of pre-fault load on the impedance seen by the relay
- Over-reaching effect for external faults, due to current flowing outwards at one terminal
- Failure to operate for an internal fault, due to current flowing out at one terminal
- Incorrect operation for an external fault due to high current fed from the nearest terminal

To overcome these problems with distance protection, a multi-ended current differential protection can be used if a communication link between the protection relays is possible. At present, many of the current differential relays only offer up to three terminal connection, so the extension in the number of terminals for several T-ed connections should be the trend in the future.

2.4.2 Co-ordination problems due to the fault current fed by DG

Radial distribution networks are generally equipped with non-directional relays because fault currents flow in one direction only. However, in case of a fault on a line adjacent to the one that has a DG connected, it is possible that the fault current fed by the DG and measured by the relay at the substation exceeding its tripping setting. This will result in an unnecessary disconnection of the line containing the DG. A relatively powerful DG together with a fault point or DG (or both) situated near the substation may lead to this kind of problems. Additionally, the fault current fed by the DG accelerates the tripping of the adjacent lines.

This problem can usually be avoided with suitable relay settings. For instance the tripping time and the current pick-up setting of the overcurrent unit can be changed, also in the relays of the adjacent lines. Tripping should always be slower on the line containing DG in comparison to the adjacent lines. However, raising the thresholds or delaying the trip of the overcurrent protection has some drawbacks with regard to the desirability of rapid shutdown and avoidance of the destruction of equipment or, indeed, the safety of personnel. It is important to keep in mind that the protection must still operate in all cases as it originally did, no matter the state in which the DG is.

The most efficient solution for this problem is to use a directional overcurrent relay on lines that have DG connected. This normally will not be necessary in HV substations because the practice of the most utilities is to install the directional relays (distance or overcurrent relays) at this voltage level, even for the radial lines. With these solutions, the fault current will cause tripping only when flowing from the substation to the line. However, in case of overcurrent relays and powerful DGs that significantly modify the fault currents, it may be difficult for the adjacent lines to find a setting that coordinates properly with the relays of the remote lines for all possible states of the DG.

2.4.3 Reclosing co-ordination

The connection of DG to the network may disturb the normal reclosing performance of the utility. In case of unintended islanded operation after a fault, the DG may continue operation during the reclosing time, sustaining voltage and feeding the fault current. For example, for a non-permanent ground fault, the fault may be extinguished with the trip of the utility breaker (usually the network side of the DG transformer is ungrounded) with the possibility of an undesirable islanded operation.

In case of automatic reclosing, if the utility breaker closes before the interconnection relays trip, the fault will not be cleared and, will become even more severe than the prevention of successful reclosing. This might jeopardize the generator turbine because of an out of synchronism coupling. Depending of the differences in magnitude and phase between the voltages in the islanded part of the utility network, overvoltages, overcurrents and large mechanical torques may arise. These can cause serious damage to the turbine-generators or add to cumulative stress. Also circuit breakers can be damaged by the non-synchronous reclosing.

Also, for HV ungrounded DG transformer after a ground fault is cleared by the utility breaker, overvoltages in the healthy phases arise as long as the fault is fed by DG, which may cause damage to the installation equipment.

Consequently, it is required that DG plants should be disconnected before reclosing of the utility breaker takes place, so means need to be provided to disconnect the DG from the network very fast because of the short times normally used for reclosing (0.3 to 1 sec). Furthermore, some generators must withstand external faults for longer times according to the requirements of the FRT capabilities (see 2.5.2.3). For this purpose, the transfer trip or other anti-islanding detection system is necessary.

Additional security against unsynchronized reclosure can be provided by voltage supervision and check synchronising which are explained below in more detail. However, these techniques can be considered as backup for transfer trip or anti-islanding protection. Otherwise their implementation will lead to the deterioration of the supply quality, because they could prevent reclosing.

Delaying the reclosing can be an acceptable solution if the DG separation before the reclosure can be guaranteed. The auto-reclose delay between 1 and 2 sec is normally recommended for lines with DG connected. From the DG point of view, this would be the simplest solution, but it would have an impact on other aspects, for instance, decreasing overall reliability and quality of supply.

Voltage supervision
Voltage supervision consists of line side voltage detection checking for the absence of voltage on the transmission line prior to completing the reclosing sequence.

Synchronising and Check Synchronising
Check synchronising is another option, it is of particular benefit for those schemes where the presence of voltage on the transmission line may be legitimate, but there is still a need to ensure that the DG is in synchronism with the network. This is shown Figure 2-6.

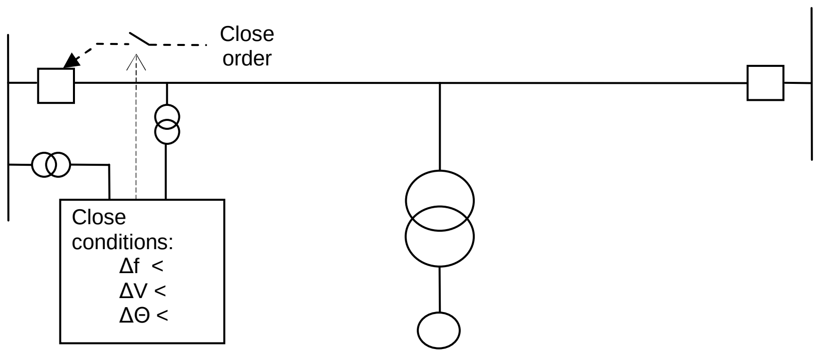


Figure 2-6: Check Synchronising scheme

Synchronising is different from a synch check function and will only work if the DG generator is slipping against the utility system (unlike a check synchronising device which will work when there is a static angle between two systems). For a synchroniser to work, it has to have the ability to send 'raise/lower' signals to the generator. Synchronisers are thus typically applied at the DG and allow the DG generation to be brought into synchronism after the transmission system has been restored.

2.4.4 Out-of-step conditions

When an DG proposal is put forward, transient analysis needs to be done to determine if non-recoverable swings can occur in the network due to the DG addition and to select the appropriated settings of the out of step protection in order to assure the trip for legitimate out of step conditions and not trip for stable or recoverable swings. Depending upon the utility philosophy various approaches can be used to deal with a potential out of step condition.

- If swing centres are located on transmission lines and provided distance protection is applied, existing line protection can trip for these conditions
- If only current based line protections are applied as line protection, then dedicated out of step protection will have to be applied
- If swing centres occur in reactive equipment, dedicated out of step protection will have to be applied since transformer protection is typically current based i.e.: transformer differential.

Other documents [5],[6] provide detailed information on the application of the out-of-step protection.

Some TSOs rely on the Special Protection Schemes (SPS) to preserve system stability or to prevent serious damages of transmission and generation equipment in case of severe or extreme events involving simultaneous or cascaded contingencies [7]. Some examples are massive generator tripping, load shedding or coordinated system separation. These protection systems should be revised with the integration of large DG plants.

It is important to take into account that the generator “ride through” requirements imply the appearance of out-of-step conditions. Also, out-of-step becomes more probable due to the low inertia constants of some types of generators.

Following the transient analysis review, it may be beneficial to replace the existing slow acting protection to avoid the DG going out of step.

2.4.5 Resonant over-voltages

Resonant over-voltages occur after islanding of DG. Self-excitation is a series-resonant condition that develops between the magnetizing inductance of generators (or motors) and power-factor correction capacitor banks on the same feeder.

2.4.6 Impacts on transmission network stability

Generator should remain connected during underfrequency excursions within some specific limits so in combination with the load-shedding scheme, they can contribute to the recovery of the system frequency. If generators trip before the loads are shed, due to under-frequency protection setting being too high, more load needs to be shed to restore the system frequency. For that reason it is necessary to ensure the appropriate co-ordination between the frequency relays used for anti-islanding protection of DG and the load-shedding frequency relays.

An illustrative example of such frequency deviation is the European power system disturbance on the 4th of November of 2006 [8] where a significant amount of generation units tripped due to the frequency drop in the West area of UCTE system. This certainly contributed to the deterioration of the system condition and to the delay in restoring normal secure operation.

Generation units which tripped were usually small power units but they are numerous and not directly controlled by TSOs. Wind generation and combined-heat-and-power is generally connected to the distribution grid, therefore the relevant standards for their performance and protection settings are less constraining. Usually they have to withstand a frequency drop down to 49.5 Hz. Thus for the 49 Hz event that occurred in the Western zone, a significant amount of these units were tripped.

Another significant disturbance is the frequency deviation and automatic demand disconnection that occurred on the 27th May 2008 in UK [9]. Unexpected tripping of a further amount of small embedded generation took place, which hastened the frequency collapse. A number of load shedding based relays operated successfully at 48.8 Hz to arrest the fall. From the data provided by the DNOs it appears that there may be a significant amount of small generation that have frequency settings that allow tripping at frequencies above 47 Hz.

As a consequence of such events, most TSOs are reconsidering the setting criteria of the underfrequency relays so it coordinates with load-shedding protection, normally set between 48 and 49.5 Hz.

As a result, the recommendations to review and align the frequency operating range required in Distribution and Grid Codes as far as reasonably practicable and to modify the frequency settings on existing small embedded generation plant to improve their resilience to frequency excursions have been given.

2.4.7 Network capacity issues

Power network capacity issues can appear at both distribution and transmission levels. The former can be related to the specific geographical area where the local distribution network is relatively weak to integrate a large number of DGs with unpredictable production. Consequently, the output of some DGs may have to be curtailed at times to prevent the local system from being overloaded.

In other cases, the DG is supporting the limited transmission capacity so overload trips of transformers or power lines could be the result of a high increase in the load due to a global trip of a large amount of DG connected to MV or HV network. For this reason it is necessary to study the dynamic performance of the system carefully in case local support from DG is used as a means to increase the transmission capacity.

The transmission level capacity problems appear at the regional and national level where the substantial proportion of installed renewable power is concentrated in a particular region far away from the major load concentrations. For example such difficulty is taking place in UK where the majority of wind generation is being installed in the northern part of the country whereas the major industrial loads are in the south, posing a significant challenge to the existing transmission system.

When thermal capacity of the lines is reached one way of increasing that capacity is the use of dynamic ratings. Discussions on possible application of dynamic ratings are under way in some utilities.

Additionally, the transmission capacity limit can be often related to the system oscillatory stability rather than the conductor thermal withstand. In such cases series capacitive compensation can be used to reduce the series line reactance and thus increase the stability limit. This, however, has an impact on the performance of the distance protection relays which need to take into account the existence of the series capacitor. The application of series compensation in some EHV transmission lines is currently being considered in the UK.

2.4.8 Impacts on Special Protection Schemes performance

Unlike traditional protection systems which aim to protect individual power system components (transformers, lines, etc.), Special Protection Schemes (SPS) are oriented to protect the overall integrity of the power system.

SPSs or Remedial Action Schemes (RAS) are designed to detect abnormal system conditions and take predetermined corrective action (other than the isolation of faulted equipment) to preserve system integrity and provide acceptable system performance. SPS actions include among others, changes in load (e.g. load shedding), generation, or system configuration to maintain system stability and acceptable voltages or power flows. System wide protection operates in multiple locations with co-ordinated control of multiple signals.

The use of an SPS is generally justified for loss of network integrity characterised by one or more of the following phenomena:

- Transient angular instability.
- Frequency instability.
- Voltage instability.
- Small signal/disturbance angle instability.
- Instability resulting from cascade line tripping.

Two main aspects can be considered when designing SPS:

- System studies for contingencies identification: The requirements on the SPS can be identified as the necessary actions to fulfil the system performance criteria, with respect to the applied contingencies or disturbances. The identification of these contingencies requires extensive system studies to provide a thorough understanding of the limitations and restrictions. These studies require modelling of the system in sufficient detail in order to accurately simulate the actual responses to the contingencies.
- Decision logic of the SPS to execute actions: The real system conditions under predetermined contingences can be used as an input to the SPS operation. The possible decisions can be:
  - Predetermined, based on the off-line simulation.
  - Intelligent, based on the on-line simulations. A special, usually simplified, power system model is needed which can run in real time.

  The SPS operates from the detection of the contingence. This detection can be based either on the event itself (event based) or on the power system response to the event (response based). An example of the event based operation could be the loss of a critical line. An example of the response based operation could be the frequency drop below a certain threshold.

The SPS would be implemented to fulfil two main purposes:

- System Security, in order to face instability, disturbances and faults
- Normal Operation, in order to support the network under congestion and thermal overload situations

In this regard, there are applications of SPS designed to allow the connection of wind generation in remote areas without compromising the stability of the network. For example, SPS can protect a corridor for the interconnection of wind power to the network [10]. SPS detects the opening of one line of the corridor and disconnects the necessary amount of generation to maintain the operation within the transmission capacity. The generation to be shed is pessimistic when assuming generators operate at rate power, especially considering the intermittent nature of wind power.

At present there are hundreds of SPS schemes installed around the world with different levels of complexity. However, some limitations can be identified. The presence of DG generation in the network increases the uncertainty regarding the load and generation conditions during the real contingencies. In order to compensate for this uncertainty, many SPSs are designed with pessimistic assumptions and consequently overreact. For example too much load could be shed in a specific network situation or disturbance. Additionally, the contingency studies need to be repeated periodically to account for the continuous development of the network. In this regard, there is a high risk of actual DG levels not being adequately considered or updated.

The impact of the network uncertainty on the SPS operation depends on its complexity. Real time SPSs have a more optimized reaction because they are based on the knowledge of the actual network condition. The acquisition of the real time information from the DGs represents a significant difficulty, especially with the high amount of dispersed generation connected to the distribution network. An additional difficulty for the system studies is the modelling of the new generation technologies. While the models are well defined for conventional rotating machines, they are not sufficiently developed for power electronics based generators. According to [11], it is particularly important to develop better models for wind turbines. For example, the dynamic behaviour of wind turbines with FRT capabilities depends on the specific solutions adopted by each manufacturer.

Usually, the simplified models are used, which could affect the accuracy of the simulation and the resulting actions.

2.4.9 Impact of the short circuit current contribution from new generation technologies on network protection

In 2.2.3, the behaviour of recent generation technologies (DFIG and full converter wind turbines, PV power plants, etc.) regarding short-circuit currents have been described and its potential influence on the current network protection practices has been pointed out. The low short circuit current expected during fault conditions with a high presence of RES generation, under some circumstances, can lead to failure in fault detection. This means not only longer clearance times with higher probability of equipment damage and blackouts, but what it is more important, a higher risk to personnel.

In [12], the behaviour of the Spanish power system protection including the influence of the renewable energy sources (as projected for 2016) was analysed by means of simulation studies, considering three-phase faults in the transmission network under different scenarios. The different protection functions have been modelled and assessed. The study provides the following conclusions:

- Line protection based on differential or distance relays and busbar protection performance in terms of security and dependability should not be affected by the scenarios of high wind turbines generation.

  However, it is necessary to stress that the protection response to the new current dynamics, when this current is provided only by the wind power generation, as in the case of direct connection through a dedicated line or tapped connection to an existing one, has not been analysed in detail and a failure to operate could be expected. For example:

  - Line differential protection will not trip if a supervision current threshold for trip is set. The same applies to busbar protection.
  - Zone 1 distance unit or communication aided schemes are expected to operate correctly with DFIG generators because a sufficiently high short circuit current is supplied for a few cycles, which should be long enough for the relay to operate, but not with full converter based generators Time delay distance units (Zones 2 and 3) for remote faults are not expected to operate correctly in any case.

- Overcurrent protection as backup or ground directional overcurrent relays could not detect the low currents appearing in the system.

- Transformer overcurrent relays could not operate for faults on the low voltage side with high wind power generation or do it with a long delay because the low through current could be even lower than the relay pickup (usually 1.4 or 1.5 times the transformer rated current).

- Converter based wind generation only provides three phase short circuit current even for single phase or two-phase faults. This would affect the performance of single-pole reclosing because current protection would not be able to distinguish the type of fault. This situation would lead to three phase tripping for all faults with the possible impact on system stability.

In distribution networks, protection against short-circuit faults on the lines is generally provided by means of overcurrent relays and/or fuses coordinated with the protection devices of the distribution feeders. Under high penetration of DG based on converters and during certain conditions, generator protections might be unable to detect a fault and supply a significant fraction of the fault current, reducing the current flowing through the substation, and therefore, hampering fault detection. This leads to a necessary revision of the protection philosophy of distribution networks, probably bringing types and schemes of protection used in transmission networks to secure a correct detection and clearance of faults [13].

2.5 DG Interconnection Rules and Regulations

2.5.1 Introduction

The change in the nature of the generation mix has pushed most of the network operators (transmission and distribution) in different countries to develope rules and other technical requirements regulating the integration of DG into the power system to ensure security of supply, reliability and power quality. This information can either be included in the utilities rules, or is required by the regulation authority under codes or laws, or both, depending on the country.

Gride codes of different countries have not been adapted to DG at the pace neither reflect the same technical requirements which responds to the specific characteristics of the respective power systems and different DG penetrations levels.

Usually, there are specific interconnection rules for small DG units, generally connected to MV, with stricter requirements on protection than for the bigger generators because of less control of the small generating installations by the network operator. For medium and large generation, technical requirements are normally included in the Grid Codes. As already mentioned in previous sections, both technical requirements have to be considered because of the great spread of DG in MV and its importance for the reliability and stability of the power system.

A generic grid code would include the following interconnection requirements for power generator:

- Point of interconnection:
  - Configuration schemes and constraints
  - Grid capacity studies
- Installation equipment requirements:
  - Circuit breakers and isolating switches
  - Substation grounding
  - Insulation co-ordination
- Performance requirements:
  - Electrical disturbance and power quality (voltage fluctuation, harmonics, phase unbalance, flicker)
  - Generators:
    - Power factor range for continuous operation
    - Frequency and voltage ranges for continuous operation
    - Voltage control (AVR)
    - Active power control and frequency control
  - Transformer: tap-changing and connection group
  - Protection requirements:
    - Sensitivity and co-ordination for internal and external faults
    - Protection against internal faults
    - Line protection:
      - Relay type for phase faults (distance, overcurrent, undervoltage) and ground faults (zero sequence voltage detection, distance, ground overcurrent)
      - Redundancy requirements and communication assisted schemes
    - Breaker failure protection

  - Under and over-voltage relay
  - Under and over-frequency relay
  - Prevention of line energization or islanding operation (anti-islanding relay, transfer trip facilities)
- o Control, telecommunication and metering requirements

Protection requirements are in some cases included in the grid codes, which can include also setting recommendations. Details of the existing codes for connection of generators to the network in various countries are given in Appendix A. In Appendix D, protection practices for the connection of DG to the network and specific solutions used in several countries are described and compared.

2.5.2 Specific requirements for wind farms

Until recently, wind generators were exempted from technical requirements and system/ancillary services capability. However, due to the increasing penetration of wind farms in some regions, formed by groups of small power plants that together form an equivalent of a medium size or even a large size power plant, this exemption was found to jeopardize the system security and power quality, so several system operators developed and issued additional grid codes that impose technical requirements on wind generators to enable system operators to have some control over wind farms.

The analysis of the specific requirements of different European grid codes for wind farms [14] shows that many of the technical aspects are only mentioned in some of them because each one reflects the technical conditions of the respective transmission system.

Analysing the grid codes of several European countries, the essential grid code requirements are related to voltage and frequency operating ranges and fault ride through capabilities, which are described in the following sections. Additionally, in some countries large DGs are required to have capabilities to contribute to frequency and voltage/reactive power control during steady state operation, which are described in section 3.2. To meet these requirements new wind generators generally include power electronics. By bilateral agreement, further technical requirements such as fault current contribution, reactive power range or harmonic performance can be specified.

Several steps for harmonizing are being developed in several standardization bodies (IEC, CENELEC, IEEE, etc.), including type testing procedures, which will make the integration of DG in multi-national networks easier (e.g. in the European interconnected system). For manufacturers such harmonisation of test procedures would facilitate the development of standard products which could provide cost effective and fast solutions. However, it is believed that introduction of a common grid code, specifying the most demanding requirements for the worst case scenarios, would be unnecessarily expensive for those countries with more benign scenarios. Instead, it is proposed to develop a standard product which meets the majority of common requirements, to which additional features can be added to meet the needs of specific, more demanding applications in some countries.

2.5.2.1 Frequency operating range

Traditionally, grid operators required wind turbines to disconnect from the network in the case of frequency drop. However, if increasing amounts of wind generation disconnect at low frequency, this may affect the system's ability to recover. To avoid that, some grid operators have reversed their requirements and now require wind turbines to stay connected and operate at a wider frequency band.

Analyzing the different European grid codes, generators, including wind farms, are required generally to be capable of operating continuously at full power output between 47.5 Hz and 52 Hz and time (or power) limited between 47 and 47.5 Hz and likewise between 52 and 53 Hz[2]. The synchronous zones of the UK and Ireland being smaller and having less inertia operate in a broader range than that of the European interconnected system to prevent large frequency changes. The wind farms should generally remain connected to the transmission system during rate of change of system frequency of up 0.5 Hz per second. Automatic isolation from the network due to the frequency relay operations should be only permissible at frequencies below 47 Hz and above 53 Hz. The wider frequency range required for operation of DGs and the increasing need to help support the grid and improve grid stability while maintaining adequate protection against unintentional islanding is a real challenge for the design and settings of anti-islanding relays.

The Australian regulations define smaller frequency ranges, with the "operational frequency" range (essentially continuous operation) being 49.0 to 51.0 Hz, and the "extreme frequency range" (time limited between 9 seconds and 10 minutes) being 47.0 to 52.0 Hz.

2.5.2.2 Voltage operating range

Generators must be able to run at rated voltage plus a specified voltage range. The voltage range depends on the level of the voltage on the transmission system, which varies from country to country. It can be concluded that continuous operation in a voltage range of around ±10% of the nominal voltage is generally required.

2.5.2.3 Requirements of fault ride through capability for wind turbine generators

First designs of wind turbines disconnected quickly when a voltage drop occurred. This was done both to comply with utility regulations that aimed at preventing islanding, and to protect the power electronics converter in variable speed turbines. However, as the wind penetration has increased, generators have been required to remain stable and connected to the network when faults occur on the transmission network. Otherwise the power system would be exposed to a great loss of generation with the consequent danger of the system frequency dropping too rapidly and load shedding becoming necessary, unless enough back-up capacity from the other power plants are kept to balance the generation outages of WPP. This is known as fault ride-through capability (FRT) and is included recently in the Grid Codes as a requirement in a few regions with large number of wind turbines. At present, all manufacturers offer turbines with FRT capabilities.

The detailed requirements of voltage level and duration of the fault for various countries are shown below in figures 2-7 to 2-15. A wind turbine generator shall remain connected without tripping to the system during external faults when system voltage measured at the HV terminals of the network transformer, remains above the corresponding curve. Under voltage protection should be set to meet the requirements described above.

[2] In 60 Hz power systems, as the Canadian one, the previous frequency limits are between 59.5 and 60.5 Hz for continuous operation and between 56.5 and 59.5 Hz likewise as between 60.5 and 61.7 Hz for time limited operation.

In addition to the previous requirement, wind turbines should not consume reactive power during and after faults or do it under restricted conditions. In some grid codes, even reactive support has to be provided to the network during and after faults, contributing to the voltage recovery of the system. Likewise, wind farms should provide its maximum available active power as quickly as the technology allows with a minimum gradient, depending on the grid code, of the rated power per second.

Comparing the different curves, we can find significant differences. Except the curves of Finland, France and Germany, the minimum admitted dip without disconnection ranges from 0.15 to 0.25 p.u. Also, the time that generators must withstand such a dip ranges from 0.1 to 0.625 s.

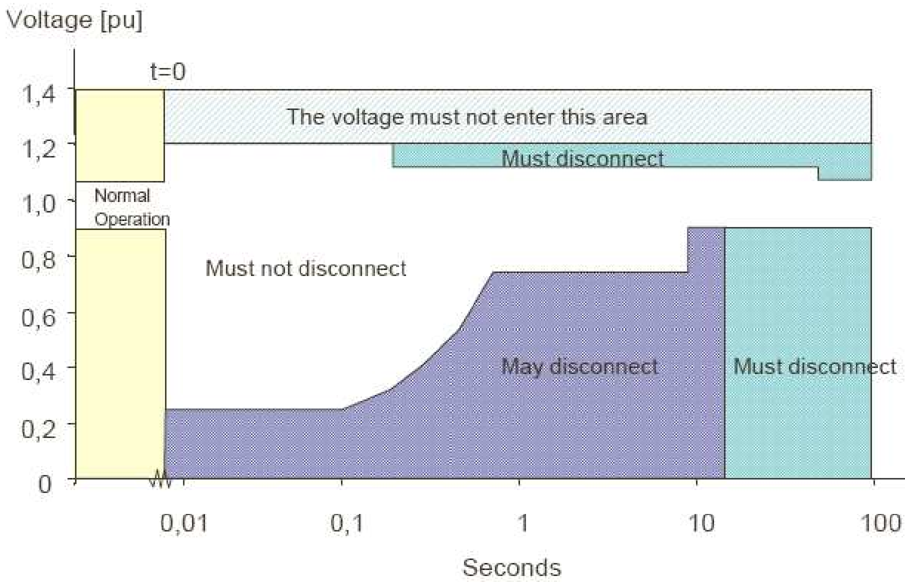


Figure 2-7: Fault Ride Through requirements in Denmark[3] [15]

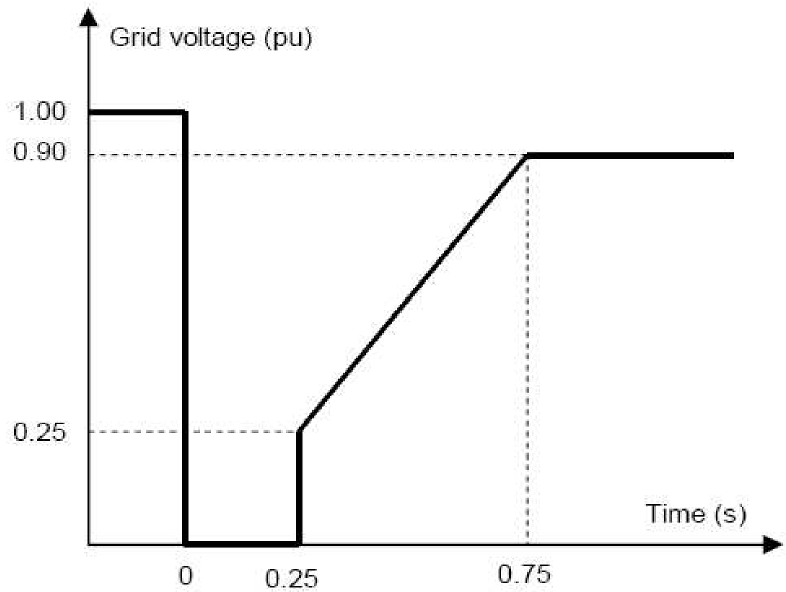


Figure 2-8: Fault Ride Through requirement in Finland [16]

[3] Requirements concerning disconnection in the event of deviations in voltage. At t=0 an operating disturbance occurs. (With a linear time axis the curve section between 0.1 and 0.75 seconds is a straight line.).

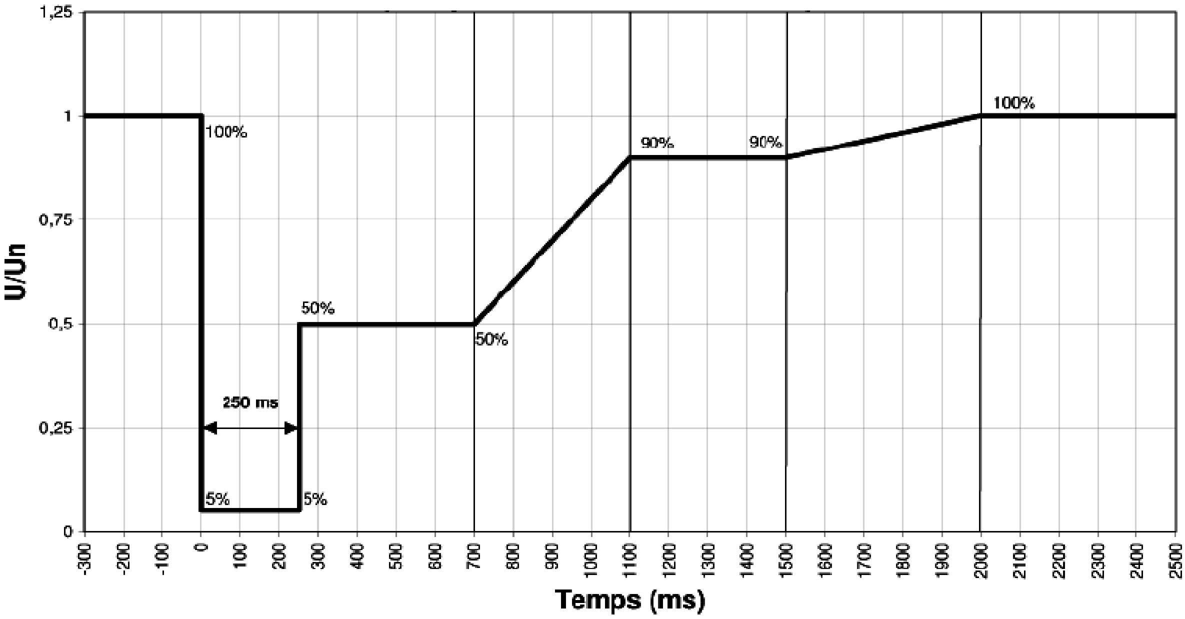


Figure 2-9a: Wind farm Fault Ride Through requirement in France (non meshed 225kV, 90kV and 63kV networks) [17]

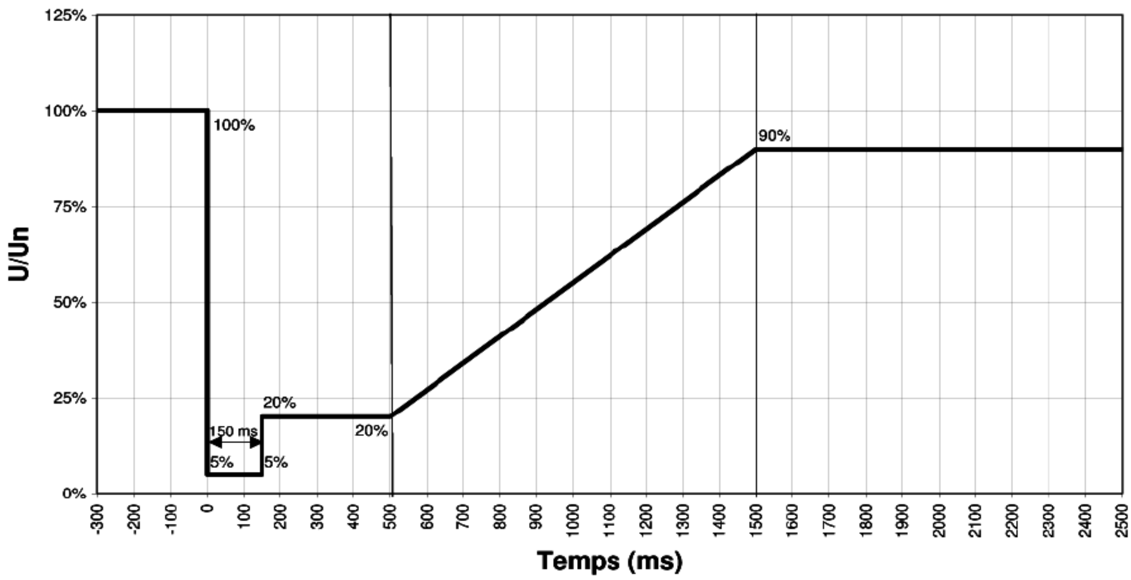


Figure 2-9b: Winfarm Fault Ride Through requirement in Distribution network in France for generators above 5MW [17]

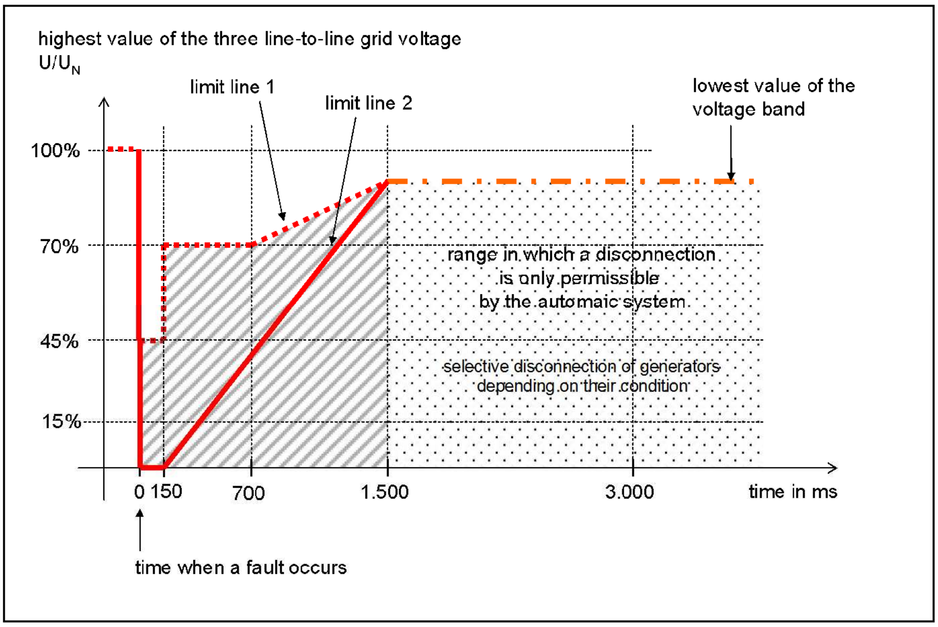


Figure 2-10: Fault Ride Through characteristic for the area in Germany controlled by E.ON Netz GmbH[18][4]

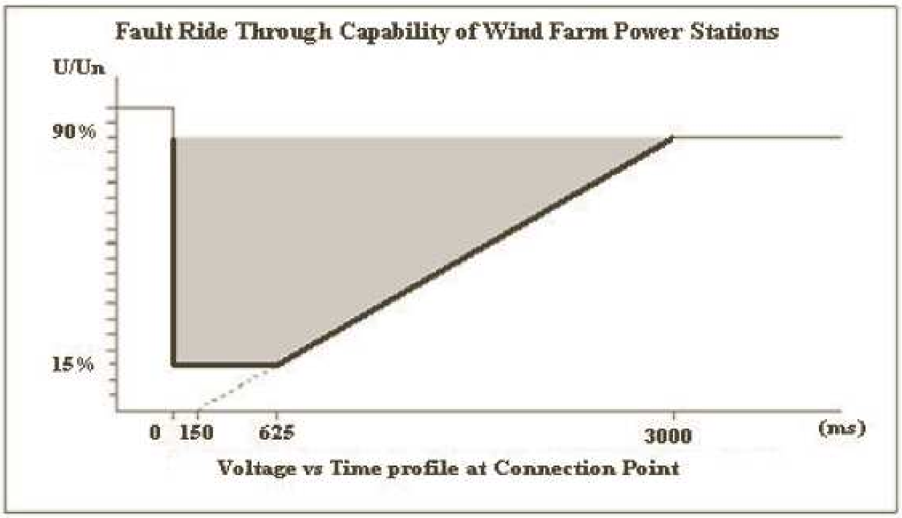


Figure 2-11: Fault Ride Through Capability of Wind Farm Power Stations in Ireland [19]

[4] Limit line1: Normal operation. Limit line 2: Supply a defined current

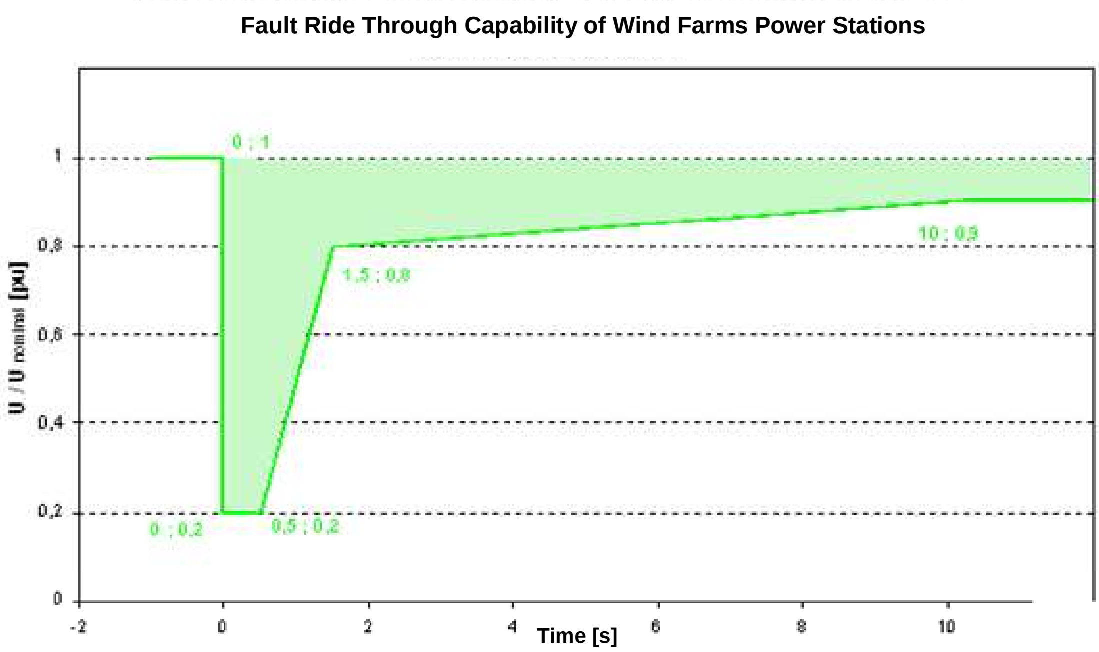


Figure 2-12: Wind Turbine Generators fault ride through required curve in Portugal [20]

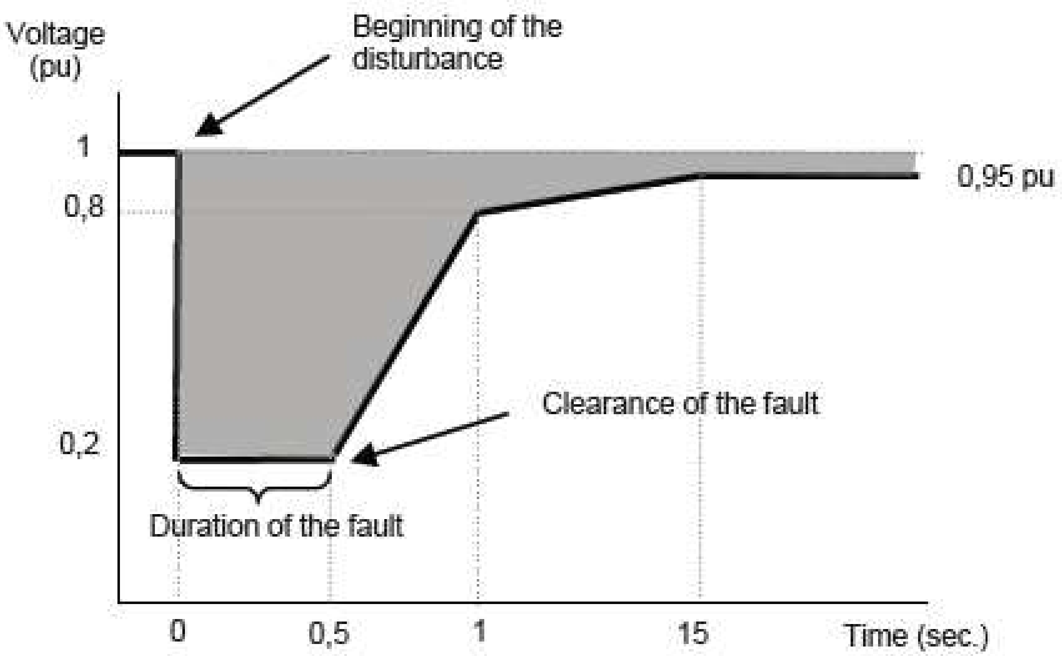


Figure 2-13: Fault Ride Through characteristic in Spain [21]

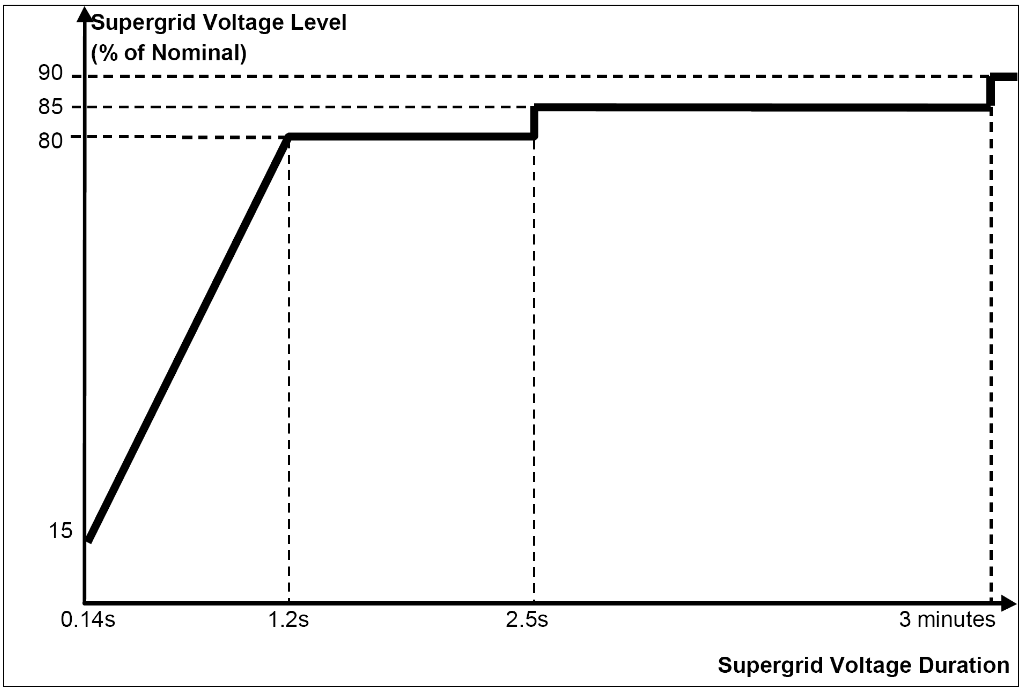


Figure 2-14: Fault Ride Through requirement in UK [22] (voltage-duration profile for voltage dips having durations greater than 140ms)

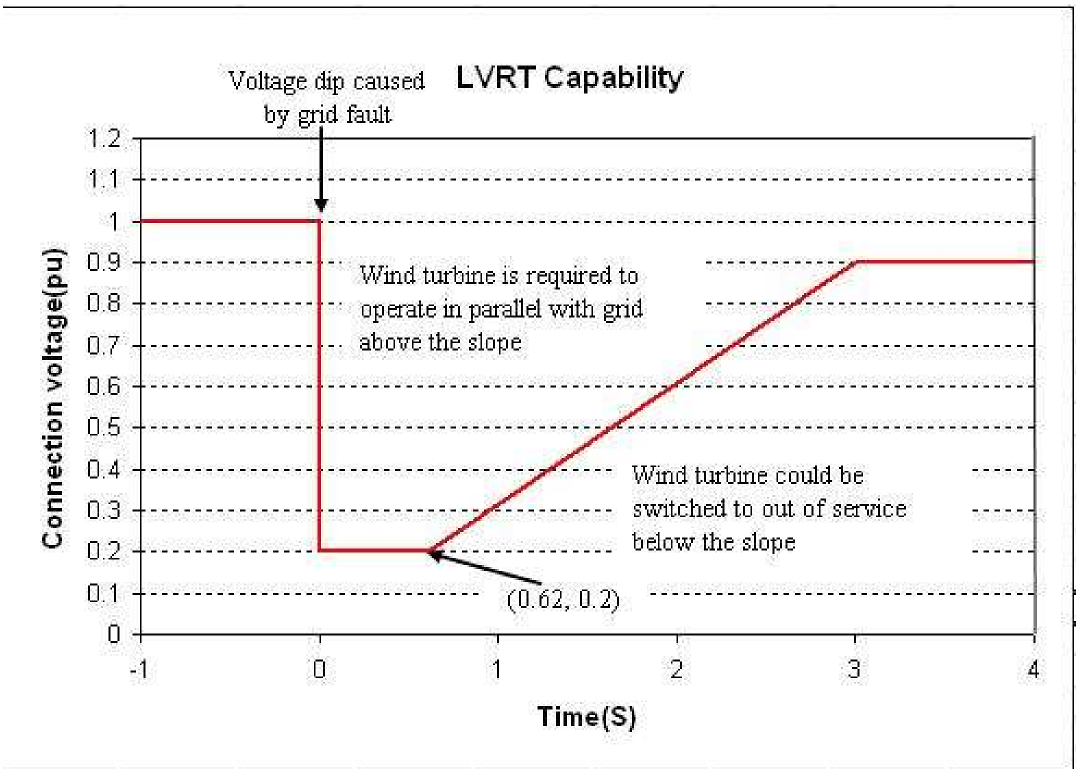


Figure 2-15: Fault Ride Through characteristic in China [23]

2.6 Conclusions

Different aspects concerning protection requirements as consequence of the connection of DG have been dealt with in this chapter.

Regarding protection of the DG interconnector, for the appropriate protection scheme selection, several system aspects should be taken into account, such as voltage level and topology characteristics of the network, dynamic response of the generator, system grounding, type of connection, DG transformer connection, etc., as well as the protection policy of the utility and co-ordination requirements.

In the DG interconnection two protection sets can be distinguished:

- Interface protection that disconnects the DG for internal faults that may be fed by the utility networks and in case of abnormal voltage or frequency, caused by abnormal operation conditions of the DG, are detected. Anti-islanding detection is also included.
- Line protection that protects the DG installation against faults in the interconnection line. The type of network to which the generator is connected and the philosophy and practices of protection of the utility network generally determine the type of protection. Co-ordination with other network protections has to be studied to prevent unnecessary trips. For example, undervoltage settings must consider the co-ordination with other network relays under external faults but also the FRT requirements where appropriate.

Regarding the implication for the network protection, several possible impacts on the distribution protection have been analysed when a DG is connected, depending on the characteristics of the network. In distribution networks, co-ordination with existing overcurrent relays of feeders may not be kept due to the short circuit current supplied by the generators, so directional relays should be installed in such a case. As the penetration level increases, the currently used protection should be redesigned, ranging from protection settings, through changes in protection schemes (directional relays), to changes in the power system architecture. Other issues are the loss of protection sensitivity in tap connections, the reclosing co-ordination, etc.

Current protection settings are very rigid for the changing conditions in the network so new adaptive solutions will be needed in the future.

At transmission level, DG could impact the system stability and transmission capacity. There is a lack of co-ordination between current WAP performance and DG.

Additionally, the short circuit current contribution of the converter based generators can affect the protection performance. The impact on the performance of the current line protection needs to be assessed, especially for those connection schemes in which current detected by relays is exclusively supplied by DG, i.e. direct line connections, tapped connections or connections to a substation with a few lines. Some conclusions can be stated:

- Line differential protection performance is not affected but the current threshold for tripping should be set very low at the generator end.
- The short-circuit current of DFIG wind turbines with crow-bar protection is reduced to the rated current level typically in 9 cycles. This gives the opportunity for the first zone of distance relays or communication aided tripping distance schemes to operate, but not for time delayed distance zones. DG generators based on converters do not provide enough short circuit current in any time so distance relays are expected to maloperate.

Some solutions to overcome the limitations of distance relays for fault detection could be by using line differential protection instead or a hybrid teleprotection scheme with weak-infeed and echo logic.

- Ground directional overcurrent relays are expected to maloperate or operate slower, so line differential protection should be set with enough sensitivity to detect high resistance faults.
- Transformer overcurrent relays may not operate or operate very slowly for faults on the low voltage side.
- For unbalanced faults, since the current provided by the generators is not unbalanced, single-pole tripping would not be possible because of the difficulty to identify the type of fault. It is necessary to increase the research and development in the design of generators to solve this limitation.

The protection challenges and priorities for integration of DG into the power network depend on the level of DG penetration which will differ from country to country. For integration of small scale DG the main priority is the safe and secure operation of the utility network. One of the main priorities is that islanding is not allowed which is the situation today in most countries. In most DG installations voltage and frequency protection is required at the point of common connection which is relied upon to provide some level of anti-islanding protection but in some countries more dedicated and sensitive protection such as ROCOF or voltage vector shift is used for this purpose. The reliability of the anti-islanding protection and co-ordination of the voltage and frequency protection with other relays in the system is important but is not critical with small scale DG as the loss of generation due to spurious tripping of anti-islanding protection lack of protection co-ordination does not constitute a major problem for the system stability.

For the integration of medium scale DG the main priority is co-ordination to avoid large scale tripping of generation. High DG penetration makes it desirable to involve DG units in the power balance on the highest system level. Instead of tripping DG units for remote system disturbances, it is desirable for DG to withstand much greater variations in voltage and frequency. Voltage protection settings must co-ordinate with FRT characteristics and frequency relay must do it with system load-shedding protection. Operation at the wider frequency band, between 47 to 53 Hz, and the wider voltage range may help the integration of medium scale DG. However, this approach entails difficulties for the distribution networks as wider frequency operation could severely limit the islanding detection capabilities of the present protection practices.

Most of the countries have developed codes or laws regulating the requirements for the above aspects in order to integrate the DG into the power system with the appropriate levels of security and stability. The FRT voltage characteristics are being specified in many countries for DG, particularly for wind farms, so that DG remains connected during external faults. These relatively complex FRT characteristics vary from country to country and are difficult to co-ordinate with the simple definite time or inverse time voltage protection characteristics in many of the protection relays at the DG point of connection to the network. FRT curves required for wind farms in several countries have been analysed and compared. It is interesting to outline the different performance required from one country to other, which do not always correspond to a real need for very strong networks. Harmonization of the FRT curves between countries and standardisation of voltage and frequency settings throughout the network will help provide better co-ordination and avoid unnecessary tripping of DG. It would also facilitate better design by turbine manufacturers.

3 Control and monitoring requirements and practices

3.1 Introduction

The greater presence of DG pushes the system operators to require more capabilities from the new generation, especially wind farms, to participate in the system stability in cooperation with the large conventional generation.

Grid codes are demanding more controllability on active power output, so wind farms can increase their power output on demand in real time, especially in countries with a high wind installed capacity where generation reserve needs to be increased during times of high winds and low system load. Also, wind farms are required to contribute to the reactive power balance.

The first part of this section presents a general view of the current situation regarding the voltage and frequency control capabilities of wind farms. The second part shows control implementations and requirements in some countries, including monitoring and control functions, etc.

3.2 Voltage and frequency control capabilities

3.2.1 Voltage and reactive power control capabilities of wind farms

When replacing large synchronous generators connected at the transmission level by small generators integrated into the sub-transmission or even distribution systems or far from the load centre, the amount of reactive power reserve needed in the transmission grid is considerably reduced. In principle, modern wind generators are able to regulate the voltage and have a considerable reactive power range. However, most wind farms are operated at constant (and unity) power factor. Furthermore since wind farms are very often connected at weak points in the network, reactive power losses are considerable, which limits the possible contribution of wind generators to the reactive power balance at the transmission level. Thus, even wind generators with voltage regulation are not able to provide any substantial contribution to the reactive power balance at the transmission level.

The reactive power contribution of wind power plants is highly dependent on the technology used, the connection point and voltage level as well as additional reactive power support (SVC, STATCOM). Unlike fixed speed turbines, variable speed technologies (doubly-fed induction generators and synchronous or induction generators connected through full power converters) offer the opportunity to control reactive power either in production or in absorption. The reactive power capabilities (either in absorption or in production) depend on the power electronics converters rating. The usual control range is ± 0.3 Sn.

In some countries there are requirements for voltage regulation in normal operation, especially for large wind farms connected to transmission network. The system will act to regulate the voltage by continuous modulation of the reactive power output within its reactive power range, and without violating the voltage step emissions. The set-point is adjustable within 95% to 105% of rated voltage. The requirements of the reactive power and the power factor are relatively similar in the different Grid Codes. Generally, wind farms should inject reactive power as a percentage of the active power and they should be capable of operating at any point within the power factor ranges by remote or local orders. There may also be incentives or penalties for specific power factor requirements either by bilateral agreement, or by grid code.

Additional compensation systems can improve the generators reactive power and voltage regulation capacities. Furthermore, some devices are now able to propose a so-called “zero power” voltage regulation. This is a solution for the reactive power control even when the wind turbines are not generating active power [25].

3.2.2 Frequency control capabilities of wind farms

Frequency response is the capability to vary active power output in response to changes in system frequency. This tends to be more demanding in countries with low inertia systems such as Ireland and the UK.

Modern rotational speed-variable wind turbine generators are either designed as a doubly-fed induction generator (DFIG) or as a synchronous generator and full-power converter. Both types of machine are ideally suited for rapid regulation of active and reactive power and/or voltage. Consequently, wind farms which are equipped with these machines essentially fulfil the requirements for taking on the constraints of regulating the grid.

There is the potential of speed-variable wind turbines with pitch control to participate in primary control. It assumes the availability of both a positive and negative power reserve, which can very quickly be activated in response to grid frequency changes. The operation mode for pitch control generally in use today only allows a reduction in power, e.g. in strong winds or at excessively high grid frequency. Up until now, it has usually been assumed that it is not possible to provide additional active power because wind speed, a factor that cannot be influenced, determines maximum power. Maximum power output has been targeted through the simultaneous optimisation of the pitch angle setting. However, if the wind turbine were operated without optimising pitch angle, this would also result in positive reserve power, which could be activated by adjusting the pitch angle. During normal operation, this would result in de-rated operating characteristics comparable with throttling in conventional power stations [25].

Also, whereas conventional power plants may take several hours to start from ‘cold’, wind generators can be activated much faster, subject to wind conditions.

3.3 Control practices of wind farms in Denmark

Wind power and local CHP plants have displaced central units which are being decommissioned, as there is no longer a commercial basis for them. It means that the regulating units are disappearing in areas where the need for regulating capacity is growing. The regulation must then be affected by the local CHP plants and the wind power. Eltra is therefore working on getting these services from the DGs.

The Eltra and Elkraft System are responsible for preparing technical regulations for connecting the electricity supply grid as well as regulations relating to market player obligations. The regulations are to provide the system operators with a possibility of maintaining the technical quality and balance within the public power grid, etc.

Previously, large power station units undertook the tasks related to regulation and stabilisation of the power system. As power production in Denmark is increasingly based on wind and on local combined heat and power production, all production units, including wind turbines, will have to contribute to solving these tasks in the future.

New technical regulations lay down the requirements for connecting wind turbines to the grid. Besides, it is necessary to ensure that the wind farm has the regulation properties and dynamic properties essential for power system operation.

The Technical Regulations apply to wind farms connected to the transmission grid in Denmark after December 1, 2004, that is, grids with voltages above 100kV.

3.3.1 Active power control

Deviation from the desired power production caused by lack of wind resources are not covered by the requirements in regulations.

It is possible to limit the production of a wind farm to a random set-point value in the range of 20 - 100 per cent of rated power. The deviation between a set-point value and a metered 5-minute mean in the connection point can not exceed ±5% of the rated power of the wind farm. It is not possible to set the regulation speed upwards or downwards in the interval 10 - 100% of rated power per minute.

For each wind farm a joint function is to ensure remote control of the farm's total active power production. The function is called "farm controller" and is to ensure that regulating orders to the wind farm's total production are met in the connection point. The farm controller enables ordering of the various types of regulation as total orders which can be given both locally and via remote control (see Fig. 3-1). Each wind farm covers regulation functions for active power output from the farm controller as indicated in Table 3-1.

Type of regulation	Purpose	Primary regulation aim
Absolute production constraint	Limit the wind farm's current power production at the connection point to a maximum, specifically indicated MW value. Constraints may be necessary to avoid overloading of the power grid.	Limit production to optional MW_{max}.
Delta production constraint	It must be possible to reduce the power production of the wind farm by a desired power value compared to what is possible at present, thereby setting aside regulating reserves for the handling of critical power requirements.	Limit production by MW_{delta}.
Balance regulation	The power production of the wind farm must be adjusted to the current power requirement with a view to maintaining the power balance of the balance responsible market player and/or the system operator. Downward/ upward regulation of production must be possible.	Change current production by –MW/+MW with the set gradient and maintain the production at this level
Stop regulation	The wind farm must maintain the power production at the current level (if the wind makes it possible). The function results in stop upward regulation and production constraints if the wind increases.	Maintain current production
Power gradient constrainer	For system operational reasons it may be necessary for wind turbines to limit the maximum speed at which the power output changes in relation to changes in wind speed. The power gradient constrainer is to ensure this.	Power gradients do not exceed the maximum settings
System protection	System protection is a protective function which must be able to automatically downward regulate the power production of the wind farm to a level which is acceptable to the power system. In the case of unforeseen incidents in the power system (for instance forced outage of lines), the power grid may be overloaded with the risk of power system collapse. The system protection regulation must be able to rapidly contribute to avoiding system collapse	Downward regulate power production automatically on the basis of an external system protection signal.
Frequency control	At frequency deviations in the power system all production units connected to the transmission grid must be able to contribute with rapid automatic power control to support the restoration of normal frequency (50Hz).	Regulate power production on the basis of local frequency metering for reestablishment of normal frequency.

Table 3-1: Types of wind farm active power regulation

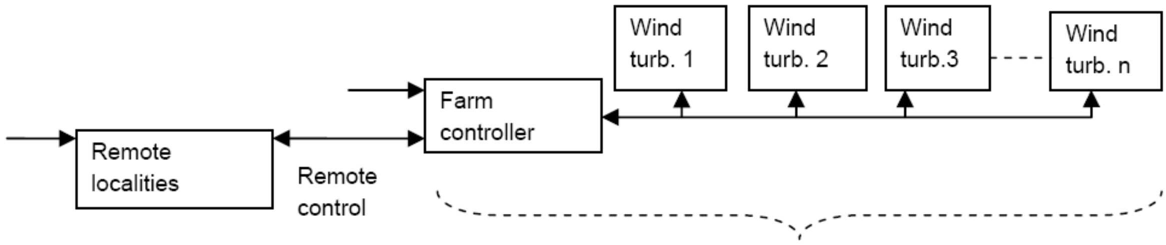


Figure 3-1: Wind farm controller principle illustration

3.3.2 Reactive power control

The wind farm is equipped with reactive power compensation ensuring that the reactive power as a mean value over 10 seconds is kept within the control band, as shown below. This applies in the connection point at all production levels in the stated full-load range for the voltage.

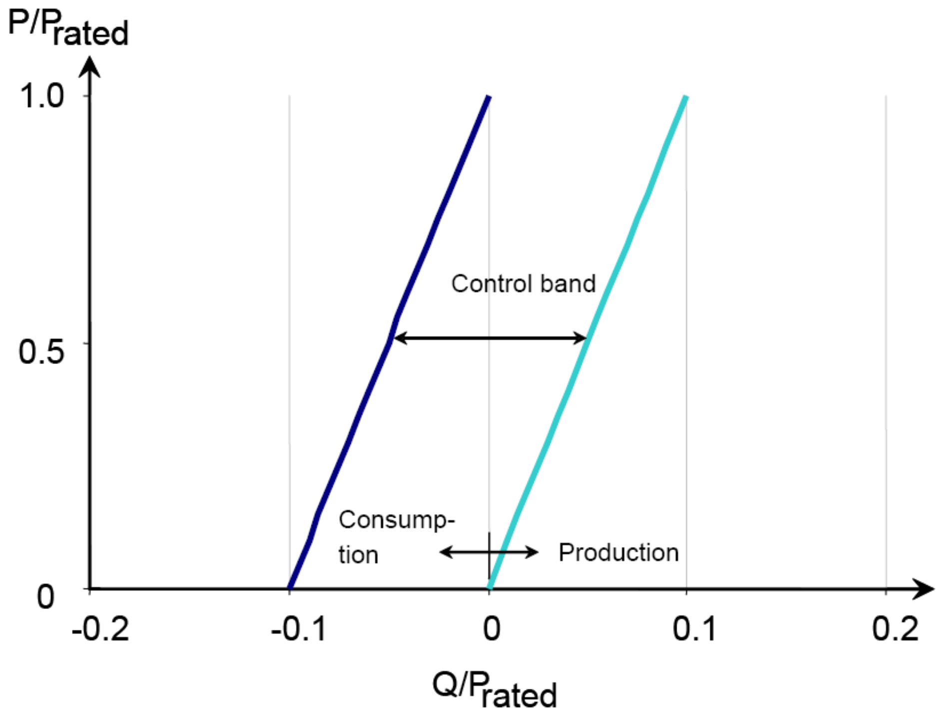


Figure 3-2: Wind farm control band for reactive power regulation

Reactive regulation of the wind farm is done for the total wind farm by the farm controller function. It is possible to place the desired reactive orders and settings here.

Type of regulation	Purpose	Primary regulation aim
MVAr regulation	Automatically ensure that the wind farm supplies the desired MVAr exchange at the reference point	Maintain the desired MVAr value at the reference point.
Voltage regulation	Automatically ensure that the desired voltage at the reference point by reactive regulation of the wind farm	Maintain the desired voltage at the reference point.
Reactive regulation according to minimum requirements	The reactive production of the wind farm shall observe the permitted reactive characteristic at the connection point.	Ensure satisfaction of reactive minimum requirement in this Regulation.

Table 3-2: Types of wind farm reactive power regulation

3.4 Control practices of RES/DG in Finland

The requirements given by Fingrid Plc [26] on the transmission network (≥110kV) consider the following aspects:

- Voltage and frequency deviations
- Large voltage changes
- Voltage control
- Power control
- Verifications
- Information exchange

The specifications are applied to new power plants as well as units being renovated. The requirements are applied to all units above 10 MVA; however units between 10-50 MVA are given some allowances. Also, it is only recommended to apply these requirements between 1-10 MVA.

The requirements considering voltage control and power control are not applied to wind power units. On the other hand, wind power must fulfil the Nordel grid code "Nordic connection code for wind turbines", which is published as an appendix of the Fingrid requirements.

Actual requirements on implementation of the power unit protection are not included. The operation of a power unit during different situations is described instead.

3.4.1 Voltage control

Primarily the units are driven in a constant voltage control mode.

The power unit must be able to produce or consume reactive power within given limits. The unit must be able to operate with a power factor at least down to 0.95 underexcited (with grid voltage at 100-105%) and at least to 0.9 overexcited (with the grid voltage at 90-105%).

During a low voltage situation the generator must be able to produce a reactive power of the magnitude of the nominal active power for 10 seconds while the grid voltage has decreased to 70% of the nominal value.

A power system stabilizer (PSS) is required for generators above 50 MVA.

FRT is required in accordance with Figure 2-8.

3.4.2 Verifications

Tests performed during the interconnection process are clearly defined. However, it is mentioned that they can also be replaced with simulations or technical calculations when agreed.

Tests and measurements considering the grid include:

- Deep voltage transient caused by a short circuit
- Changeover to house load operation
- House load operation

Tests and measurements considering the power unit include:

- Nominal power and the capability curve
- Step response of the generator voltage
- Power system stabilizer (PSS) test

3.4.3 Monitoring and supervision

It is defined that for power units above 10 MVA, real-time measurement for active and reactive power as well as the state of the connection must be available to the transmission system operator Fingrid.

3.5 Control practices of Power Generators in France

According to the most recent French legal text (Ministerial order NOR DEVE0808736A 23/04/08) [17] some automation or control devices are required on power generators, particular requirements dedicated to RES are mentioned, if existing, in the text below.

General requirements are split in two parts:

- Requirements for voltage control
- Requirements for frequency control.

3.5.1 Requirements of voltage control

Automatic voltage control on the EHV grid is important for system reliability because it can prevent the occurrence of phenomena, such as voltage collapse and stability loss. The voltage map of the EHV grid is defined in real time by RTE, which lays down the voltages to be maintained at a certain number of points called "pilot points", by relying on forecast network studies, if necessary.

Real-time control is based on two automatic, complementary actions called primary and secondary voltage control.

3.5.1.1 Primary voltage control

Generators are the only sources which make it possible to have constant voltage points on the transmission system; to do so, they must be equipped with a primary voltage controller. This automatic device controls local magnitudes at set points (more often voltage, more exceptionally reactive power), by acting on the generator excitation voltage.

A local regulator must be installed on every generator connected to RTE’s grid.

3.5.1.2 Secondary voltage control

In order to maintain the voltage level within bounds, a secondary voltage control has been defined (called RST). Only generators on 225kV or 400kV may be required by RTE to contribute to secondary voltage control.

When called upon, the primary controllers act instantaneously and automatically find a new working point of the generator. If no action is carried out on the set points of the controllers, some generators may needlessly produce reactive power that will be consumed by others.
Furthermore, over and above the local action of the primary controllers and of that of on-load tap changers, control of the voltage map requires more global actions, at the regional level, to cope with variations in load and topology.
This co-ordination of actions is ensured automatically on the French EHV grid by "Secondary voltage control".
Its principle consists in organising the network in "control areas" and in monitoring the voltage map separately within each area by acting in an automatic and co-ordinated way on the reactive power of certain generators in the area.
RST action consists in controlling the voltage of a particular point in the area, the "pilot point", which is chosen so that its voltage is indeed representative of that of the whole area.

In each area, RST simultaneously ensures control of the voltage map and distribution of reactive power between the generation units contributing to secondary control.
The control scheme consists of a control loop situated at the regional dispatching centre (zone controller) which makes it possible to automatically change the set point of the primary voltage controller of the generators contributing to control.

3.5.2 Requirements of frequency control

These requirements are not relevant for RES like wind, waste and hydro plants.

RTE agrees with UCTE[5] policies (P1-Policy 1: load-frequency control and performance).

3.5.2.1 Primary frequency control

Primary control is carried out by control loops ("speed controllers") situated on the generation sets. Rapid (in a matter of seconds) and decentralised adjustment makes it possible to restore the generation-load balance after a disturbance, provided that the available primary frequency reserve is sufficient.

Generators above 40MW contribute to the available primary reserve (2.5% of the rated power of each generator is required).

3.5.2.2 Secondary frequency control

The quick adaptation of generation to load carried out by primary control leaves a frequency deviation at the end of the action. It also brings about flow variations between the countries: all

[5] The "Union for the Co-ordination of Transmission of Electricity" (UCTE) is the association of transmission system operators in continental Europe, providing a reliable market base by efficient and secure electric "power highways".

the generation sets of the various countries react to the variation of the common frequency, even if the disturbance has occurred in another country of the synchronous interconnected system.

A centralised mechanism, located at the National Dispatching Centre, has the task of automatically modifying the generation programme of the generation sets in order to cancel the power deviation. To do so, it uses the remote measurements of frequency and flows on the interconnection lines as a basis to elaborate a signal called secondary load frequency control level, comprised between -1 and +1, and send it to the generation sets contributing to the secondary control in order to change their power set point values (that means typically – or + 9% of the generator's rated power, with respect of the maximum rated power).

Generators or generation plants above 120MW contribute to secondary frequency control.

3.6 Control practices of Wind farms in Norway

3.6.1 Monitoring and supervision

Normally supervisory control of wind farms is remote and located in a few central locations. In theses control centre all available power production is controlled in a common way and connected to the load control market. Each hour a day will have a unit price and a price connected to a need for more power or less power. In addition, planning and preservation is done by means of this same centralized computer system.

Concerning wind farms it is important to be aware of ongoing preservation activity when production planning is done. Each unit in the wind farm normally, in addition to supervisory control of the owner, is connected to the contractor supervisory system.

3.6.2 Operating conditions

At the start, each wind turbine is synchronized to the network one by one. In the recently commissioned wind farms there is a limited ride through capability for faults in the network.

All wind turbines are equipped with automatic adjustable capacitor banks to be able to adjust voltage output and compensate the internal consumption of reactive power.

As part of EPS planning some of the biggest wind farms will be able to take an active part in case of a network failure by disconnecting only some of the wind turbines. By doing this the wind farm hopefully can help to avoid a grid break down.

So far none of the wind farms are taking an active part in intentional islanding.

Normally the wind farm will be automatically restarted after a stop without any blocking alarms.

3.7 Control practices of RES/DG in Portugal

3.7.1 Monitoring and supervision

The first wind farm connected to the Very High Voltage (VHV) system in Portugal was at the end of 2004, and since then, all RES/DG connect at 150 kV and 220 kV must be connected to the TSO SCADA system and deliver real time data of the wind farm.

Several private owners of RES are building control centres to monitor their renewable generation.

The TSO has obtained their commitment to connect both control centres using the ICCP protocol. The first connection is foreseen for autumn 2008. The wind farm owner will deliver meteorology data and the TSO will send active and reactive set-points.

To cover the maximum real time information of the RES/DG the interconnection to the SCADA of the Distribution network is required. The TSO and the DNO are implementing the ICCP connection to enable the TSO to observe the remaining RES that is not covered by private RES control centres.

3.7.2 Control requirements

Since 2008, the Portuguese TSO is sending active power limit and power factor for the off-peak period, for specific wind power producers.

The new requirements for wind generation, currently under debate by the Ministry of Economy and Innovation, include the possibility for the wind farms to provide additional reactive power control with tan φ in the range [-0.2, +0.2].

3.8 Control practices of RES/DG in Spain

3.8.1 Monitoring and supervision

Since 2006, all RES generators with power greater than 10 MW are required by the code PO 3.7 to be associated to a generation control centre which is co-ordinated with the TSO, Red Eléctrica de España (REE). The control centre must send the information of individual productions to the TSO in real time and receives the maximum production set points in order to guarantee the network reliability all time, taking into consideration that RES have full preference in dispatching their production in the balancing market in front of conventional generation sources. This permits the TSO to manage the wind farms almost in the same way as conventional power plants.

In order to allow wind farms to contribute support to the grid voltage, generating or consuming power as demanded, an economical incentive/penalty that depends on the power factor and the demand period was introduced in 2004 by the Royal Decree 436.

REE: Control Centre for Special Regime (CECRE)

The Control Centre for Special Regime (CECRE) is planned as a dedicated centre for the special regime integrated within REE dispatch (CECOEL/CECORE). CECRE will have interlocking with other control delegated dispatches, e.g. CORE, for monitoring and issuing control instructions, but will not command generation facilities directly (except for those considered as "last resource").

REE thus receives in real time the individual power production of wind farms. This information, apart from being used in real time, is stored in data bases integrated in hourly data and used by a wind power prediction tool, for a wind power production forecast for the following 48 hours and also used to prepare different reports and statistics.

The Renewables Control Centre of Iberdrola (CORE)

Specifically, the Renewables Control Centre of Iberdrola (CORE) is an on-line supervisory and control centre for all wind farms. It has the following energy control functions:

- Communication with the TSO or with other energy management centres
- Send the production forecast to the market
- Active power control

  The control centre sometimes needs to operate at a reduced power level during periods with reduced transmission capacity or in order to solve technical restrictions. For example, during the last several years, the TSO has required some curtailments of wind farm production, in certain cases when the network stability could be compromised. For that purposes, the following functions are available:
  - Active power regulation at each wind turbine
  - Active power regulation at the wind farm.
  - Transmission of set points from the control centre

- Co-operation in voltage and reactive power control

  Iberdrola's wind farms are mostly DFIG, so the absorbed/generated reactive power of the wind turbine may be modified by regulating the input and output currents of the converters, using vectorial control techniques and the capabilities of the electronic converters itself.

  The power factor can be regulated at the wind turbine and wind farm level, with compensating elements in the substation if needed (reactors, capacitors, etc.).

Other control functions are:

- Restoring of a complete wind farm (just one order) or any turbine separately
- Stop of a complete wind farm due to electrical grid conditions
- Automatic reporting and monitoring of alarms to maintenance squads
- Informs Maintenance squads of failures and preventive maintenance actions
- Operation and monitoring of substation switchgear and equipment

For these purposes, a Control and Communication Unit (UCC) in each wind farm, with capacity to connect to all different systems that compose the local network of a wind farm, acquires the wind farm data and sends it to CORE. Both UCC and CORE are able to ensure a proper control of active and reactive power, as well as any operation algorithm that may be implemented in the WF (start, stop, emergency, special operation under specific network conditions, etc.). Besides this they are able to send and receive any signal or alarm that any other dispatch centre may require.

3.9 Conclusions

Present practices, limitations and opportunities regarding automatic control capabilities and SCADA supervision functions of DG have been reviewed in this chapter.

Regarding reactive power/voltage control, we can conclude:

- Control capability depends on the generator technology. Power electronics based generators offer wider ranges to import/export reactive power
- The network characteristics and location of the point of connection can limit the reactive power contribution
- The control requirements in the countries considered are diverse:
  - Automatic voltage control through the continuous variation of reactive output (Denmark, Finland and France, depending on the generator type and size, voltage level, etc.)
  - Operating with power factor set-points either fixed by the system operator or by the producer according to a schedule with financial compensation/penalties (Portugal, Spain,..).

Regarding frequency control:

- Some technologies, such as DFIG and synchronous full converter generators have capabilities for frequency control.
- Turbines equipped with pitch-angle control can respond to frequency changes, normally reducing the power output, as they normally operate at the maximum rate, although they offer the possibility to operate at different pitch angles to permit a reserve power.
- Automatic frequency control is only required and performed for large RES generation in a few countries (Denmark, Finland) or in low inertia systems such as Ireland and the UK, but it could be expected that at high penetrations other TSOs will demand it, especially for "low demand – high wind" situations, when there may be few thermal sets with governors to provide frequency response. The trend is for the capability of this control to be required in all countries, regardless of whether the control is actually performed or not.
- In other countries such as Spain or Portugal, large wind farms or those connected to the transmission voltage level are monitored either directly or through local control centres by the TSO so they receive active power set-points or power curtailments orders from the transmission control dispatch.

Regarding supervision, in many countries RES/DG are being progressively integrated in the TSO distpatching through local control centres that combine local automation functions, centralized SCADA applications, and energy management through powerful communication networks.

These functionalities together with more control capabilities (voltage and frequency), greater contribution to ancillary services and advanced forecasting applications are permitting, especially for renewable sources, the integration of the DG into the network and their participation in the electricity market similar to conventional generation.

4 Islanding

4.1 Introduction

Islanding (also known as loss of grid or Loss-of-Mains - LoM) occurs when some parts of the utility network (incorporating generation) lose connection with the rest of the interconnected system. After disconnection, in certain scenarios the embedded generator can maintain supply to local loads or even to a small part of a network (depending on its capacity and network topology).

Up until recently intentional islanded operation was not permitted due to a number of technical, safety and economical reasons. Recent increase in the penetration levels of smaller scale energy sources gradually changes the perception of islanding. This chapter explores the current status of islanding, highlights possible future scenarios and presents the main implications on power system protection.

4.2 Inadvertent Islanding Detection

4.2.1 Impacts of inadvertent islanding

It is very important, for safety reasons, to obtain reliable information about the islanded parts of the system and, in many cases, to effect isolation of any generation contained within the islanded network. Detection of islanding may be difficult in some cases, particularly when the local load connected to an embedded generator closely matches the generator's output level. In the worst case scenario, if islanding is not detected, then the generator could remain connected, causing a safety hazard within the network (for example, through personnel working on the network under the assumption that no parts of the network are energised), or automatic reconnection of the generator to the network may occur (e.g. through automatic recloser action), which may cause damage if the generator and the main system are not in synchronism at the instant of reclosing. This concern is only valid for radial systems where single point of disconnection can lead to isolation of a part of the utility network.

On the other hand, it is also undesirable to issue a false trip from an anti-islanding relay as this leads to the unnecessary disconnection of the generator. In most situations this would only pose a temporary loss of revenue to the generator and not have any significant affect on the rest of the network. However, with ever increasing population of DG larger groups of generators fitted with anti-islanding protection can be disconnected at the same time as a result of a single network event. Therefore, immunity of the anti-islanding protection to system disturbances becomes increasingly more important. Unplanned loss of large amounts of generation can result in both stability and power quality problems.

Depending on grounding arrangements inadvertent islanding can also lead to systems with very low single phase-to-ground fault levels. In cases where DGs are ungrounded the existing protection system is incapable of detecting single phase-to-ground faults as the fault level is below normal operating current. In order to prevent undetected ground faults fed from the DGs side additonal protection arrangement needs to be made. One such arrangement practiced in UK is Neutral Voltage Displacement (NVD) protection installed on the side of the utility network. This protection detects imbalance in three phase voltages and operates when the ratio of zero to positive sequence voltage is above a certain threshold.

Apart from a number of technical and safety challenges imposed by the inadvertent islanding there is also a legal implication. Under normal operating condition the utility is legally bound to deliver adequate quality of power to the customer terminals. However, under islanding scenario it becomes physically impossible for the utility to control voltage and frequency in the islanded part of the system. Therefore, a clear definition of responsibilities needs to be established an included in the relevant legal documents such us grid codes if intentional islanding was to be permitted.

The following sub-sections describe a number of methods utilised in order to prevent unintended islanding.

4.2.2 Islanding detection techniques

There are a number of existing protection techniques capable of detecting islanding conditions. Generally, they can be classified as:

- *passive methods*, which make decisions on the basis of naturally occurring voltage (and/or current) waveforms and
- *active methods*, which rely on the measurements of the signals actively injected into the network by specially designed control system. These are usually high frequency signals which change their characteristics under certain system conditions (e.g. islanding) allowing reliable detection of the event independently of other system events.

Although, there is an abundance of active methods proposed in the technical literature, their application in the engineering practice has been limited to date. The traditional protection philosophy of independence from other systems makes the introduction of those methods rather difficult. However, with increasing reliability of hardware and general tendency to reduce cost through integration active methods may become feasible in not so distant future.

The following sections list the most commonly used methods for islanding detection and also provide a literature review of the alternative methods found in technical literature.

4.2.2.1 Rate of Change of Frequency (ROCOF)

The most commonly utilised method for loss of grid detection is the Rate of Change of Frequency (ROCOF). This is a passive method based on the local measurement of the generator voltage. A change of frequency is caused by the imbalance between the input mechanical power and the prevailing load. Accordingly, the rate of change of frequency is often approximated by the following equation:

$$dROCOF = \frac{\Delta P \cdot f}{2 \cdot G \cdot H} \tag{4.1}$$

where :

dROCOF – calculated Rate of Change of Frequency [Hz/s]
$\Delta P = P_b - P_a$ – change in active output power during Loss of Mains event [MW]
P_b – active output power of a generator before loss of grid [MW]
P_a – active output power of a generator after loss of grid [MW]
G – nominal generator rating [MVA]
f – system frequency [Hz]
H – inertia constant of the generator [s]

The actual calculation of the df/dt by a relay can be performed in many alternative ways. One practical example algorithm is given by equation (4.2), where three cycle average frequency is used.

$$\frac{df}{dt} = \frac{f_n - f_{n-3cycle}}{3cycle} \tag{4.2}$$

Additionally, in order to minimise the chance of spurious tripping, often two or more consecutive calculations must indicate a setting threshold violation before the trip signal is initiated. A time delay setting can also be applied to improve the stability of the protection relay to non-islanding events that cause frequency perturbations.

4.2.2.2 Vector Shift (VS)

The Voltage Vector Shift protection algorithm is based on voltage angle measurements performed on phase voltages; some relays measure only a single phase quantity while others use all phases. For example, a measurement of each phase voltage angle can be performed every half-cycle and the decision as to whether a trip condition exists is made every full cycle. The angle difference between the present and previous measurement is calculated and compared with the preset threshold. The use of the three phases is beneficial as it makes the algorithm immune to harmonic distortion and to many other non-symmetrical sources of interference. Additionally, in order to further increase the stability of anti-islanding relay under system faults, under-voltage or negative sequence over-voltage can be utilised as a blocking signal.

4.2.2.3 Direct transfer trip

Another anti-islanding protection method which can be applied to prevent unintended islanding is Direct Transfer Trip (DTT). A signal to disconnect the generator is initiated by the utility line protection or circuit breaker open status. A typical arrangement is illustrated schematically in Figure 4-1.

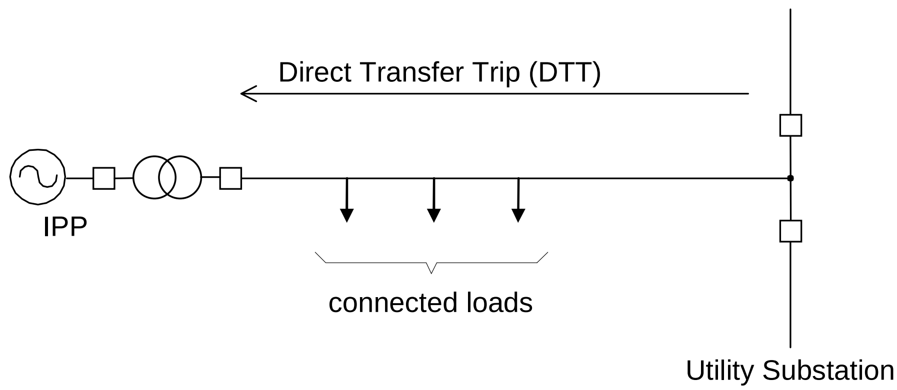


Figure 4-1: Example Direct Transfer Tripp anti-islanding protection arrangement

The DTT is more reliable compared to the previously described local measurement based methods because it is not affected by the local power balance and it is also immune to the remote system events. However, it needs to be noted that the cost of providing adequate communication media may be prohibitive in some cases. Additionally, the network topology may require transfer trip to be supplied from more than one location which adds to the cost and complexity of the scheme.

4.2.2.4 Frequency and voltage protection

In some specific circumstances it may be sufficient to apply a combination of under/over frequency/voltage protection to detect an islanding condition, especially, in cases with physical impossibility of forming a stably operating island. This includes situations such as fixed speed induction based generation without reactive power compensation or DFIG based generators without voltage control loop or Phase Locked Loop (PLL) based frequency control.

4.2.2.5 Other methods

As the problem of reliable islanding detection has been recognised as one of the most challenging aspects relating to distributed generation [27], there are various techniques proposed published in technical literature. As detailed explanation of each method is beyond the scope of this document, a summary of the islanding detection techniques is listed below.

The following passive methods have been proposed:

- detection principle based on rate of change of power [28]
- voltage magnitude variation method [29]
- method based on the elliptical trajectory technique [30]
- method based on the rate of change of voltage and the change of power factor [31]
- various methods based on the rate-of-change of frequency [32][33]
- method based on the measurements of system impedance [34]

A number of active anti-islanding methods have been developed:

- methods based on the introduction of small disturbance signal into a generator’s Automatic Voltage Regulator and Active AC power Filter [35]
- method based on the analysis of the frequency of oscillation and damping factor [36]
- protection method based on frequency shift using Twin-Peak Band-Pass filter [37]
- utilisation of power line carrier for reliable detection of islanding [38]
- methods based on the insertion of inductance and/or capacitance [39]
- active frequency drift method [40]
- method utilising active and reactive power control [41]
- method using frequency domain analysis [42]

There are also a few publications attempting to evaluate the performance and compare different loss of mains detection methods, mainly by means of extensive simulation studies [43]-[45] but also based on the comparison of test results [46].

4.2.2.6 Application of anti-islanding protection in different countries

In different countries different practices have been established with regard to anti-islanding protection [47].

In UK distribution system protection practice, only ROCOF and Vector Shift (VS) methods have found practical application, despite their apparent unsatisfactory performance [48]. This is mainly due to the recommendation given in the technical report ETR 113 [49], which favours these methods. The settings recommended by the report are as follows:

- for ROCOF based protection – 0.15Hz/s;
- for VS based protection – typically 6deg which can be increased to 1-12deg for systems with higher than normal impedances.

The reasons for widespread popularity of the ROCOF based anti-islanding protection are both historical and practical. Historically, up until relatively recently, there was little DG in the system and anti-islanding protection was mainly employed to protect from the perspective of ensuring safety of the public and personnel. Practically, ROCOF was used as it provides a reliable, economical and fast detection of genuine islanding events, and therefore, fulfilled the safety requirement. Stability of such systems has always been a problem, but has not been a threat to system stability due to the relatively low proportion of embedded generation compared to the overall system generation. However, when penetration levels become high the immunity of islanding protection to external system faults becomes an important issue. In order to improve the islanding protection performance the recommended setting values are currently under review in UK. The new settings are, therefore, likely to be higher than the existing ones in order to minimise nuisance tripping.

VS performance is also unsatisfactory. Although, it appears to be less susceptive to nuisance trips it is also less sensitive to genuine islanding events than ROCOF method, and therefore, does not provide a better solution for the anti-islanding protection. More detailed assessment of the ROCOF and VS performance is included in the following section 4.2.3.

Australia, Austria, Belgium, Canada and Italy have adopted ROCOF and VS methods as with the UK; simple frequency based protection is utilised in the Netherlands and Portugal, and direct transfer tripping is employed in Spain, France, Norway and Germany. Active methods are still not widely utilised due to power quality concerns, however, some methods are accepted in the US with inverter based generation.

In Portugal the simple frequency protection is installed at the interconnection point between DG and Grid, or in same cases, this frequency protection is provided by the machine protection.

4.2.3 Anti-islanding protection performance assessment

Due to the identified unsatisfactory performance of the existing anti-islanding methods and also due to the fact that the relay performance is often affected by the particular algorithm implementation (e.g. frequency estimation methods applied), it is important to establish a comprehensive testing methodology in order to assess the performance of the anti-islanding protection. The following subsections present an example process of scenario definition and laboratory testing. Although, the example is based on the UK experience, it is believed the proposed general methodology is applicable to any system distribution system when the relevant localised network and generator data is utilised.

4.2.3.1 Test network and scenarios

In order to assess the performance of any protection scheme there are two main aspects which are necessary to consider: (a) the ability to detect abnormal conditions when they occur within the operating zone and (b) the capacity to remain stable under all other system conditions which are out with the protected zone of operation.

Therefore, two separate sets of scenarios need to be defined in order to address these two aspects of protection performance (i.e. sensitivity and stability). The network model utilised in the example islanding scenario definition is presented in Figure 4-2.

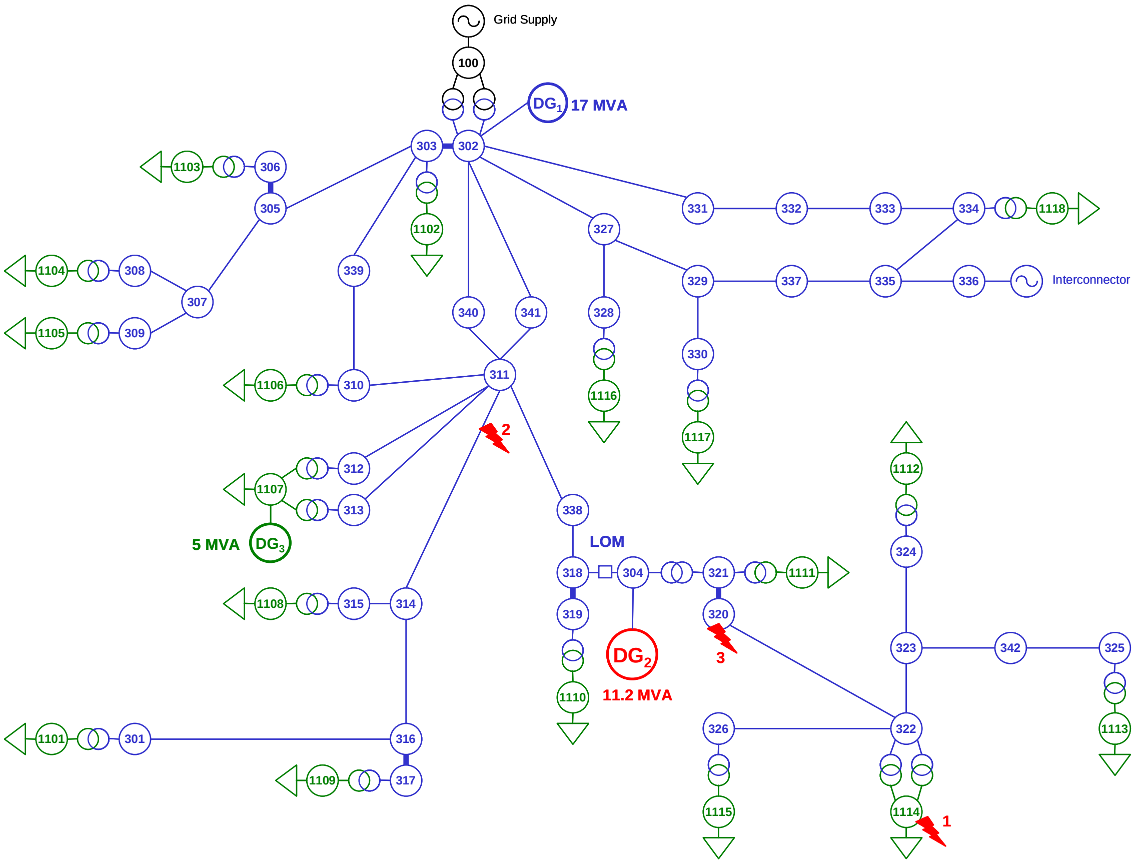


Figure 4-2: UKGDS EHV Network 1

It is based on one of the networks included in the UK Generic Distribution System (UKGDS) repository, a public domain database representing typical distribution system arrangement designed to provide common resources for the simulation and analysis of the impact of distributed generation [50]. Three distributed generators DG_1, DG_2 and DG_3 were connected to the nodes 302, 304 and 1107 respectively. The testing scenarios were defined for the anti-islanding protection installed on generator DG_2. The generator was represented dynamically using two different technologies: (a) as a synchronous machine (SM) with first order transfer function controllers for AVR and governor and (b) as a DFIG machine driven by a wind turbine.
The network simulation for SM based generator was performed using ATP power system simulation software [51]. The model of the DFIG and the wind turbine [52] are available within the RSCAD real-time simulation environment [53]. The remaining two generators were modelled as ideal voltage sources behind impedance. The dynamic data for the DG_2 (both SM and DIFIG) can be found in Appendix C of this document.
The ATP Draw implementation of the test network with SM generator is illustrated in Figure 4-3, whereas the RSCAD implementation with DFIG machine is presented in Figure 4-4. It needs to be noted that due to the local capacity limitations of the RTDS simulator the network size had to be reduced. An equivalent circuit was obtained which preserved the dynamics of the system during islanding events.

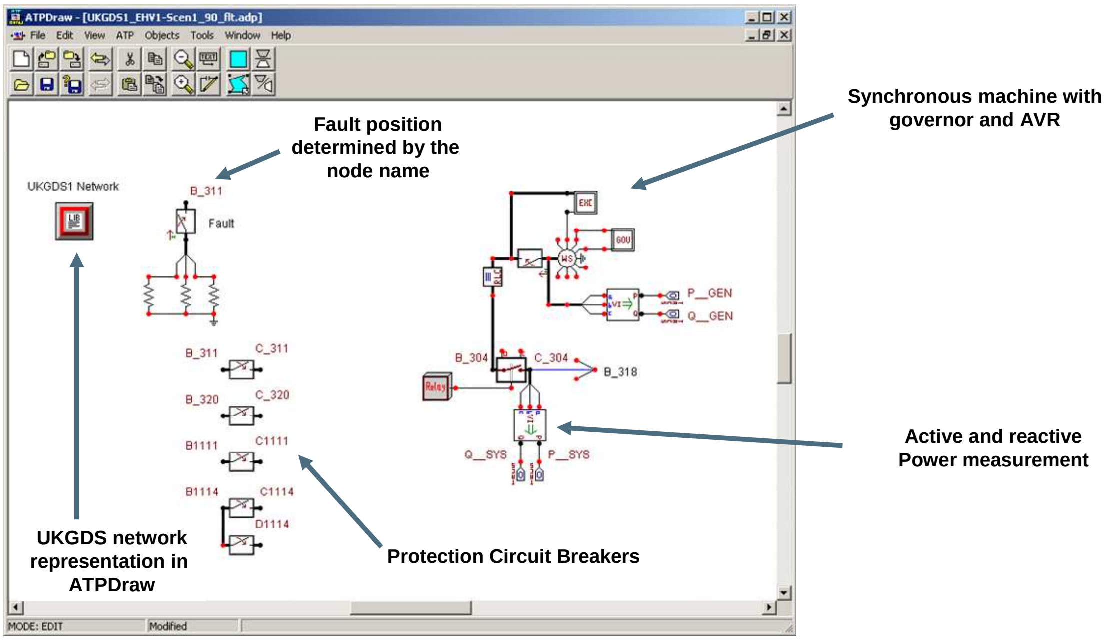


Figure 4-3: ATP Draw implementation of UKGDS EHV1 network with SM based generator

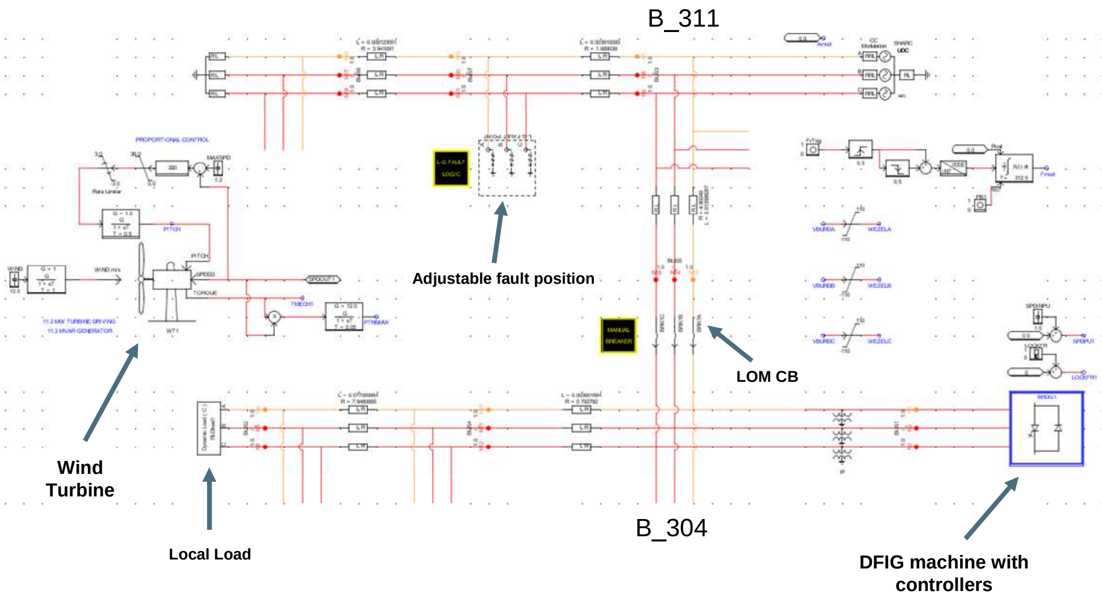


Figure 4-4: RSCAD implementation of the UKGDS EHV1 network with DFIG based generator

4.2.3.2 Sensitivity test scenarios

From the sensitivity point of view the most challenging scenario for the loss of grid detection is the case when there is a close match between the local load and the generator output directly prior to the disconnection from the main grid. Theoretically, under perfectly balanced conditions no detectable change occurs in the system voltages and currents when the interconnecting circuit breaker opens. In practice, however, such conditions are not likely to occur. Seven scenarios have been proposed for sensitivity testing. The generator output was assumed to be constant at 90% of its nominal power. The local load varied from 80% to 100% of the generator nominal power as indicated in Table 4-1. The most difficult to detect is scenario 4 with perfect balance between the local load and generator output prior to islanding.

Scenario No	Generator output [%Sn*]	Local Load + Losses [%Sn*]	Power Export to the main grid [%Sn*]
1	90.0	80.0	10.0
2	90.0	85.0	5.0
3	90.0	87.5	2.5
4	90.0	90.0	0
5	90.0	92.5	-2.5
6	90.0	95.0	-5.0
7	90.0	100.0	-10.0

* Sn=11.2MVA

Table 4-1: Islanding sensitivity scenarios

4.2.3.3 Stability test scenarios

The purpose of the stability tests is to ensure that the generator anti-islanding protection remains stable under system remote faults which are correctly isolated by the relevant network protection. Three different fault positions were selected as indicated in Figure 4-2. Three-phase, phase-to-phase and single phase-to-ground faults were included forming 9 fault scenarios in total as listed in Table 4-2. It was assumed that the faults at 11kV level are cleared within 300ms and 33kV level faults within 200ms.

Scenario No	Fault position (ref. to Figure 4-2)	Fault connection	Fault clearance time [ms]
8	1	Phase-to-ground	300
9	1	Phase-to-phase	300
10	1	3-phase	300
11	2	Phase-to-ground	200
12	2	Phase-to-phase	200
13	2	3-phase	200
14	3	Phase-to-ground	200
15	3	Phase-to-phase	200
16	3	3-phase	200

Table 4-2: Anti-islanding protection stability fault scenarios

The retained voltages during the 3-phase faults are 90%, 50% and 20% for fault positions 1, 2 and 3 respectively.

In addition to the described above scenarios the test set can be further extended to include:

- Sensitivity test scenarios involving different reactive power balance conditions
- Stability scenarios with main system frequency variations
- Stability scenarios with events involving loss of reactive power compensation
- Additional types of generation such as a fixed speed induction generator

4.2.3.4 Testing of the islanding detection devices

The 16 scenarios defined in the previous sections have been simulated using ATP transient simulator [51] for SM based scenarios and RSCAD real-time simulator [53] for DFIG based generator respectively. Both sets were subsequently converted into common COMTRADE format for injection into the actual relays. The tests were performed on the commercially available relays, denoted in this report as 'ROCOF Relay 1', 'ROCOF Relay 2' and 'Vector Shift Relay'.

4.2.3.5 Sensitivity tests

The first part of the test aimed to establish marginal settings for protection operation under the test scenarios described in section 4.2.3.2. The relay settings were increased gradually to the point where no tripping was encountered. The highest value which ensures relay operation within a 500ms period following the loss of grid event has been noted. The example results for scenarios 1 to 7 obtained for SM based generation are presented in Figure 4-5. As expected the most challenging from the sensitivity point of view are the conditions where local load matches the generator output (scenario Sc_4). A complete set of results is included in Appendix B of this document.

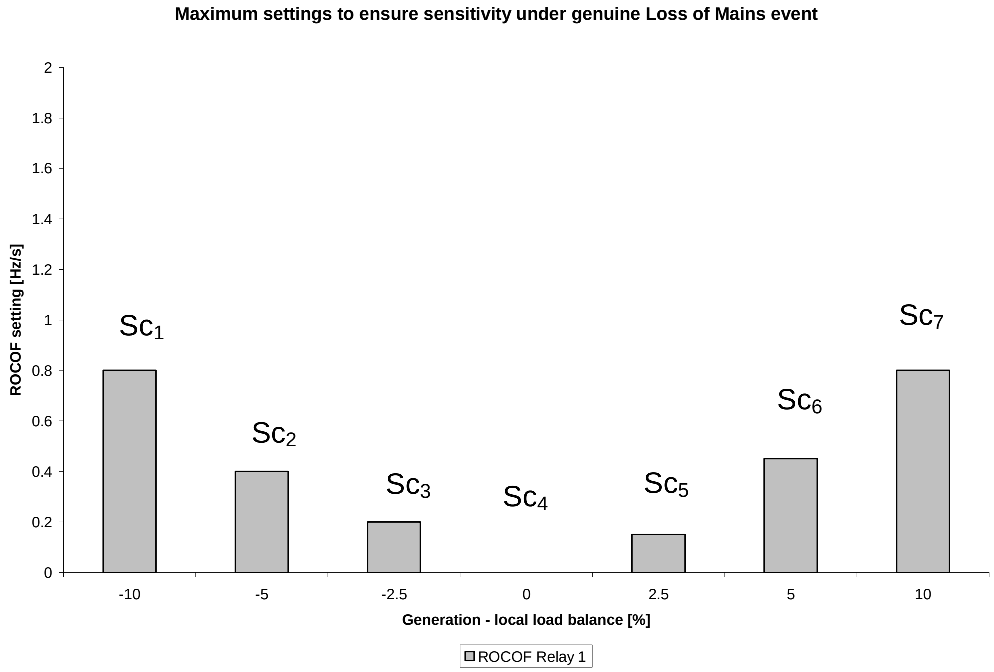


Figure 4-5: Maximum settings to ensure sensitivity of ROCOF Relay 1 (SM based generator)

From the sensitivity tests general conclusion can be drawn that the operation of the anti-islanding relay depends to a large extent on the type of generation technology.

With SM based generator and the setting of 0.15Hz/s, 'ROCOF Relay 1' is capable of detecting loss of grid events even if the local load differs from the generator output only by 2.5%. 'ROCOF Relay 2' is less sensitive and recognises islanding events only in cases when the local load/generation mismatch is greater than 10% of the generator capacity. VS seems to be less sensitive than any of the ROCOF methods as it is incapable of detecting islanding condition even at the lowest setting.

It should be emphasised that the dynamic response of the SM to loss of grid connection is primarily determined by the inertia constant of the machine. The controller parameters although important do not significantly impact on the dynamic response in the first few hundred milliseconds of the transient. On the other hand, the behaviour of the DFIG based generator depends mostly on the control system – in the presented case the DFIG model utilised a Phase-Locked Loop (PLL) controller. Shortly after disconnection from the grid and the loss of the reference signal the controller becomes unstable. Identification of the islanding event is therefore relatively easy in such cases and the need for anti-islanding protection might be even debatable as the under/over-voltage and under/over-frequency might be sufficient to detect these events.
The loss of stability of the DFIG controller results in high sensitivity of the anti-islanding protection. Even at high settings (10Hz/s for Relay 1 and 24deg for Relay 2 respectively) both ROCOF methods recognise the case of 2.5% local load/generation mismatch. Vector Shift relay operates in this case at the setting of 3deg.

4.2.3.6 Stability tests

Stability tests have been performed in order to assess the minimum required settings to ensure protection immunity to fault conditions described in section 4.2.3.3. For each scenario the lowest setting value which preserves stability of protection was noted. The example results for scenarios 8 to 16 obtained for SM based generation are presented in Figure 4-6. It is clear that 3-phase faults have the highest impact on stability as the required settings are much higher than those for the remaining types of faults. A complete set of results is included in Appendix B of this document.

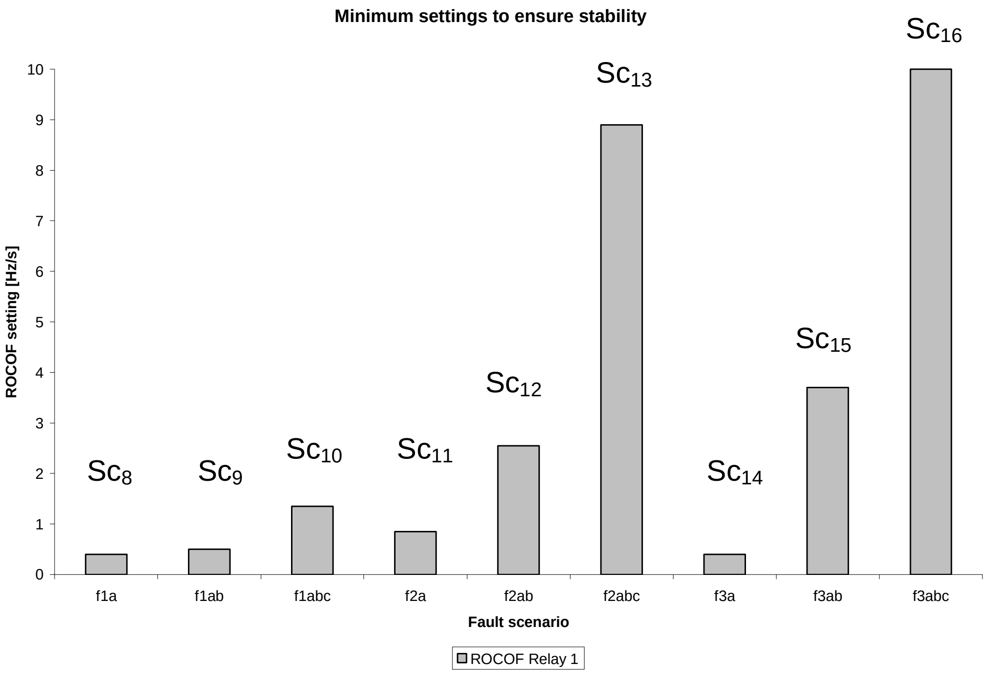


Figure 4-6: Minimum settings to ensure stability of ROCOF Relay 1 (SM based generator)

Similarly to the sensitivity test results the difference in operation of anti-islanding relay for different generation technologies can be observed. Distant faults have a high impact on the anti-islanding protection when SM generator is in place. Spurious tripping is often caused by the transient following the clearance of the system fault. Swinging of the generator rotating mass causes local frequency to oscillate. This effect is particularly visible during three-phase faults.

On the other hand DFIG machine does not possess inertial properties of an SM generator and therefore its frequency response is determined by the controller response. Therefore, due to much shorter transient response, ROCOF algorithm is less likely to be confused by system faults.
In case of three-phase faults regardless of the generation technology the requirements for the anti-islanding protection settings to preserve stability can be very high which creates difficulties to provide the settings which would satisfy both sensitivity and stability. It is therefore necessary to accept loss of protection stability under some severe system faults which are likely to cause other types of protection to operate.

4.2.3.7 Conclusion

The general process of developing testing scenarios for the assessment of the sensitivity and stability of the anti-islanding protection has been described. Three example currently applied methods have been tested in the laboratory including two different ROCOF methods as well as VS.

The full record of the test results is included in Appendix B. These results lead to the following conclusions:

- The results clearly demonstrate the impossibility of providing single value setting guidelines for the loss of grid detection, mainly due to the significant differences of performance between different relay manufacturers
- DFIG-based generation is relatively easier to protect against islanding using ROCOF techniques; the DFIG generation is much less stable than SM-based generation when disconnected from the main system due to the phase-locked loop (PLL) control technique for controlling the driving frequency of the power electronics interface
- It is evident that in order to achieve significant improvement in anti-islanding protection performance, each DG connection needs to be studied individually, taking into account generation technology (& controller type) and protection relay type
- Dedicated anti-islanding protection may not be required in many cases as particular generation technologies will not sustain islanded operation in single-generator mode
- Type tests could be based around a set of agreed tests similar to those reported here (i.e. sensitivity and stability simulation waveforms)
- From the studies to date, generator size and network characteristics have a limited effect on the best compromise setting
- VS is very unstable and was found practically unsuitable for the detection of islanding events

4.2.4 Risk assessment of inadvertent sustained islanded operation

When considering anti-islanding protection it is also important to consider the probability of forming a stable island in a particular situation. There may be circumstances where formation of a stable power island is practically impossible or very unlikely. For example when the minimum load is double the DG generator rated power or more, the island cannot be formed due to impossibility of meeting output demand at any time. Therefore, it would be questionable whether anti-islanding protection is necessary as the generator is incapable of sustaining operation when disconnected from the grid. In such cases generator anti-islanding protection can be limited to simple under/over voltage or frequency relays.

Therefore, it would seem reasonable to take an element of risk into account when considering DG anti-islanding protection. For example in the paper [47] the probability distributions of the load-to-generation ratio are used in order to assess the likelihood of undetected islanding operation and thus assess the necessity of the dedicated anti-islanding protection.
In the Canadian study [54] a risk of forming undetected island is assessed based on the load and generation daily profiles (refer to Figure 4-7). Each anti-islanding protection can be characterised by so called 'non-detection zone'. When the local load falls within the non-detection band there is a high risk of forming an undetected island. The risk can be quantified in terms of relative time during which local load remains in 'non-detection zone'.

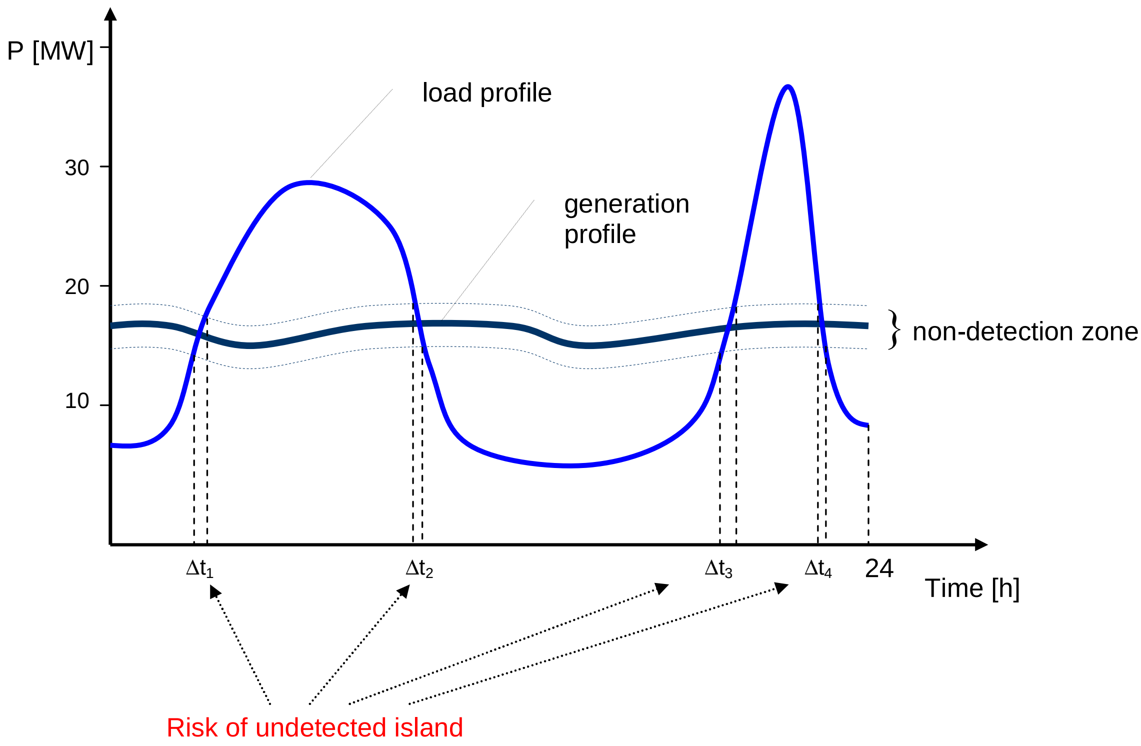


Figure 4-7: Non-detection zone and islanding detection probability

The risk assessment based approach to anti-islanding protection can help in selecting the best applicable method, although, it relies on the availability of load profiles. These may not be readily available.

4.3 Intentional Islanding

In a competitive energy market there is an increased pressure on utilities to improve the continuity of supply to customers. In a situation of passive distribution network this could only be achieved by power line redundancy and advanced automation, both potentially expensive solutions. However, the recent trend towards of increased levels of DG penetration in distribution and subtransmission levels opens new opportunities for improved reliability and Customer Minutes Lost (CML). Supply system faults should no longer lead to the disconnection of all the customers as the local generation may provide an alternative energy source. There are, however, a number of technical, economical and regulatory issues which need to be addressed before this can come to effect. These concerns often lead network operators to the position of relative scepticism whenever intentional islanding is proposed. In this section a review of basic requirements and additional considerations is presented in order to discuss the main islanding issues in a systematic manner.

4.3.1 Basic requirements for sustained islanded operation

Generally, there are three fundamental requirements which need to be satisfied by the protection and control system if any part of the network was to operate in an islanded mode:

1. **Safety** – avoid incidentally back energised distribution networks
   Safety is a fundamental requirement which has to be fulfilled either by the prompt disconnection of all local generation or by the implementation of safe maintenance practice which would prevent accidental access of the personnel to the energised circuits.
2. **Statutory power quality requirement** (licence obligations) with regards to voltage, frequency and fault level (time scale is few cycles)
   In the interconnected mode of operation the utility has a direct influence on voltage and frequency regulation of the system. The islanded mode of operation is fundamentally different in a way that some parts of the network supplying customers are physically separated from the utility network, and therefore, there are no means of direct control over V and f. Special mechanisms would have to be in place in order to fulfil the power quality obligation, both during the transition periods and during the stable islanded operation. Distributed generators would possibly have to adopt a control strategy similar to one utilised by large interconnected systems.
3. **Prevention of the out-of-phase switching**.
   Out of phase switching can potentially have far greater impact than other system faults. In the worst case scenario voltage across the contacts of a circuit breaker could amount to double the nominal value. Therefore it is essential to have adequate protection against such an event. Adequate protection and resynchronisation facility would have to be provided at the predefined points in the system.

The above requirements can be fulfilled in a number of alternative ways. Current practice in most countries favours disconnection of all local generation following islanding condition, and therefore, naturally fulfils the above safety and out-of-phase switching obligations. However, as a consequence, customer supply is lost until the main grid connection is restored.

If the possibility of islanded operation was to be considered, the customers would not have to experience loss of supply due to the main grid supply failure.

4.3.2 Additional considerations

A number of papers have been recently published on the subject of intentional islanding and its potential benefits for both utilities and generators. Various aspects have been touched upon by the authors which indicates high complexity of the problem but also highlights that there are significant gains to be achieved through careful implementation of islanding regimes.

4.3.2.1 System stability

With low penetration levels of DGs the disconnection (or islanding) of a generator does not have any major impact on the overall system stability. However, with increased proportion of DGs at system subtransmission and transmission levels it has been recognised that some system events may lead to the disconnection of a large generation capacity (e.g. due to spurious anti-islanding protection tripping) and pose stability threat to the rest of the system. The study [55] concludes that the current approach to island detection and elimination may lead to reduced system stability, security and reliability. Therefore, from the transmission system stability point of view it is crucial that DGs do not trip off spuriously which calls for more reliable islanding detection methods. As DG interconnection standards evolve, the dynamic performance impact needs to be continually assessed.

4.3.2.2 Reliability

A comparative study of the power supply reliability has been presented in [56]. The authors conclude that by utilising active network management and islanding similar levels of supply reliability improvement can be achieved as in case of conventional approach based on redundant supply paths. This highlights clear opportunity for improved power delivery at much reduced additional cost.

4.3.2.3 Island control issues

The study [57] analyses control and protection requirements for intentional islanded operation. The authors propose a detailed framework for forming intentional islands and their resynchronisation with the interconnected system. The concept of Power System Cells was also introduced as a means of island management. Each cell has necessary provisions for network energy management, system support, autonomous voltage and frequency control, flexible protection and demand control. The proposed methodology was tested using power system simulation. It was assumed that communication demands can be fulfilled by means of radio wave frequency.

4.3.2.4 Reducing blackouts

The paper [58] presents a methodology for the assessment of the viable power island which could potentially be automated and run in real-time in the future. When an island is formed a detailed study is performed in order to determine if the separated part of the system can operate as an island. The main components of the island viability assessment include load flow study, test of the voltage and frequency control capabilities, protection system assessment and possible adaptation, small signal stability study and transient stability study for the predefined critical events. Most of these studies require good communication infrastructure to be in place in order to provide necessary on-line data for the analysis.

4.3.2.5 Energy prices

In [59] the authors investigated the electricity market prices under islanded scenarios and found that the customers in an islanded situation may experience price spikes due to a non-competitive environment, created by the monopoly of the local generation. Depending on the length of time in an islanded mode this may become an issue for some customers. It is also suggested that utilities may want to introduce special rules in order to minimise unnecessary price fluctuations.

4.3.2.6 Various protection considerations

Various protection considerations given to high penetration levels of DG in distribution systems and the possibility of intentional islanding are presented in [60]. The authors explore the issues such as grounding arrangements, automatic re-synchronisation, widening the windows of statutory voltage and frequency limits during islanding and various communication alternatives.

An interesting concept of protection scheme was presented in [61] where the authors proposed an adaptive protection methodology independent of size, number, and placement of DG in the distribution system. The scheme is adaptive to temporary as well as permanent changes in distribution network and its implementation region can be extended to more than one feeder. The authors claim the method would also support islanded operation, although, is not particularly geared for intentional islanding.

The existence of the requirement for the anti-islanding protection was seriously questioned in [62]. The authors investigated the efficiency of under/over frequency relays for protection of distributed synchronous generators considering islanding detection and frequency-tripping requirements. Comparison between frequency and vector surge relays, which are islanding detection-dedicated devices, shows that the former can be as effective as the latter. This feature supports the idea that frequency relays can replace vector surge relays for islanding detection purpose.

As it is expected that in an islanded mode of operation the conditions for detecting faults are likely to differ significantly from the normal interconnected operation, the need for more sophisticated (possibly adaptive) protection approach is apparent. With today's protection equipment automatic transition into islanded operation is not possible. Reliable ways of communication would be required in order to inform the relays about the system conditions including the information on the islanded mode of operation and the characteristic of load and DG units. The technology currently used in anti-islanding protection may be used to activate the appropriate change of protection settings.

All these technical issues should preferably be solved at the planning stage. Otherwise, in order to implement intentional islanded operation at a later stage, large investments might be necessary.

4.3.3 National and European projects related to intentional islanding

4.3.3.1 Denmark

Denmark has a particularly high proportion of its electricity demand provided by distributed generation. It contains approximately 5,000 MW of Combined Heat and Power plants and over 2,500 MW of wind generation. This distributed generation capacity comes from over 750 CHP units and 4,150 wind turbines connected at all voltage levels from 400 kV to 0.4 kV.
An ambitious project called "Cell Controller" [63] is currently being conducted in Denmark in order to enable higher penetration levels of DG through the decentralised power management system based on semi-autonomous "Cells". These Cells are designed to use local CHP, wind power, and other distributed resources to facilitate ride-through, grid support, intentional islanding, and black start capabilities. The overall goal is to run cells close to balanced state and thus provide the best conditions for island formation should anything unexpected happen.
It is, therefore, expected that in Denmark islanding will be permitted as a result of the new decentralised management system. However, the islands will have prescriptive size reflecting the structure of the pre-defined Cells.

4.3.3.2 Netherlands

In the Netherlands a dedicated EU-Fifth framework project has been conducted on distributed intelligence in Critical Infrastructures for Sustainable Power (CRISP - http://crisp.ecn.nl). The central objective of the CRISP project is to investigate, develop and test how the latest advances in distributed intelligence by information and communication technologies (ICT) can be exploited in novel ways for cost-effective, fine-grained and reliable monitoring, management and control of power networks that have high degrees of DG and RES penetration.

Resulting from this project was a novel control strategy (PowerMatcher [64]) based on intelligent agents, which is geared towards the decentralised electricity networks. The proposed multi agent approach is designed to cope better with complex systems than traditional centralised approach. Initial small scale system trials showed promising results [65].

4.3.3.3 Norway

In Norway an interesting project has been undertaken (The HSAPS Market Analysis project - http://www.hsaps.ife.no) in order to address the issues of sustainability of Stand Alone Power Systems (SAPS). The project established a broad understanding of the technical and economical market potential for hydrogen SAPS based on local renewable energy sources and developed a few demonstration cases.

4.3.3.4 United Kingdom

In the UK a few initiatives have been established in order to investigate the future of islanded operation. The Distributed Generation Co-ordinating Group (DGCG) has led a detailed study [66] on the potential impacts of islanding in distribution networks. The report includes a wide spectrum of technical, economical and legislative issues involved in the provision of islanding, as well as, a comprehensive assessment of potential benefits. A number of real life cases are also included for the illustration purposes.

Co-ordination of various tasks and activities relating to future distribution system scenarios were suggested in a special report [67]. The project was to analyse the current status of distribution networks, review possible future scenarios and to propose projects that would close any gaps identified. To ensure a co-ordinated approach, it is proposed that a single entity is given responsibility to be the focal point for developing future technical architectures.

4.3.4 Intentional islanding in different countries

Although the benefits of intentional islanding have been noted in many countries, up until now, there is no evidence of wide spread application of this mode of operation in the utilities' practice. It can be said that current legislative framework in the vast majority of countries does not permit islanding with the exception of the IEEE standard P1547 [68] where some specific inverter connected installations are designed to run in islanded mode.

A few selected views on intentional islanding originating from different countries are included in the following sections.

4.3.4.1 Canada

The recent study in Canada [54] concluded that anti-islanding protection has become the single largest technical barrier for DG interconnection in Canadian distribution systems at present. The high cost associated with anti-islanding protection has made various environment-friendly DG proposals unattractive.

Two complementary strategies are proposed to address this barrier. One is to develop a "Canadian Application Guide for Anti-islanding Protection of Distributed Generators" which would contain, but not be limited to, the following materials:

- Probability and risk associated with the formation of DG islands
- Performance characteristics of commercially available anti-islanding devices
- The characteristics of Canadian systems that have important impacts on the performance of anti-islanding protection schemes
- Industry experiences and application examples
- Methods and procedures to evaluate and select proper anti-islanding schemes and
- Test methods for performance verification

The second strategy is to investigate if changes can be made to the existing distribution systems to reduce the barrier for anti-islanding protection. This proactive approach of making distribution systems work in harmony with distributed generator can be very effective to lower the cost of anti-islanding protection. It is also visionary in the sense that this could be one of the steps to create "DG-friendly" distribution systems.

The following are two example strategies to revise the practice:

- Eliminating the reclosing practice. In this approach, the faulted feeder segments will be disconnected by fuses or breakers once and for all. Consequently, there is no reclose to distributed generators. In this way, a lot more time will be available for anti-islanding protection.
- Single pole operation of reclosers. This scheme will only open and reclose the faulted phases. As a result, the DGs can maintain some connections to the system for the majority (70% to 80%) of fault conditions. The probability of islanded operation can be significantly reduced in this way.

The authors of the document [54] believe that the strategy of making utility systems DG-friendly will have more potential to bring significant benefits to Canadian DG and utility industries. The goal is to create distribution systems that embrace distributed generators and work in harmony with them.
Despite this proactive stance to utility practice in the Canadian study there is no mention of significant benefits in prolonged intentional islanding under normal operating conditions.

4.3.4.2 France

In France, the issue of intentional islanding has been discussed recently but up until now it has not been practiced. The large penetration of renewable energy sources (RES) is recent in France. A few studies demonstrated overloaded lines in some circumstances on 63 kV and 90 kV grids. RES are allowed to be connected to the grid following the studies described in the French grid code. However, the French 63 kV and 90 kV networks are currently built with the following principles in mind:

- Overhead lines are designed for permanent maximum current density value (considering extreme expected temperatures in summer and winter). They do not support long overloaded periods. The risk is that the conductors may sag too close to the ground or trees, houses etc. The main control point of the grid checks the current density in real-time.

- The protection panels do not include an overload relay (i.e. time delayed overcurrent relay).

The problem is that in some cases, when the RES plants are connected and a fault occurs on a line not far from the connecting point, the faulted line is tripped, and the studies highlight that some other lines may become overloaded, due to the presence of the RES. Immediately after the fault, it is not known if the fault is intermittent or permanent. This information is given by the automatic recloser that orders the circuit breaker to close a few seconds later (typically 5s). If the fault is intermittent, the event is over.

On the other hand, if the fault is permanent, the faulted line protection sends a second tripping signal and puts the automatic recloser into 'off' state. Thus, with one line removed, there is a higher chance of other lines to become overloaded. This situation must be studied carefully before connecting the RES, and must be known by the real-time main control point of the grid.

Depending on the grid topology, there are maybe ways to control other circuit breakers by automation in order to remove the line overloads. If this is not possible, keeping in mind that the overhead lines are not designed for long periods of overload, automatic tripping must be sent to the RES.

Another recent study point out that in general overhead lines can support 50% overload for a limited period of time (60s) without the risk for people near the line. This is the maximum time permitted before disconnecting the RES (by automation).

At the time of writing (June 2007), the French Transmission System Operator (RTE) does not have any specific written automaton policy relating to the RES tripping.

4.3.4.3 Norway

To date most of the generation is connected to 66kV or higher voltages. For this reason there are currently no examples where intentional islanding is possible incorporating a part of the utility system. In DG systems at lower voltages all DG generation is shut down in cases of loss of mains.

Years ago hydro based generation was installed with some small units engineered for undertaking frequency and load control in cases of loss of mains. Due to the electrification with high reliability there is no will to pay for the equipment needed for the sustained intentional islanding operation.

Currently in Norway there are no planned projects concerning intentional islanding with exception of the research study HSAPS Market Analysis project.

4.3.4.4 Portugal

In Portugal intentional islanding has not be practiced before. Also the new Grid Code, which is still under review, does not include the possibility of legalisation of the intentional islanding.

4.3.4.5 UK

In UK the issue of intentional islanding has been discussed following a number of case studies based on various islanding scenarios included in an industry discussion paper [69].
It should be noted that the majority of utilities naturally perceive any form of islanding as a necessary evil rather than an opportunity for the improvement of the system operation. The main limiting factor is the incurred cost of adequate protection and control necessary to operate stable and safe power islands, especially, at medium voltage levels (33kV and 11kV). Although, it has been recognised that islanding can potentially contribute to the improvement of the continuity of supply (especially in remote areas), it seems that in the majority of cases there is not enough reason to invest in islanding infrastructure. There seems to be a general agreement among the major UK utilities that there is little or no advantage in islanding a system that is capable of running interconnected. Intentional islanding would only offer advantages under the following anomalous conditions:

- Where it is difficult or impossible to interconnect. The most extreme cases are ships, aircraft or offshore oil fields, which are obliged to operate as islanded systems
- Where there is concern about the power quality of the host utility
- When the supply from the host utility is lost altogether

Considering the current mix of generating technologies in the UK (mainly DFIG connected wind) running systems in islanded mode will result in lower fault levels. This will have an effect on the power quality of the system. In addition to the need to allow wider voltage levels and frequency range having low fault levels could have other effects:

- Any load providing harmonic injections into the islanded network could require installation of harmonic filters in order to keep within limits
- Negative sequence voltages could increase with unbalanced loads
- If more than one generator is connected to the island the steady state and transient stability of the machines would need to be studied
- The adequacy of the protection system operation would have to be reconsidered
- Voltage flicker and step changes are also likely to be higher with low fault levels
- Starting of large induction motors, which are normally acceptable under grid connected minimum fault levels may not be possible due to low fault levels

Moreover, prolonged islanding is perceived as a barrier to free trade, and therefore, in breach of legislation designed to liberalise energy markets.

Based on the above rationale, it is difficult to see how the costs of providing all of the additional facilities and resources can be justified in terms of payback. Designing generation to operate in parallel to provide support to the existing network would seem a more cost effective route to pursue.

4.3.4.6 El Hierro island project – Spain

An interesting project aiming at 100% energy self-sufficiency has been undertaken in Spain in the Canary Islands. More detailed description of the project can also be found on the project website [70].

4.4 Conclusion

This chapter has considered the issue of power system islanding. In the first part the methods for loss of grid detection were presented together with the proposed testing procedures for the assessment of the islanding detection performance, both in terms of sensitivity to genuine islanding events and stability under remote system faults. It has been demonstrated through systematic testing that for the existing established methods such as ROCOF and Vector Shift it is difficult to achieve a single value setting, i.e. protection which is set to be sensitive to loss of grid events may also be unstable in response to remote system faults.

The analysis of the probability of undetected islanded operation can help in selecting the most appropriate strategy for the DG anti-islanding protection.

With growing DG penetration levels of all sizes and connection voltages there is an increased need for high performance anti-islanding protection. Taking into account current relay (ROCOF or VS) offerings the implementation of anti-islanding protection is always a question of compromise between sensitivity and stability (they do not guarantee island detection without compromising the immunity to external faults) as well as between the performance and cost. Traditionally, the stability aspect was of lesser importance as the network operation did not depend on the presence of DG. This situation is gradually changing and reliable islanding detection is becoming increasingly more important. New solutions are needed as the limitations of the existing methods may eventually pose a barrier to further integration of DG. More reliable and sensitive anti-islanding protection and standardised testing guidelines for this type of protection are very important to encourage medium scale integration of DG into the network and avoid unnecessary tripping of DG.

The subject of intentional islanding has also been explored in depth. The review of basic requirements and additional considerations has been presented with the view to assess the need and feasibility of intentional islanding. There are many aspects which need to be considered when considering intentional islanding. Currently the view of many countries is that the cost of additional infrastructure outweighs the benefits. However, with increased levels of DG penetration in the future and the tendency of connecting these generators at higher voltage levels, it is expected that the benefits of islanded operation will be more significant and the additional cost relatively lower.

5 Comparative Analysis of Protection Practices and Recommendations

Practices of protection and typical connection arrangements of eleven countries (Australia, Canada, Denmark, Finland, France, Germany, Norway, Portugal, Spain, United Kingdom and China) have been shown in this section. A comparative analysis, under a protection perspective, and conclusions about the best practices and limitations or issues to be studied are outlined in the following sections. Detailed information about practices of each country is included in Appendix D. Additionally, for ease of reference and direct comparison, a summary of DG protection practices and settings have been collected in Appendix E.

5.1 DG/RES situation and perspectives

In the recent years, a spectacular growth of DG/RES has happened widely in all countries. The determinant factors, although with different weight in each country, have been mainly, the reduction of greenhouse gas (GHG) emissions according to the objectives fixed by each country, the need for a wider diversification of energy sources in order to reduce the high dependence from fossil fuels, which are imported in many cases, thus increasing the security of supply. Although in practically all countries there are prospects for RES growth, mainly from wind power and, to a lesser extent, from PV, biomass and even tidal, the penetration substantially varies depending on the peculiarity of each country in terms of the current generation mix and renewable sources available. In Australia, Canada, China, Norway, France and UK, the wind power penetration is relatively low, whereas in Denmark, Germany, Spain and Portugal is higher. In Canada, Norway and France there is a lower concern to greenhouse gas emissions due to the high weight of the hydro power (Canada and Norway) and nuclear power (France), but there is a need for a greater diversification of the mix. The UK is very dependent on conventional thermal generation, especially from coal, and there is a great interest for RES growth. The construction of new nuclear power plants is also currently being considered in the longer term. Spain and Portugal have ambitious objectives for wind power growth. In Denmark and Germany, the tendency is to develop off-shore wind power due to the increasing difficulties of finding appropriate locations for on-shore installations.

The following table shows the estimated percentage of installed power of RES (excluding conventional hydro power plants) in all eleven countries included in the analysis.

Country	% RES	Comment
Australia	10.0	
Canada	2.0	
Denmark	36.0	
Finland	19.1	
France	2.2	
Germany	10.0	
Norway	1.0	98% hydro
Portugal	16.2	
Spain	25.2	
United Kingdom	4.0	
China	8.0	Including hydro

Table 5-1: Review of RES penetration levels in different countries

5.2 Regulation framework

For several years, practically all countries have counted on technical requirements, which are included in the law, utility guides, codes or recommendations from electrical associations, for the connection of small/medium size DG (i.e. < 10 MVA) to the distribution network.

Most of them have also developed grid codes for the connection of the large and dispatchable generation to the transmission network. However, the increase of the DG penetration in distribution networks with the emergence of large RES and non-dispatchable power plants connected to the (sub)transmission network has pushed recently some countries to develop new requirements or revise the existing codes to cope with the new scenario. Canada, Denmark, Germany, Spain and France have recently elaborated specific requirements for the connection of WF, and in Australia, Norway, Portugal and UK, they are in preparation.

The protection requirements for small/medium DG are also under revision or are expected to be revised soon in some countries in order to assimilate the settings criteria of the interface protections to ones of the traditional generation to avoid nuisance tripping and obtain more generation availability and so network stability. The standardization in the connection requirements of DG, particularly of the protection equipment and settings criteria, will be very positive for the development of the DG, especially in highly interconnected networks such as the European one. In this respect, an IEEE standard [71] has been developed recently and others are under preparation by other standardization organizations (CENELEC, IEC, etc.).

5.3 Typical connection schemes

In view of the different connection arrangements shown for each country, it is commonly acceptable to establish different DG connection criteria for each network voltage level. For some countries there are no schemes available (Australia and Denmark) or only schemes for distribution or transmission have been included (Germany and Norway).

Regardless of a precise definition for LV, MV, HV and EHV terms, as they can vary from country to country, it is commonly accepted the following network structure and the associated generation size.

- LV distribution network (< 1 kV). Small DG
- Local MV distribution network (1 to 35 kV radial). Medium DG.
- Regional MV subtransmsission network (35 to 100 kV mainly radial, but also meshed in some cases). Large DG
- HV subtransmission network (100 to 170 kV). Large DG.
- HV transmission network (170-345 kV). Large concentrations of DG (WF)

We can also establish the following different types of connection arrangements:

- Connection to a dedicated/non dedicated line

- Tap connection to a loaded/non loaded line
- Direct connection to a dedicated/non dedicated substation

Table 5-2 shows a summary of the most typical possible arrangements for MV and HV networks.

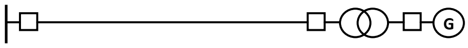
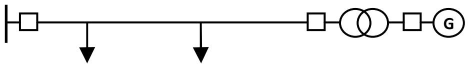
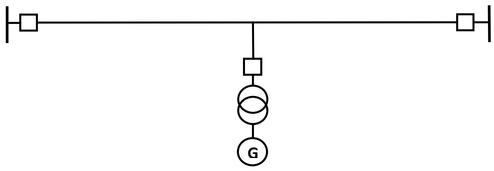
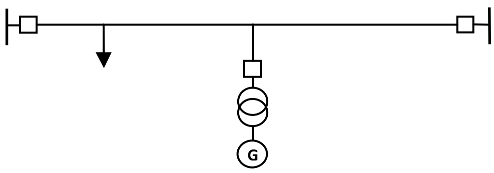
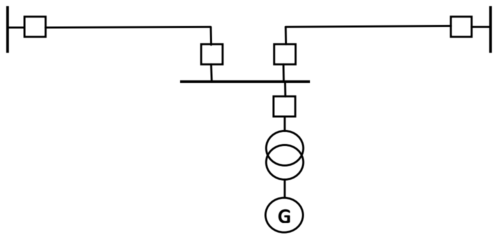
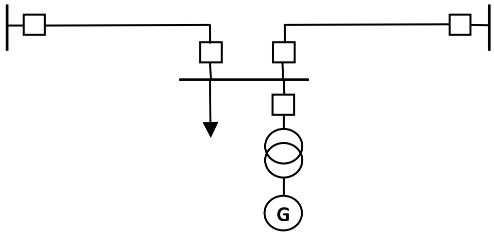
DG connection		**1 to 35 kV**	**35 to 100 kV**	**110 to 400 kV**
Dedicated line		X	X	X
Non dedicated line		X	X	
Tapped connection to a non loaded line			X	X
Tapped connection to a loaded line			X	
Connection directly to a dedicated substation			X	X
Connection directly to a non dedicated substation			X	

Table 5-2: Typical connection schemes for different network voltage levels

In transmission networks, the DG is normally connected to a dedicated substation, directly or through a dedicated line. Also, tapped connection to an existing two ended line, although unusual, is acceptable in transmission networks in some countries.

Regarding grounding practices of the high voltage side of the transformer, in MV distribution and in general for tapped connections, the transformer is ungrounded (delta connection is generally used) to avoid the infeed for phase to ground faults and its effects on protection selectivity and sensitivity. Otherwise, a grounded star connection is normally used.

It is worth pointing out some peculiarities of some countries, such as the use of the three breakers containerised switchboard for a tap connection to a 33 kV line in UK. The interface protection normally trips the high voltage side of the transformer, although there are some exceptions: in the UK the low voltage side of the transformer is tripped even in connections to dedicated HV/MV substation; in France the generator side breaker is tripped instead. Other particularities are the use of two breakers at both sides of the connection point in UK or the use of interface relays also at the utility breaker in Germany.

Best practices for line protection:

For line protection, the DNO or TSO protection criteria for the voltage level at which the DG is connected is generally applied and they are similar in all countries.

In HV (sub)transmission networks:

- Redundant protection based on distance protection with a teleprotection aided tripping scheme (POTT or PUTT) and line differential protection is widely used.
- In tapped or dedicated line connections, line protection should be also provided at the generator end. A weak-infeed scheme at this end is a good solution to preserve the single pole reclosing cycle in case of the generator is off-line.
- Single and three-pole reclosing and synchrocheck should be used.

In MV subtransmission networks:

- Directional overcurrent relays or distance protection, depending on the voltage level and the utility protection philosophy.
- Line protection at the generator end based on distance or directional overcurrent relays is not very common, so 27 and 59N (or 51N if the transformer is grounded) relays, usually carry out this function.
- Three-pole reclosing and dead-line check (radial network) or synchrocheck (meshed network) should be used.

In MV distribution networks:

- Non directional phase and ground overcurrent relays. Directional relays should be used if co-ordination is necessary and a change of settings is not enough.

- At the generator end, 27 and 59N relays are used.
- Three-pole reclosing and dead-line check should be used

For non dedicated HV/MV transformers (loads and DG connected in MV) which are connected to a HV line (directly or tapped), distance protection in the high voltage side of the transformer can be used for line protection for a faster fault clearance. Furthermore, transfer trip from this protection to the DG feeder breakers is applied. This is the solution used in Germany (see Fig. 5-25). Protection based on measurement of reverse flow of real or reactive power can be used when the DG capacity is such that the installation will always import power from the utility network.

It is clear that whatever the connection to a non dedicated line or substation (embedded loads) there is a risk of islanding operation of the generator and loads if the utility breakers are tripped. In these cases, an anti-islanding protection should be provided. For example, for a connection to a non dedicated substation, a good practice can be tripping the DG breaker in case the two breakers (local or remote) of both lines are simultaneously open.

5.4 Interface protection requirements and settings

All countries use practically the same set of interface protections, which are under/overvoltage relays, under/overfrequency relays, phase and ground overcurrent relays complemented with transformer differential relays.

Particularly in Germany, a backup interface protection, associated to the utility breaker, includes an underimpedance and a combined undervoltage/reactive power relay.

The interface protection and their settings are usually specified in some regulatory document or guides, as mentioned in 5.2, although in some countries, precise values are not available and are selected in accordance with the DNO/TSO in each case. Protection settings are in some cases, specified separately for distribution and transmission networks. In this case, for transmission networks the settings are usually similar to those of the conventional generation with wider settings. Furthermore, protection settings requirements for distribution and transmission networks are progressively converging in many countries.

Comparing the specified relay settings in the different countries, significant differences can be found. Still, we can establish some illustrative setting ranges for thresholds and times for both distribution and transmission that comprise the majority of cases.

Relay function	Distribution		Transmission	
	Threshold range	**Time (sec)**	**Threshold range**	**Time (sec)**
Undervoltage	< 50%Un 50-80%Un	< 0.5 0.5-2	< 80%Un (several steps)	Several sec.
Overvoltage	>115%Un 105-115%Un	0.1-1 1-60	>115%Un (several steps)	Several min.
Underfrequency	47-49 Hz (59.4 Hz)	< 0.5 (0.5)	47.0 to 49 Hz (59.4 to 56.4 Hz)	0.1 to 180 (0.1 to 180)
Overfrequency	51-52 Hz (60.5 Hz)	< 0.5 (0.5)	50.5 to 52 Hz (60.6 to 61.7 Hz)	0.1 to 180 (0.1 to 180)

Table 5-3: Typical voltage and frequency protection settings used in many countries

Regarding undervoltage relays, it is observed that in general, settings are not coordinated with the FRT curve required for wind turbines. Figures 5-1 to 5-5 show for some countries both undervoltage (dotted line) and FRT characteristics overlapped. Where the undervoltage operation region (shaded area) lies above the FRT characteristic (e.g. Finland, Porugal) the undervoltage relay will trip before the FRT requirement is fulfilled.

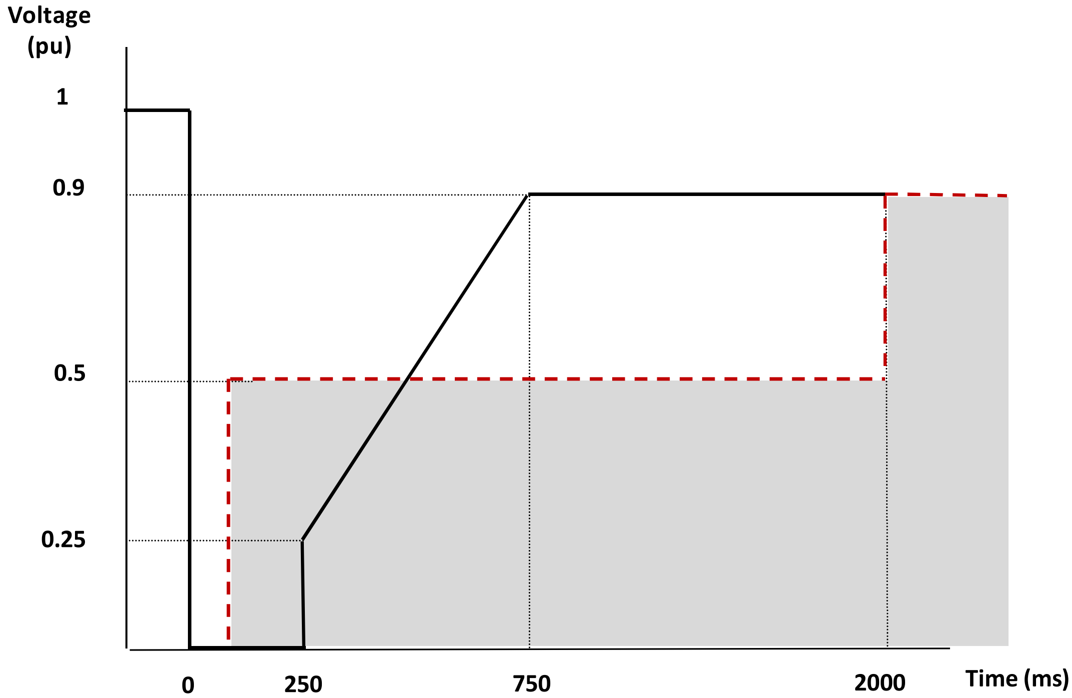


Figure 5-1: Undervoltage and FRT co-ordination in Finland

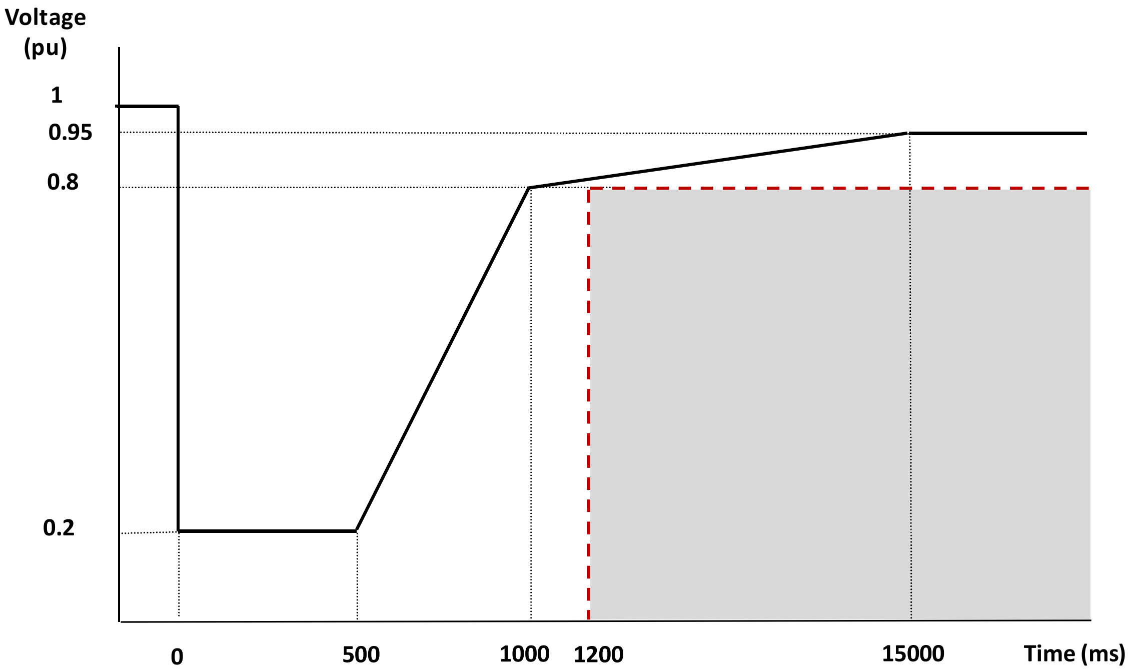


Figure 5-2: Undervoltage and FRT co-ordination in Spain

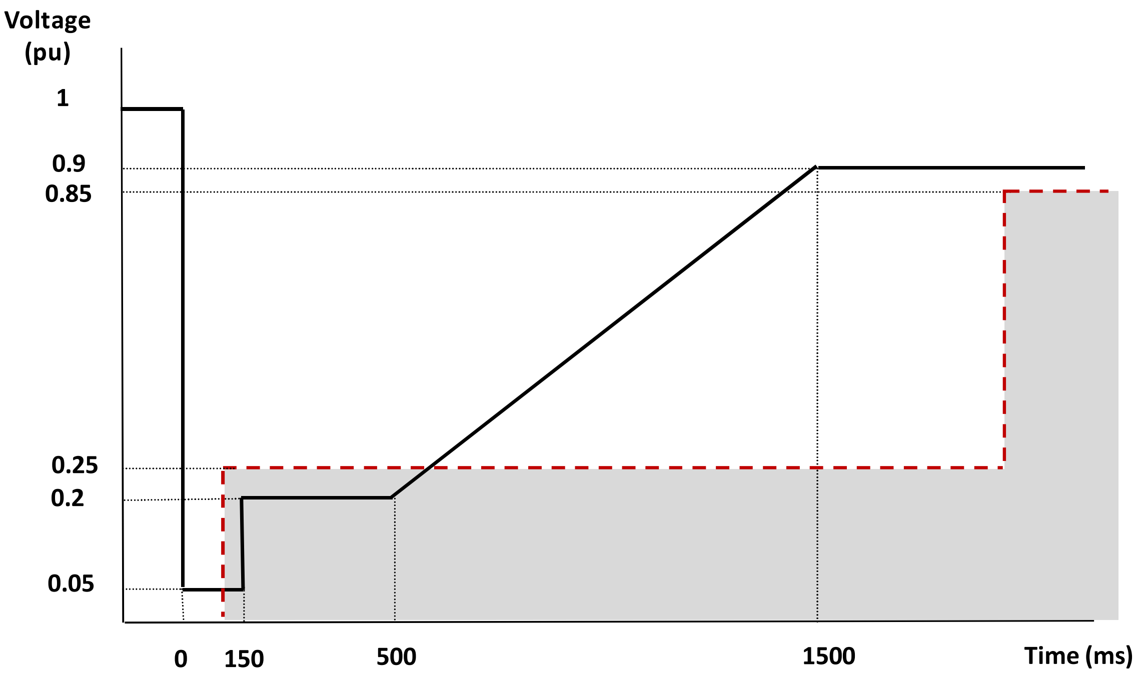


Figure 5-3: Undervoltage and FRT co-ordination in France

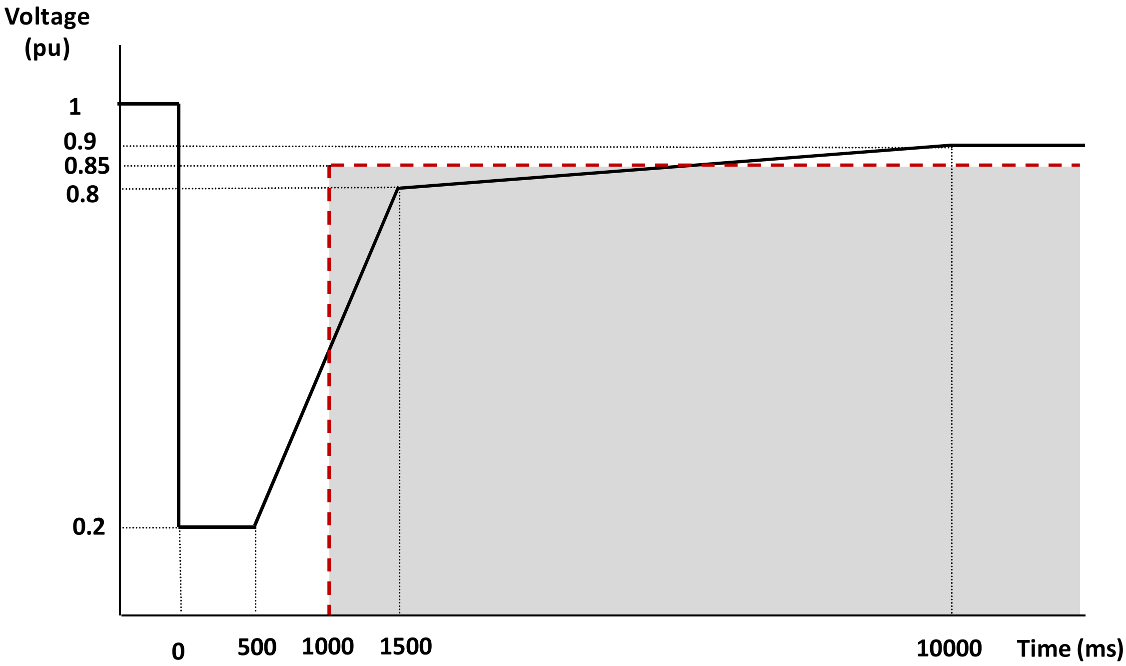


Figure 5-4: Undervoltage and FRT co-ordination in Portugal

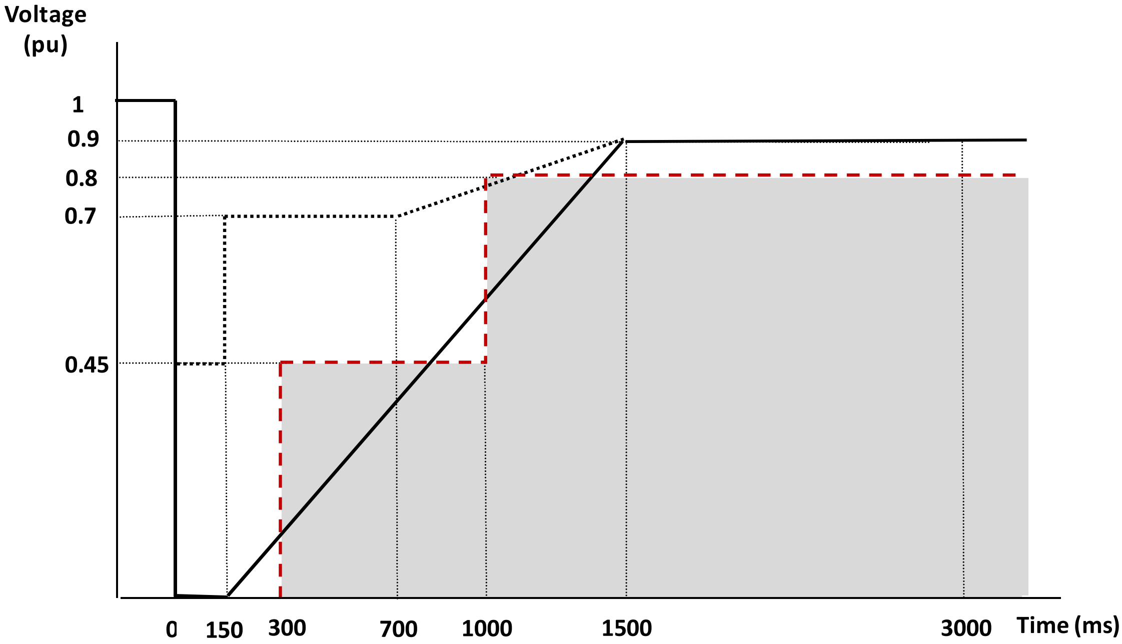


Figure 5-5: Undervoltage and FRT co-ordination in Germany

Regarding frequency relays, some countries have found the need to extend the threshold to keep the system stability for frequency excursions and so to get a better co-ordination with load-shedding protection (i.e. from 50.5 to 52.0 Hz in the UK and from 49.0 to 48.0 Hz in Spain).

The overvoltage relay is also specified with several settings steps in some countries.

<u>*Best practices:*</u>

- For networks with low penetration, the classical protection scheme of DG based only on relays 27, 59, 59N, 81O and 81U with sensitive settings and fast operation has been used with good results as long as spurious trips have not represented serious problems for the power system stability. In this case, the approach is to avoid any risk of islanding operation.
- For medium/large penetration, protection co-ordination to avoid unnecessary losses of generation is required:
  - Wind farms are required in most countries to stay connected for voltage dips (FRT) and in some countries, for large wind farms, frequency and voltage control is being required. For a better co-ordination with undervoltage relay, a good practice is to delay the tripping of undervoltage relays to 1 sec or more. In some countries, two or more undervoltage steps are required even for MV connections, so the greater the voltage dip the faster the trip for a better co-ordination. Figure 5-58 shows an example of co-ordination with two undervoltage steps, one set at 35%-0.7 sec. and the second at 80%-1,2 sec. Programmable voltage curves in the relay would provide more flexibility to co-ordinate with FRT characteristic.

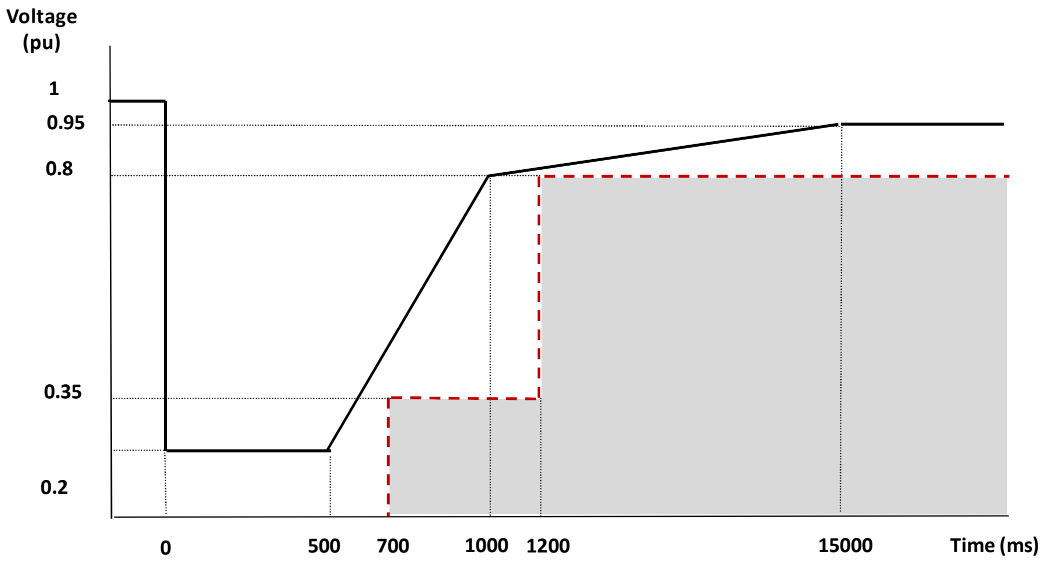


Figure 5-58: Example of two step undervoltage and FRT co-ordination

  - Frequency relay settings are co-ordinated in many countries with those of load-shedding protection in order to avoid additional disconnections in case of frequency excursions. 47 Hz for the underfrequency setting and 53 Hz for the overfrequency setting can be a good practice.

5.5 Reclosing co-ordination

When reclosing of the utility breaker is used, some of the following measures are normally used to avoid the interference of the DG with the reclosing operation:

- Transfer trip, which is also used as an anti-islanding protection, is the most common technique to guarantee that the generator is not energizing the line when reclosing takes place, which is more likely when FRT capabilities are required. It is also used to prevent the energization of ungrounded lines when the line is open at the utility terminal in cases where the DG's transformer has a delta connected HV winding (Canada).
- Line voltage check is used to prevent the closing of the utility breaker if the line is energized in order to avoid an out of synchronism coupling of the generator when reclosing.
- Synchrocheck is used to prevent the closing of the utility breaker unless the line voltage, phase angle and frequency of the line are within tolerances.
- Delayed autoreclosing is used to assure that the interface or generator protection trips first. In this case, the reclosing time should be co-ordinated with the undervoltage and anti-islanding time delays, especially when FRT requirements exist.

Best practices:

- In HV (sub)transmission networks, single and three-pole autoreclosing with synchrocheck should be used. Delayed reclosing for a connection scheme to a line can also be a way to ensure that the reclosing takes place with the line de-energized.
- In MV networks, with loads embedded, since the presence of generators should not interfere with the reclosing performance, disconnection of the generator before the reclosing is required by means of anti-islanding protection, which has to operate in a coordinated way with the reclosers. Three-pole autoreclosing with line voltage check, for connection scheme to a line is recommended. For tapped and substation connection schemes, synchrocheck should be used. Delayed autoreclosing is not recommended for connection in these networks where loads are embedded.

5.6 Anti-islanding

In Chapter 4 it has been highlighted that there are a variety of methods (both active and passive) found in the technical literature but in the utilities' practice only a few are commonly used.

At (sub)transmission level (110kV and above) there is currently no requirement for a dedicated anti-islanding protection apart from Spain where teleprotection transfer trip is used, which is extended even to the remote ends of the substation at which generation is connected.

At lower voltage levels 69kV and below the requirement for anti-islanding protection is more common, where the probability of balance between load and generation can be higher. The methods found in practice can be grouped as follows:

- ROCOF and Vector Shift (VS) are a dedicated form of passive anti-islanding protection for distribution system connections (currently adopted in UK, Australia, Austria, Belgium, Canada and Italy)

- Voltage and/or frequency based protection is used in all countries. The settings vary as discussed in section 5.4. Where no other dedicated anti-islanding protection is installed the voltage and frequency protection with fast operation fulfils this function.
- Direct transfer tripping is also a common practice which although relatively expensive provides the best performance for anti-islanding protection (used in Spain, France, Norway, Germany and also by some utilities in UK).

In some countries other alternative solutions are adopted. In Portugal, for connection to a non dedicated HV line, the reclosing delay is coordinated with the tripping time of 27 and 59 relays and in the MV network, lines with DG connected do not have automatic three-pole reclosing.

It is worth noting that active methods are still not widely utilised due to power quality and reliability concerns, however, some methods are accepted in the US with inverter based generation.

Best practices:

In HV (sub)transmission networks where normally there are no embedded loads, transfer trips or other anti-islanding relays should not be necessary. Synchrocheck would then be used to prevent a possible out-of- synchronism reclose.

In MV networks, where embedded loads are present, anti-islanding protection is necessary to prevent an islanding operation:

- For small DG plants, for which the stability and co-ordination requirements are not strong and nuisance trips are accepted, voltage/frequency or dedicated anti-islanding relays, such as ROCOF, can be applied.
- For medium/large DG, where interface protection is needed to co-ordinate with network protection and avoiding unnecessary trips is required, anti-islanding protection based on transfer trip is recommended. Depending on the connection scheme, there are different solutions for the intertripping scheme:
    - Connection to a non dedicated line: intertripping from the remote utility breaker
    - Tapped connection : intertripping from the remote utility breakers
    - Connection to a non dedicated substation: intertripping from the local/remote line breakers

The operation of the anti-islanding protection must be faster than the autoreclosing delay in order to guarantee a successful reclose and prevent a possible out-of-synchronism coupling.

Some utilities take a view that anti-islanding protection requirements could potentially be subject to a carefully performed risk assessment exercise. In cases where the chance of forming a stable island is negligible (e.g. when minimum local load is significantly larger than the generator capacity) there could be scope for the exclusion from the requirement of dedicated anti-islanding protection.

There is a correlation between the requirement for the maximum time of islanding detection (0.5 s in most cases) and the settings of the auto-reclose schemes. Perhaps the requirement could be less stringent in parts of the distribution system with much longer auto-reclose settings.

5.7 Conclusions

A comparative analysis of current practices in 11 countries and a set of recommendations have been outlined in the previous section according to these requirements.

Below is a summary of limitations and issues to be solved that have been identified:

- Current protection practices in some countries are not valid for medium/high penetration scenarios and protection scheme and settings should be revised. At present:
  - There is generally a lack of co-ordination between undervoltage interface relays and FRT capabilities.
  - Classical frequency settings can result in significant tripping of DG for disturbances in the transmission network, so settings should be adapted to those of conventional generation for proper co-ordination.
- FRT requirements for wind generation are different between countries. In some networks, the requirements are unnecessarily very demanding. The reactive consumption and time responses are not appropriate for system stability. Harmonization in FRT requirements would be very positive.
- The protection requirements for small and medium DG should be revised in some countries in order to assimilate the settings criteria of the interface protections to ones of traditional generation to avoid nuisance tripping and obtain more generation availability and so network stability (see Chapters 2 and Appendix D). The standardization in the connection requirements of DG, particularly of the protection equipment and settings criteria, will be very positive for the development of the DG, especially in highly interconnected networks as in Europe. In this respect, an IEEE standard [71] has been developed recently and others are under preparation by other standardization organizations (CENELEC, IEC, etc.).
- There are a variety of approaches regarding the detection of an islanding condition in different countries ranging from the sensitive ROCOF method or highly reliable intertrip to the protection. Moreover, even within the same country, different utilities approach the issue differently. This highlights the need for a higher degree of standardisation in anti-islanding protection requirements and laboratory tests.
- For large size generators, intertripping can be effective, but there is no definitive solution for small and medium size DG because of the unavailability for reliable communication links, cost and maintenance implications.

6 Future Trends

6.1 Introduction

DG is becoming an increasingly important part of national planning for future electricity supplies. The EU for example has set an indicative target of 22% of electricity in the EU15 to come from renewable sources by 2010 (compared to 14% in 2000). The benefits of increasing DG are clear; reducing the environmental impact of the electricity industry, security of energy supply and economic efficiency. It will be important to encourage installation of DG and enabling participation in this new market is important for competitiveness as well as the environment. Therefore, opportunities will be created in the coming years for appropriate components and technical services in the field of DG.

Integration of large scale renewable energy sources and small size generating facilities into the electricity structure will require new electricity grid structures and new strategies for their operation and management to ensure efficiency, security, sustainability, reliability and high quality power supplies. This integrated grid will have to be sufficiently intelligent and flexible to operate reliably with intermittent generation technologies such as wind power and with generation embedded in the distribution grids. The Smart Grids approach, which is described in 6.6, will permit this intelligent integration. A co-ordinated approach, to overcome the technical and non-technical barriers to this advanced electricity grid, is needed. Finding new solutions to protect these new electricity grid structures will be important to encourage installation of large scale DG. New requirements for the protection systems are expected to provide the reliability and flexibility required by these new network structures and generating technologies. These new grid structures and future protection trends for DG are discussed below.

6.2 Protection and Automation Challenges for Integration of Large Scale DG in the Power Network

For integration of large scale DG the main priority is to effectively contribute to the network stability and operation. An integrated approach is needed for large scale integration of DG.

From the protection and automation perspective the following could be required.

For the transmission network:

- New requirements and capabilities of DG concerning transient stability (angle, voltage, frequency, small signal stability) and voltage and frequency control.
- New wide area protection and control systems capable of taking advantage of these new capabilities.
- Protection systems adapted to the DG fault contribution capabilities.
- Increased network capacity. Dynamic line rating schemes could help ease network capacity limitations.

For the distribution network:

- Operation and protection of distribution networks could develop to become more similar to transmission systems, which will solve many of problems encountered in the distribution networks with greater integration of DG.
- New protection schemes to cope with the lower short circuit currents in the system because of the greater contribution of converter based generators.
- More automation applications of DG connected to the distribution network; control capabilities, reconfiguration, synchronization and reclosing and advanced adaptive setting techniques.
- Development of powerful communication networks in the distribution system with data integration based on the standard IEC 61850 communications. This could help to make adaptive protection schemes and intertripping based anti-islanding schemes more widely used in the distribution system.
- Reliable islanding detection and intentional islanding capability.

Some of the recent technological developments in protection and automation aimed to resolve these future protection challenges are described in more detail in the following sections.

6.3 Trends in Protection Systems

6.3.1 Use of nested settings and custom curves

Many manufacturers of numerical protection relays have provided the ability to implement different relay settings on the same relay and to be selected by remote means. This functionality is little used and yet provides the ability to re-protect the affected network after a circuit re-configuration for example. If the facility is used then normally manual selection is required by an operative at the device. These facilities could provide the first step in pseudo adaptive protection if used in an automated manner for example if controlled islanding is allowed to adapt the settings to the different conditions during island operation.

The custom curves are usually in the form of a points table that can be input to create a user configurable curve. This will make the protection relays more flexible and adaptable to possible future solutions for adaptive protection and to meet the many current customer specific curves for fault ride through protection for example.

6.3.2 Adaptive protection

Today it can be clearly stated that adaptive protection is not available on a commercial basis. The more adventurous designers of future protection devices are considering the use of real-time adaptive protection curves that could adapt to different network conditions. E.g. to manage wind-farms in a micro-grid application, to keep generation connected even during a fault condition would require protection to "hold-off" while fault-ride through and other network actions are tried before disconnection of the generation. This application would lend itself to real-time adaptive protection.

There are some adaptive protection schemes proposed in literature related to high penetration of DG and system stability [72][73].

6.3.3 Dynamic Thermal Protection

Wind farms tend to be located at the extremes of the distribution system where overhead lines may not be rated to carry the full output of the wind farm in all circumstances. Often a line has been designed originally to supply a relatively small load, and the installation of new wind generation may cause a large reverse power flow, causing the standard winter and summer line ratings to be exceeded. The worst case in this respect is with maximum wind generation and minimum local load. Rather than applying fixed summer and winter line ratings, load management based on a dynamically derived line rating can be adopted. Use of a dynamic thermal rating or a real time thermal rating of transmission lines can avoid unnecessary and costly network reinforcement and add extra capacity to the DG project. Some methods that could be used to determine the real time rating are described below.

The line thermal rating can be calculated dynamically in real time from the local weather measurements such as wind speed and ambient temperature to co-ordinate allowed generation automatically. As this method takes into account the cooling effect of the wind it is expected that such a dynamic line rating method could facilitate connection of up to 30% more generation as compared to fixed winter/summer ratings. As a back-up system, in case for some reason the wind farm power output is not reduced on command by the control system, tripping of the overhead lines can be initiated [74].

A dynamic thermal protection approach to network generation and load management consisting of estimating or measuring the component temperature or real current carrying capacity of overhead lines, cables and transformers in a network to allow the power system component utilisation to be safely increased has also been proposed in technical literature [75][76]. The dynamic thermal system proposed comprises a number of different weather stations and temperature measurement devices, placed in different locations over a wide network area. They are connected with a central computer responsible for calculating real time rating estimation. This information may then be used as a decision support tool for the secure operation of the distribution network and control of distributed generation. This computational device can be placed either in a remote substation or in a centralised control room.

PMUs can also be used for line thermal monitoring applications by determining the mean line temperature from the phasor measurements of voltage and current at both ends of the line. The PMUs can calculate the actual impedance and shunt admittance of a line and extracts the line resistance. Based on the known properties of the conductor material, the actual average temperature can be determined. This temperature includes the environmental conditions such as wind speed, solar radiation and line current. Consequently, this data offers much more information than the line current to provide a loadability limit. The line thermal monitoring can serve as an early warning system in case of potential overloads where the operators gain information to initiate corrective actions and thus avoid tripping of heavily loaded lines. [76]

Another method that is presently being used by some utilities to measure the real time rating of an overhead line is based on measuring the line tension. A variation of the same method is EPRI's DTCR system, which provides ratings based on the identical tension measuring technology, backed up by weather-based ratings. Additionally, some utilities are experimenting with optical, ultrasonic, radar and laser-based sag measurement methods, none of which has yet progressed to operational use [77].

6.3.4 New Trends in Islanding Detection

Chapter 4 explores the current status and performance of existing islanding detection and highlights possible future scenarios and presents the main implications on power system protection.

Reliable islanding detection (to be able to sensitively detect a genuine island condition but also be stable for external faults and frequency excursions) has been recognised as one of the most challenging aspects related to distributed generation protection.

Current solutions for islanding detection (rate of change of frequency, voltage vector shift, direct transfer trip and voltage/frequency protection) based on local measurements are not completely satisfactory in this respect. Therefore, the use of active methods and solutions based on local and remote measurements are likely to be implemented in the future as the development of technologies and communications networks are increasing progressively. Wider implementation of PMUs may be helpful to these types of solutions. As communications networks develop and become more standardised then this will help to bring down the costs of transfer trip schemes which may become more popular.

Also, islanding detection performance is often affected by the particular algorithm implemented (e.g. frequency estimation methods applied for df/dt) and there is a need in the future to establish a standard comprehensive testing methodology to assess the performance of different relays. Also, the operation of several generators in parallel and the interaction of different detection methods should be analysed and considered in future standard tests.

6.3.5 Wide Area Monitoring, Wide Area Protection and Special Protection Schemes

Because of the connection of DG on all voltage levels, transmission and distribution networks will tend to evolve towards a unified network. Therefore, there is a trend towards the increased application in distribution of transmission protection practices. Future networks will represent significant challenges to the protection system. One of the protection practices that probably will have opportunities to be developed is WAP/SPS. For further information, the report of WG B5.14 "Wide Area Protection and Control Technologies" is planned for the end of 2009. Concepts of WAP including synchrophasors will probably be applied in order to maintain stability of the distribution network with high penetration level of DG.

Current designs and concepts for WAP/SPS should evolve in the following directions:

- Capabilities to cope with new networks architectures (reinforced intercontinental interconnections)
- Self operating and self healing functions
- Distributed architecture in order to integrate the generation disseminated in the distribution networks
- Flexibility to cope with complex and almost unpredictable contingencies, changing operational conditions and fluctuating generation
- Capabilities to manage the new capabilities of the new generation technologies (see 6.6) to efficiently contribute to the power system stability. It should be able to manage entities such as virtual power plants (VPP), microgrids and power cells

- Intensive use of communications systems with more demanding requirements regarding reliability and response time
- Capabilities to manage islanding creation, synchronization and reclosing. Some present defense plans are based on splitting the network into several islands in order to prevent a large incident cascade. This kind of intentional islanding operation will probably increase in high penetration scenarios of DG.

All these new concepts would be integrated following the approach of System Integrity Protection Schemes (SIPS) that integrates not only WAP but also other local actions such as underfrequency or undervoltage load shedding. It seems clear that the integrated SIPS approach will need to consider DG embedded in the distribution network. Intelligent load and embedded generation control would probably be one of the main challenges in order to achieve self healing networks.

In order to achieve the above mentioned SIPS functions, new technological developments will be necessary. In this regard, the application of synchrophasor measurements in Wide Area Monitoring Systems (WAMS) deserves special attention. A synchrophasor is defined as a phasor calculated from data samples using a standard time signal as the reference of the measurement. Synchronized phasors from remote sites have a defined common phase relationship.

WAMS provide the means to monitor phasor measurements at millisecond accuracy in real-time providing Network Operators the ability to gain a much greater understanding and observability of the extended transmission network. Voltage dips and frequency variations can be tracked across the network providing insight into possible critical disturbances leading to an otherwise irrecoverable blackout scenario. With early warning these disturbances can be localised and controlled thus preventing total network collapse.

Synchrophasors have come a long way since their conception. Many useful applications have been identified, including improved state estimation, frequency estimation, instability prediction, post event analysis, adaptive relaying and wide area control [78]-[81]. Some DG related applications of synchrophasors include islanding detection [82] and line thermal monitoring [81]. The recently published IEEE Standard C37.118 will assure that compliant phasor measurement units will all report phasors using the same convention for measuring phase angle. However, the present installed base of phasor measurement units (PMU) is still small.

The most advanced installation in the world is China where 1600+ PMUs are installed and operational. The USA is probably the next most populated area with Europe falling a long way behind both of these.

Once the use of IEC 61850 90-1 for wide area communication between substations or communication between substation and control centres is introduced, it will offer the protection engineer many new possibilities. Not only will it support a standardized information exchange between protection relays at the two ends of a line, it may also support new applications in the area of SIPS and WAP schemes [83].

6.3.6 Impact of RES and short circuit contribution on distribution protection systems

In chapter 2, some impacts on the distribution protection system due to the short-circuit and load contribution of DG have been described. The following can be highlighted:

- The spread of DG in the distribution network leads to a situation of multiple infeeds which is further accentuated if the network is meshed. This complicates the co-ordination of overcurrent relays. For example in the case of a fault on a line adjacent to the one that has a DG connected, it is possible that the fault current fed by the DG and measured by a non directional overcurrent relay at the substation exceeds its tripping setting resulting in an unnecessary disconnection of the line containing the DG. The trend in the future to overcome these problems will be the use of directional overcurrent relays or even distance relays in distribution networks. Alternatively, current-differential protection can be used which eliminates any co-ordination problems but this requires telecommunication links which is more costly.
- Loss of sensitivity for fault detection in DG tapped connections. A delta connection on the high voltage side of the DG transformer is normally used to avoid this problem for phase to ground faults.
- A sudden loss of generation can lead the distribution transformers to overload
- For tapped connected HV/MV substations or H configurations with embedded DG in MV, faults on the HV network should be effectively detected. Multiphase faults can be detected by impedance relays on the high voltage side of the transformer or by reverse power protection. In the case of an ungrounded connection of the transformer ground faults are normally detected by a neutral voltage displacement relay (59N).

The opposite situation appears when the DG is mainly based on converters with lower levels of fault current contribution. On the one hand, this would represent an advantage because it overcomes some of the problems mentioned above (loss of selectivity and sensitivity). The solution adopted to avoid current contribution for phase to ground faults by means of ungrounding the high voltage side of the transformer is thus extended for phase to phase faults. On the other hand, lower fault currents have an impact on fault detection, protection speed and co-ordination when overcurrent relays or back up distance relays are used, as seen in 2.4.9, so greater use of transmission type protection such as distance and current differential protection may be required to obtain fast discriminating fault clearance for lower fault levels. Transfer trip schemes or other solutions based on communications could also be applied. Also, new protection systems should be re-designed to be able to cope with the new dynamic behaviour of power electronic based generators.

Regarding power quality, since DG tends to substitute traditional generation, it must provide what traditional generators provide (harmonics, negative sequence currents, etc.). Converter based generator manufacturers must face the challenge to develop the technology that facilitates these capabilities.

We can conclude that the increasing presence of DG in distribution networks leads to a revision of the protection philosophy, incorporating some of the transmission protection practices.

6.4 Trends in Automation and Communications Systems

6.4.1 Interaction of protection and automation

Today the connection between Protection and Automation is still tenuous and is rooted in the hardwired past. Inter-locking and inter-tripping traditionally used hardwired solutions. With the advent of numerical relays soft interlocking was possible. Numerical relays also provided software functions that could now interact with substation automation systems, mainly for co-ordination or data maintenance (commissioning, configuration, etc).

With increasing numbers of numerical relays now entering service around the world, the opportunity to utilise their full functionality, flexibility and automation capability has never been stronger than in the connection of new distributed generation sites. Indeed, the need to **integrate** rather than **connect** is driving a requirement to utilise these devices in the most cost effective, efficient and safe way.

The interaction between multiple wind farms connected in the same part of a network, dependent on voltage level and geographical location, usually requires complicated "hardwired" constraint management solutions based on complex commercial "rights". As increased numbers of generators wish to connect the ability to control these "hardwired" solutions becomes almost impossible to manage, especially at the MV level. In the event these are intermittent type generators, such as wind, then the network may be lightly utilised while other generators who could generate are constrained off.

All of these examples provide ample evidence for a broader approach to the use of automation. Instead of extended remote control, automation could be embraced to overcome many of the problems encountered.

6.4.2 Extension of SCADA functionality

Traditionally the majority of SCADA systems are able to provide automation functions that can be used in a closed-loop implementation. Today most are utilised to a mere fraction of their capability due to concerns over integrity and security. Therefore the majority of systems used at present for grid control are mainly used for remote monitoring and manual control actions. This is in sharp contrast to the smaller generation control systems that are routinely being utilised for their automation functionality. In the future, it is expected that many control and automation functions will become carried out by the SCADA systems in a centralized way, whereas others will be distributed residing in the different SAS (Substation Automation Systems).

6.4.3 Information and Communication Technologies (ICT) for the development of DG

ICT will clearly contribute in the improvement of the system operation and management via development of the distribution automation system, automatic metering system, power quality monitoring, demand side management, and so on. Some current R&D initiatives deal with the following themes [84]:

- Technology to detect and avoid islanding, using transfer trip based on PLC
- Optimum voltage control by integral control of all distribution equipment
- Technology to use DG as a reliable source via centralized control
- Optimum system configuration for the use of DG

Some conditions will have to be met in the future to get the benefits of the use of ICT:

- To build economical huge capacity, high speed, reliable and secure communication infrastructure for the distribution system

- Standardization of the information interfaces will be necessary when using a single set of communication infrastructures in versatile ways
- Information security

6.4.4 Standards and protocols

Communication technologies and numerical protection IEDs have evolved to form an integrated network to enhance the efficiency and reliability of the electric power industry. There is a trend for more standardised communications between protection relays of different manufacturers. Consequently, a recent international standard, IEC 61850, has been released to facilitate efficient communication, interoperability, and interchangeability of the IEDs. In IEC 61850, all functions of SAS are data modelled and decomposed into logical nodes with the physical devices communicating with each other using the available network, such as Ethernet. Most applications of IEC61850 are largely concentrated on the IEC 61850-8.1 station bus, emulating and improving on the conventional SCADA approaches. Section 9.2 of the standard describes the process bus where physical devices such as IED based protection relays communicate with non conventional instrument transformers via merging units to collect analogue measurements [85][86][87][88]. The concept of process bus offers new opportunities for functional integration of SAS and HV equipment as well as new opportunities regarding WAP.

This data model integration would allow standardized engineering, commissioning and maintenance and disturbance analysis, contributing to improve reliability and minimize life cycle costs.

The extension of standards in the electricity supply industry faces some barriers. The reason is probably due to the exceptionally slow roll-out times for any large adoption of network wide standards, especially protocols. The large investment in obtaining a complete roll-out is protected by the replacement cycle of up to 40 years for major equipment items on the networks. Compare this with the telecoms industry where movement from the original GSM standard to the third generation (or 3G) took less than ten years for almost complete roll-out.

It is not surprising therefore when we investigate contained areas on the network (e.g. with-in a single primary sub-station) a standard can be said to exist. Typically new build primary sub-stations will use the new IEC 61850 communication standard within the substation but may communicate to the control-centre by a proprietary protocol that may be up to 30 years old.

Protocol standards, such as IEC 60870-5-101,103,104 and DNP3 provide a core of "standard" message sets but also provide "special" reserved message areas that can be utilised for particular manufacturer's functionality rendering these messages unintelligible to other vendors.

It is important when selecting different vendors equipment to understand the inter-operability issues that will be defined by the selection of standards and protocols. E.g. the wrong choice could see large amounts of functionality purchased in one product not being able to contribute to the solution because the appropriate message sets are not available in the chosen protocols to enable this functionality.

Different standards have to be selected dependant on the exact nature of the functionality required, the installed legacy "standards" and the strategic plan for replacement and upgrade of the entire network architecture. This is not an insignificant amount of work especially when connection versus integration of DGs is considered. The typical on/off signals used to curtail generation when capacity is being threatened on the network will (probably) give way to a need to maximise "green" generation capacity and have complex integration and control between grid and generator to achieve this desired result. Unfortunately the initial decision on protocol selection may turn-out to be a very costly mistake if the chosen groups of standards do not allow this functionality to become a reality.

6.4.5 Information security

As substations become more interconnected and automated, potential cyber vulnerabilities grow. The cyber security of protection and control systems associated with critical infrastructure has been the subject of considerable interest in recent years. Recent cyber threats have awakened the concerns of major countries' concerning the power control systems.

Threats and countermeasures to the cyber security of the power system, such as system configuration, security protocols and cryptology, are discussed in a number of papers [89] -[96]. More secure communication networks are required in the future to keep data confidentiality and integrity and promote wider use of standardised communications in protection schemes especially wide area protection schemes.

6.5 Trends in the requirements and capabilities of new generation technologies contributing to the network stability

The connection of large scale DG to the power system requires an integral approach. All the issues of power quality, system stability and operational requirements should be analyzed in a global and integrated approach. DG and bulk generation from RES will not only deliver energy but may/must contribute also to the ancillary services. As a result of this, new requirements for DG will be established, which will probably take advantage of the operational opportunities of the new generation technologies.

New generation technologies based on power electronics[6] are more flexible and have a much better response time than conventional synchronous machines. They will allow new functions and then new requirements for DG that satisfy the needs of the network taking into account both cost and technical efficiency.

Therefore, one can foresee contributions to the power system stability such as:

- Angle stability. New generation would supply energy via the power electronics inverter with virtually no inertia. Appropriate control (power system stabilizer) could make RES generation able to compensate the acceleration angle of synchronous machines after a three phase fault, damping the active power oscillations.
- Voltage stability. Wind power generation already has reactive power control capabilities. The reactive power control capability of the RES could not only be applied to steady state conditions, but also for voltage transient control during a long or short time voltage collapse condition. [25]

[6] To this group belong power plants such as full converter wind turbines and photovoltaic systems and in a smaller scale, micro-turbines, fuel-cells, energy storage systems, battery energy storage systems, flywheels and certain types of wind turbines.

- Frequency stability. Control of RES could have virtual inertia capabilities in order to compensate under or over frequency instability conditions. Some means of energy storage will be needed. [25]
- Small signal stability. Some studies show a beneficial influence of wind turbine generation in damping small signal oscillations.

These requirements should consider both the DG size and the time scale. An example outline of the proposed functionalities is presented in Table 6-1.

DG size	**Stability aspect**		
	Subtransient	**Transient**	**Steady state**
Small	I_{cc}	FRT Contribution to transient stability in: • Angle • Voltage • Frequency	Voltage and cosφ control
Medium			Active power/frequency control
Large			Small disturbance stability

Table 6-1: Proposed DG requirements to contribute to system stability

The use of power electronics equipment for wind farms based on induction generators, such as Static Var Compensators (SVC) or static synchronous compensator (STATCOM) [97] can also offer several benefits:

- Rapid reactive power control during and after a system fault.
- Support for the ac network voltage, which can increase the fault ride through capability of a wind farm.
- Stabilisation of the voltage on the line, and can be used to extend the distance over which the power can be transmitted.
- Reactive power ancillary services to the network.
- Help to suppress voltage fluctuations due to generator starting and stopping action, or changes in wind velocity

Energy storage solutions to compensate for variations in the output of wind generation are commercially available, and could significantly improve the technical performance of a network with a high penetration of wind generation. However, the cost of storage systems is still too high and their efficiency too poor to make them appropriate for anything but special cases. The continuing R&D efforts in this area will result in future generations of energy storage systems being able to support increased penetration of wind generation in an economic manner.

Thus, converter based generators can have a beneficial influence on the system behaviour, which can be significant in the future as the penetration of DG progressively increases. In combination with energy storage more options are possible enabling the inverter to participate in grid-forming or grid-supporting modes of operation:

- System restoration after a disturbance
- Intended islanding
- Extended voltage control
- Peak shaving
- Inverse current supply during disturbances

With this in mind, the generic functionalities required in a grid can be reassessed in order to restructure the overall approach, to accommodate very high and growing levels of renewable (intermittent) and distributed energy generation and consumption, part of which may be remotely and decentrally controlled [13].

Standardization bodies in collaboration with utilities and manufacturers should contribute to grid codes of different countries to converge and allow the connection of large DG penetration as considered in the scenarios of the future network.

Together with generation dispatching the possibilities of load management (demand-side management) can be used to adapt the load to some extent to the actual generation situation.

Most of these features are only possible by integrating the distributed generation and the loads in a sophisticated management system taking advantage of the future possibilities of information and communication technologies.

6.6 Smart Grids

Smart Grid is an electricity grid concept defined by a number of enhanced functionalities like automatic selection of the best production source, ability to integrate distributed generation, enhanced interconnection, real-time analysis of consumption patterns, etc. [98][99]. According to [100], to modernise transmission and distribution power networks to maintain reliability and infrastructure protection, a smart grid should have functions such as:

- self-healing and fault-tolerant capability.
- integration of all energy generation and storage.
- dynamic optimization of grid operation and resources with full cyber-security.
- incorporation of demand-response, demand-side resources and energy-efficient resources.
- providing timely information and control options.
- Improving reliability, power quality, security and efficiency of the electricity infrastructure.

This concept has emerged as a consequence of the deployment of Information and Communication Technologies (ICT) throughout the electricity industry, which comes after the deployment seen in other industries (phone, entertainment …).

Clear views of what the grid is today and what it will ultimately be with a Smart Grid approach exist. However, there are very few ideas on how to go from one point to the other. The main technologies to be developed, the main stakeholders and the main drivers are identified, but how the market will react, what consumers will adopt or not, the pace that utilities will adopt, standards and regulations that will emerge, and ultimately the market organization will only be known through experience.

Several research and development programs have been formed in recent years with the goal of improving the intelligence of the electric power infrastructure. Several major programs are listed in Table 6-2. These programs, along with other established R&D organizations, are addressing the technical, economic, and policy barriers to creating a smarter grid. This abundance of research has bolstered the confidence of industry stakeholders, who now recognize that transformation of the grid indeed can be accomplished within the next few years.

From a functional stand-point the majority of these early adoptions of Smart Grid concepts are in the domain of system intelligence and automation and the associated challenges are related to IT System scalability, basically consisting of applying existing algorithms and processes but in a larger and more distributed manner. It is worth noting that the majority of the main software building blocks exist today but used at scales quite different from the future distribution of sensors in grids. Besides, the software and modelling technologies are improving a lot because of other technology trends in other industries like aeronautics, mobile phone, and military applications.

RESEARCH PROGRAM	DESCRIPTION
ADINE	Active Distribution network.
ANEMO.PLUS	Advanced tools for the management of electricity grids with large-scale wind generation
CRISTAL	Control of renewable integrated systems targeting advanced landmarks
EWIS	European wind integration study – towards a successful integration of wind power into European electricity grids
GROW-DERS:	Grid reliability and operability with distributed generation using transportable storage.
INTEGRAL	Achievement of an integrated ICT-platform based distributed control of decentralised energy resources
IS-POWER	Increase reliability and supply guarantee in a large-scale integration of renewable energies and other distributed generation technologies
RELIANCE	towards a European Centre for Electricity Networks
REALISEGRID	Research, methodologies and technologies for the effective development of pan-European key grid infrastructures to support the achievement of reliable, competitive and sustainable electricity supply
SUPWIND	Development of regional and Pan-European guidelines for more efficient integration of renewable energy into future infrastructures.
SUSPLAN	Development of regional and Pan-European guidelines for more efficient integration of renewable energy into future infrastructures.
TRADEWIND	Wind power integration and exchange in the trans-European power market
VSYNC	The virtual synchronous generator concept

WINDGRID	Wind on the Grid

Table 6-2: Smartgrid research programs

6.6.1 New functions for smart grids

In order to complete the transition that has already started the following new system intelligence functions will in the future be required to approach the Smartgrid infrastructure targets. However, it should be recognized that these are only some system-level functions and a full implementation of Smart Grids will also require smart equipment such as Fault-Current Limiters, new protection schemes/algorithms to facilitate increased DG connection some of which are discussed in this chapter and a massive growth in the use of power electronics (FACTS, STATCOMs, etc) and embedded energy storage, even at lower voltage/power levels than those for which they are used today.

So far, in this environment, major stakeholders have just started communicating on these new smart-grids challenges. This topic has so far been dealt through other terms like grid reliability, energy efficiency, sustainability, enabling intelligent grid processes, or by using only the generic European language (safe, reliable …).

As a result, smart grids appear to all stakeholders as a wide field of innovation, as much commercially as technologically speaking. All stakeholders now recognize that deployment of smart grid can indeed be accomplished, and the majority of energy regulators have decided for a strong push towards developing more hardware equipments within substations to accelerate the deployment of smart grids.

6.7 Non Technical Challenges and Barriers

One of the most important non technical barriers to the development of DG concerns the permission and the grid connection procedures for DG which in many countries are currently complex and lengthy. These procedures are regulated at the national level and sometimes even differ between the regions inside a country. Other issues can be a high number of authorities involved in application procedures and co-ordination problems between them and the promoter. Also, many of the standards concerning grid connection of DG are adapted to the requirements of large conventional power plants and are not well adapted to the particular characteristics of DG plants (i.e. smaller plant size, intermittency of power output, availability of DG in areas with a weak grid infrastructure, etc.). Consequently many stakeholders are calling for streamlining, simplification and harmonisation of existing permission procedures. The introduction of a one-stop agency is seen as a possible solution for the major administrative problems. Therefore, regarding permission procedures, the standardisation, the increase of transparency and the simplification of permit procedures will be helpful to the development of DG.[101]

Several working groups and/or agencies/associations, like EWEA (European Wind Energy Association) are proposing a new approach, with the objective to create a unique Grid Code, e.g. the European Grid Code Requirements for Wind Power Generation. Therefore, it is possible in the short term that these same working groups with contributions from the TSOs, DSOs and wind turbine manufacturers will carry out the elaboration of a unique Grid Code.

Especially with regard to renewables, there are a number of other non technical barriers slowing the rate of their deployment:

- The most competitive technologies (onshore wind and hydropower) are limited by the scarcity of suitable sites.
- It is increasingly more difficult to secure consent for renewables (especially onshore wind) which puts developers under the risk of significant delays.
- Maturing technologies such as offshore wind and biomass are still more expensive than anticipated.
- A lack of stable regulatory framework in some countries that gives promoters more guarantees when financing their projects
- While electricity can be transported over long distances using power lines, project economics often do not allow for the construction of transmission lines for a new DG installation that cannot be built near existing transmission lines. Hence, some DG resources can only be exploited where nearby transmission lines with free capacity already exist. Some governments try to overcome such barriers through public-private partnerships. Sometimes, sharing costs between several projects may be possible to finance new transmission lines or to upgrade existing lines.

6.8 Conclusions

DG is becoming an increasingly important part of national planning for future electricity supplies. In order to meet their commitments to reduce greenhouse gas emissions over the next decade, governments will need to encourage the development of DG and meet the challenges the increasing presence of DG will impose on electricity networks. An effective integration in the electricity network is needed for the proper functioning of the energy market. This integrated grid will have to be sufficiently intelligent and flexible to operate reliably with intermittent generation technologies such as wind power and with generation embedded in distribution grids.

The protection challenges and priorities for integration of DG into the power network depend on the level of renewable energy penetration which will differ from country to country. For small and medium scale DG, priorities and challenges have been discussed in chapter 2 and different recommended practices and measures, some of them currently implemented by system operators in their grid codes have been outlined in chapter 5.

For integration of large scale DG the main priority is to effectively contribute to the network stability and operation in co-operation with the conventional generation, for which an integrated approach is needed.

From the protection and automation perspective the following summary list of trends and requirements have been described in the previous sections:

- New requirements and capabilities of DG concerning transient stability (angle, voltage, frequency, small signal stability) and voltage and frequency control using the potentialities of power electronic based generation.
- New wide area protection and control systems capable of taking advantage of these new capabilities.
- Protection systems adapted to the DG fault contribution capabilities.

- Increased network capacity. Dynamic line rating schemes could help ease network capacity limitations.
- Operation and protection of distribution networks could develop to become more similar to transmission systems, which will solve many of problems encountered in the distribution networks with greater integration of DG.
- New protection schemes to cope with the lower short circuit currents in the system because of the greater contribution of converter based generators.
- More automation applications of DG connected to the distribution network; control capabilities, reconfiguration, synchronization and reclosing and advanced adaptive setting techniques.
- Development of powerful communication networks in the distribution system that improve system operation and management through monitoring and automation applications and permits data integration, based possibly on the standard IEC 61850 communications. This could help to make adaptive protection schemes and intertripping based anti-islanding schemes more widely used in the distribution system.
- Reliable islanding detection and intentional islanding capability.

Currently the view of many countries concerning intentional islanding is that the cost of additional infrastructure outweighs the benefits. However, with increased levels of DG penetration in the future and the tendency of connecting these generators at higher voltage levels, it is expected that the benefits of islanded operation will be more significant and the additional cost relatively lower. Intelligent protection schemes which can adapt their protection settings will play an important role to enable stable operation and protection of these power islands.

Streamlining, simplification and harmonisation of existing permission procedures and standardisation of the grid codes for the connection of DG is also required to encourage large scale integration of DG. The standardization in the connection requirements of DG, particularly of the protection equipment and settings criteria, will be very positive for the development of the DG, especially in highly interconnected networks to avoid nuisance tripping and obtain more generation availability and so network stability.

Local automation functions and the development of communication networks to control the operation of DG by the transmission system dispatch together with more advanced forecast applications will permit, especially for renewable sources, the integration of DG into the network and exploit their control capabilities similar to conventional generation. In the future, new control technologies such as pitch control and the development of new power management tools will allow more flexible operation of windfarms and a greater integration into the market mechanisms.

New generation technologies such as inverter based generators, offer capabilities to steady state voltage, power factor and frequency control. In the future, the technology will evolve to provide new capabilities that permit maximization of the production of non-synchronous generators. This technology can be significant in the future to accommodate very high and growing levels of renewable (intermittent) and distributed energy generation and to guarantee the security of the system.

There is a trend for more standardised communications between protection relays of different manufacturers. The recent IEC 61850 communications standard aims to facilitate efficient communication, interoperability, and interchangeability between the IEDs, between the IEDs and the station bus and between instrument transformers and the IEDs on the process bus. The standardisation of these communications will help promote more use of WAP/SPS and adapative protection schemes in the future required for DG protection applications. This trend towards more standardised communications also allows standardised engineering, commissioning and maintenance and disturbance analysis, contributing to improved reliability and minimizing life cycle costs. Cybersecurity is a growing issue in the power industry and more secure communication networks are required in the future to keep data confidentiality and integrity and promote wider use of standardised communications in protection schemes, especially wide area protection schemes.

7 Conclusions

The main outcomes and conclusions from the work of this group can be summarised as follows:

- In the recent years, a spectacular growth of DG/RES has been happening widely in all countries and this is expected to continue over the next few decades.
- The increase of the DG penetration in distribution networks with the emergence of large DG power plants connected to sub-transmission network has pushed recently some countries to develop new requirements or revise the existing codes to cope with the new scenario. However, this process is has not been co-ordinated internationally. This work highlights the pressing need for better international co-ordination of these requirements.
- In view of the different connection arrangements analysed for each country it is commonly acceptable to establish different DG connection criteria for distribution networks generally radial up to 69kV networks, and for (sub)transmission meshed 100kV and above networks. In transmission networks, the DG is normally connected to a dedicated or existing substation, directly or through a dedicated line. Also, tapped connection to an existing two ended line is acceptable in transmission networks in some countries.
- All countries use practically the same set of interface protections, which are under-/over-voltage protection, under-/over-frequency protection, phase and ground overcurrent protection complemented with transformer differential protection. For more detailed recommendations and best practice in generator interface protection refer to chapter 5.
- The impact of reduced short circuit current contribution from new generation technologies on the performance of the current line protection needs to be assessed, especially for those connections where current detected by the relays is exclusively supplied by the DG, i.e. direct line connections, tapped connections or connections to a substation with a few lines.
- With growing DG penetration levels of all sizes and connection voltages there is an increased need for high performance anti-islanding protection. Taking into account current relay offerings the implementation of anti-islanding protection is always a question of compromise between sensitivity and stability as well as between the performance and cost. Traditionally, the stability aspect was of lesser importance as the network operation did not depend on the presence of DG. This situation is gradually changing and reliable islanding detection is becoming increasingly more important. New solutions are needed as the limitations of the existing methods may eventually pose a barrier to further integration of DG. The use of active methods and alternative communication technologies to improve performance should be considered.
- With low levels of DG penetration or small units, system operation does not depend significantly on the generated power from DG sources and in case of abnormal situations all DG units are required to trip. In these cases conventional philosophies for protection and restoration are valid and few implications or adaptations in the existing network protections are required.
- As the penetration increases the units are considered more important for the security of the power system. Also, the implications in the network protection and the need for co-ordination becomes greater. System operators are demanding more capabilities from generators to stay connected under certain voltage disturbances (defined by FRT curves) or frequency excursions, even contributing to support the system parameters during these

conditions. Classical frequency settings can result in significant tripping of DG for disturbances in the transmission network, so settings should be adapted to those of conventional generation for proper co-ordination. There is also a noted lack of co-ordination between undervoltage interface relays and FRT capabilities.

- The FRT requirements for wind generation in some networks are unnecessarily demanding. The reactive consumption and time responses are not appropriate for system stability. Therefore, the harmonization in FRT requirements is highly recommended.

- New generation technologies, such as inverter based generators, can offer capabilities to steady state voltage, power factor and frequency control. In the future, the technology will evolve to provide new capabilities that maximize the output of non-synchronous generators, allow increased integration of new generation technologies and provide better system security.

- Current automation, monitoring and control practices are not sufficient for the needs of DG integration. Regional control centres for DG/RES should be extended and integrated. Also, more control capabilities (voltage and frequency) and contribution to ancillary services should be added. Local automation functions and the development of communication networks to control the operation of DG by the transmission system dispatch together with more advanced forecast applications will permit, especially for renewable sources, the integration of DG into the network and exploit their control capabilities similar to conventional generation. In the future, new control technologies such as pitch control and the development of new power management tools will allow more flexible operation of windfarms and a greater integration into the market mechanisms.

- There is a trend for more standardised communications between protection relays of different manufacturers. The recent IEC 61850 communications standard aims to facilitate efficient communication, interoperability, and interchangeability between the IEDs, between the IEDs and the station bus, and between instrument transformers and the IEDs on the process bus. The standardisation of these communications will help promote more use of WAP/SPS and adaptive protection schemes in the future, required for DG protection applications. Cybersecurity is a growing issue in the power industry and more secure communication networks are required in the future to keep data confidentiality and integrity and promote wider use of standardised communications in protection schemes, especially wide area protection schemes.

- Streamlining, simplification and harmonisation of existing permission procedures and standardisation of the grid codes for the connection of DG is also required to encourage large scale integration of DG. The standardization in the connection requirements of DG, particularly of the protection equipment and settings criteria, will be very positive for the development of the DG, especially in highly interconnected networks to avoid nuisance tripping and obtain more generation availability and so network stability.

- In order to further increase the security of supply DG units could be allowed to operate in an islanded mode in a meshed distribution network. Currently the view of many countries concerning intentional islanding is that the cost of additional infrastructure outweighs the benefits. However, with increased levels of DG penetration in the future and the tendency of connecting these generators at higher voltage levels, it is expected that the benefits of islanded operation will be more significant and the additional cost relatively lower. Intelligent protection schemes which can adapt their protection settings will play an important role to enable stable operation and protection of these power islands.

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Appendix A

A.1 Country Specific Legal Regulations

Some European countries have released grid codes, for example :

- Belgium : Royal Decree, technical rules 19/12/02, (see http://www.elia.be/repository/Lists/Library/Attachments/336/KB20021219technischreglementwijziging_NL_FR.pdf)

- France: technical reference book rev 2 July 06, from RTE company (see http://www.rte-france.com/htm/fr/mediatheque/offre.jsp)

- United Kingdom (UK) : grid code rev 17 01/09/06, from National Grid company (see http://www.nationalgrid.com/uk/Electricity/Codes/gridcode/)

- Spain: Procedures for access and linking up generation, consumer and distribution systems to the transmission grid are established in Royal Decree 1955/2000. Transmission, distribution, trading, supply and the steps to authorise electricity facilities are regulated by that Decree (See the Royal Decree Titles I and IV of the Official Gazette dated 27/12/2000, pdf, 53 pgs, 303 kb). The technical requirements are developed by the Operating Procedures 12.1 and 12.2 published in the Official Gazette 01/03/2005.

- Netherlands: The Electricity Act (1998) stipulates that the joint grid administrators must submit proposals to the Office of Energy Regulation (DTe) detailing a tariff structure and a set of technical conditions (regulations) for grid administration. DTe will evaluate and eventually approve these proposals. Technical codes : the joint grid administrators have drawn up four sets of regulations governing tariff structures and the conduct of grid administrators and customers. It concerns the following regulations:
  Tariff Code; Grid Code; System Code; Metering Code.

- Portugal: The institutional arrangement and administrative rules to manage and process the application for transmission and distribution networks connection of new power projects was reviewed and redefined in 2001 in the Decree-Law 312/2001 (see http://www.dgge.pt/ ; http://dre.pt/). The tariff structure for Renewable Energy is presented in the Decree-Law 33-A/2005 and Decree-Law 313/2001 (see: http://dre.pt/).

- Australia: the Australian electricity generation, transmission and distribution system is regulated by the Australian Energy Market Commission (AEMC) (see http://www.aemc.gov.au/rules.php). The National Electricity Rules govern the operation of the National Electricity Market. The Rules have the force of law, and are made under the National Electricity (South Australia) Act 1996. This differentiates between generators >30MW and smaller generators for the purposes of dispatch in the market.

- In general, all generation is bound by the National Electricity Rules (NER) and the requirements laid down for communication with the national market control centre for metering, ancillary services and system operations. The latest version of the NER extends the coverage to address the specifics of wind and other intermittent generation only in terms of operational control rather than in terms of different or special technical standards.

- Also applicable are the Australian Wiring Rules, including AS/NZS 3010:2005 "Electrical installations - Generating sets", and various State (as opposed to Federal) based regulations. Small inverter based installations below 10kVA per phase are regulated by AS4777, with protection covered in part 3, AS 4777.3-2005 "Grid connection of energy systems via inverters - Grid protection requirements".

  Legislation at an Australian Federal level is currently being formulated based on work done for the Utility Regulators Forum (URF) to prepare a "Code of Practice for Embedded Generation". Details of this are publicly available at http://www.ret.gov.au/Documents/mce/rdg/cop/default.html

A.2 DG Protection Related Regulations

This section provides a summary of country regulations relating to protection of DG/RES based on the DISPOWER project "International standard situation concerning components of distributed power systems and recommendations of supplements".

Austria

Title	Purpose of the document	Outline of the protection requirements
TOR - Part D4 "Parallelbetrieb von Erzeugungsanlagen mit Verteilernetzen Technische Richtlinien für den Parallelbetrieb von Eigenerzeugungsanlagen mit dem Niederspannungsnetz."	Technical rules for the grid-interconnection and operation of DG units in parallel with the distribution grid.	The document is the national reference guideline for the connection of distributed generation units (independent on the generation technology and including back-up power systems) to the public distribution grid. For issues related to PQ and interferences, TOR D2 is referenced. Opinion: Dedicated to DG, includes a comprehensive explanation of topics specific for DG as well as typical examples for grid-interconnection of different generators. Currently under extension (new protection systems for small DG,...) adaptation to the latest international standards. New rev. is scheduled for mid 2004.
ÖVE/ÖNORM E2750 – Photovoltaische Energieerzeugungsanlagen Errichtungs - und Sicherheitsanforderungen (Photovoltaic power-systems – Erection and safety requirements)	This is the national standard defining safety requirements for planning, installation and operation of photovoltaic power systems.	This draft national standard defines safety related requirements for planning, erection and operation of grid-connected PV-installations. Covered topics include: PV-Generator and DC-installation (safety, protection, grounding, dimensioning); conversion system (inverter, decoupling/islanding protection, PQ related issues, testing procedures) operation and maintenance. Covers all aspects of PV systems, currently under revision, including new requirements for anti-islanding.

Belgium

Title	Purpose of the document	Outline of the protection requirements
C10/11 - 07.08.2003 "Technical requirements for connection of dispersed generation systems operating in parallel on the distribution network"	Purpose: protection of the grid and personnel Application: all generator units up to 15MVA connected to LV or MV grids	generally good and complete guidelines: appropriate for DG/RES, sufficiently regulated, does not hinder further dissemination of DG/RES, no unnecessary barriers for DG/RES
"Algemeen Reglement op de Elektrische Installaties (AREI)"	Safety regulations for electrical installations, some issues about protection are relevant for DG	This is a general document on regulations for all electrical installations, recently small modifications are made to this document concerning the protection of distributed generation units (loss of mains protection as alternative for an accessible disconnection switch for small generation units (e.g. PV).

Canada

Title	Purpose of the document	Outline of the protection requirements
BC Hydro. Connection requirements for utility or non-utility generation, 35 kV and below, December 1998	This guide describes BCH connection requirements, the minimum design standards the generation developments must satisfy, and the range of normal and emergency system conditions the generation facilities could encounter while connected to the BCH distribution system. It only applies to rotating machines	Minimal protection equipment is specified, including settings, anti-islanding and prevention of energization of ungrounded lines.
Draft Standard CSA C22.3 No.9 Interconnection of Distributed Resources with Electricity Supply Systems	This standard is issued under the Canadian Electrical code, Part III and address technical criteria for interconnection of distributed resources to electricity supply systems up to 50 kV, with aggregate capacity of 10 MVA or less at the point of common coupling.	Minimum protection requirements, low voltage ride-through and anti-islanding protections are specified.

France

Title	Purpose of the document	Outline of the protection requirements
NOR ECOI9700444A Journal Officiel “Arrêté du 21 juillet 1997 relatif aux conditions techniques de raccordement au réseau public des installations de production autonome d'énergie électrique de moins de 1 MW”	NOR ECOI9700444A is dealing with requirements concerning the connection of DG (power under 1 MW) to the LV and MV grid on main land France. This document is dealing with the following issues: Permanent Voltage, voltage fluctuations, islanding protection, harmonic levels, reactive power regulation, flicker and grounding.	This document is an abrogated ministerial order and it has been replaced by new rather general government decrees and ministerial orders. It is still useful since the technical reference documents that will detail the law have not been published by EDF yet.
NOR ECOI9900230A Journal Officiel “Arrêté du 15 avril 1999 relatif aux conditions techniques de raccordement des installations de production autonome d’énergie électrique aux réseaux publics HTA et BT non reliés à un grand réseau interconnecté”	NOR ECOI9900230A is dealing with requirements concerning the connection of DG (power under 10 MW) to the MV and the LV grids in French islands or isolated areas. The main issues are: capacity to withstand voltage and frequency variations, stability, decoupling protection, network operation and exchange of information, contribution to voltage and frequency control.	This document is an abrogated ministerial order that complemented or modified the ministerial orders NOR ECOI9800523A and NOR ECOI9700444A for island and isolated grids. It has been replaced by new rather general government decrees and ministerial orders. It may still be useful since the technical reference guides that will detail the new law have not been published by EDF yet.
NOR ECOI9800523A Journal Officiel “Arrêté du 3 juin 1998 relatif aux conditions techniques de raccordement au réseau public HTA des installations de production autonome d'énergie électrique de puissance installée supérieure à 1 MW”	NOR ECOI9800523A is dealing with requirements concerning the connection of DG (power between 1 MW and 10 MW) to the MV grid in France. The main issues are maximum allowable power, maximum shortcircuit currents, steady-state voltage, voltage fluctuations, decoupling protection, harmonic levels, reactive power regulation, ripple control signal, flicker, grounding, coupling criteria and start-up, metering and exchange of information	This document is an abrogated ministerial order and it has been replaced by new rather general government decrees and ministerial orders. It is still useful since the technical reference guides that will detail the new law have not been published by EDF yet.
NOR ECOI00005A Journal officiel “Arrêté du 30 décembre 1999 relatif aux conditions techniques de raccordement au réseau public de transport (réseau à 400 kV exclu) des installations de production d'énergie électrique de puissance installée inférieure ou égale à 120 MW”	NOR ECOI00005A is dealing with requirements concerning the connection of DG (power between 10MW and 120 MW) to the HV grid in France.This document is dealing with the following issues: grid capacity studies, Voltage and reactive power control, frequency and active power control, connection configurations and schemes, protection and stability issues, islanded operation and network restoration, power quality, coupling requirements, metering and exchange of information, installation and commissioning, DG units performances monitoring.	This document is an abrogated ministerial order and it has been replaced by new rather general government decrees and ministerial orders. It is still useful since the technical reference guides that will detail the new law have not been published by RTE yet.
DRE SPECIFICATIONS	DRE specifications present guide lines for standalone systems using renewable energies: types of system, design, installation, testing, operation and maintenance. This guide has been established by EDF with professional experts of the sector in France.	These guidelines have been published in the form of a UTE guide (UTE C 57305): Rural decentralised electrification

CONSUMERS SUBSTATIONS FED BY MV GRID NF C 13-100	NF C 13-100 is dealing with consumer substations established inside a building and fed by MV public distribution system.The main issues are: general structure of substations, protection (Electric defects, faults…), measurement devices	
NOR INDI0301060D Journal officiel Décret n° 2003-229 du 13 mars 2003 relatif aux prescriptions techniques générales de conception et de fonctionnement auxquelles doivent satisfaire les installations en vue de leur raccordement aux réseaux publics de distribution	Government decree dealing with specifications for the connection of generating units and consuming installations to the distribution grid.	Rather general government decree that is complemented by the following ministerial order and will be complemented by the technical reference guide which is being prepared by the distribution system operators.
NOR INDI0301276A, " Arrêté du 17 mars 2003 relatif aux prescriptions techniques de conception et de fonctionnement pour le raccordement à un réseau public de distribution d'une installation de production d'énergie électrique	Ministerial order dealing with the specifications for the connection of generating units to the distribution grid. Main issues : voltage and reactive power regulation, power quality, decoupling protection, network operation and exchange of information, specific measures for island grids.	Rather general ministerial order that will be complemented by the technical reference guide which is being prepared by the distribution system operators.
NOR INDI0301440D Journal officiel Décret n° 2003-588 du 27 juin 2003 relatif aux prescriptions techniques générales de conception et de fonctionnement auxquelles doivent satisfaire les installations en vue de leur raccordement au réseau public de transport de l'électricité",	Government decree dealing with specifications for the connection of generating units and consuming installations to the transmission grid.	This document is an abrogated ministerial order and it has been replaced by a new one in 2008 (see NOR : DEVE0808815A).
NOR INDI0301719A Arrêté du 4 juillet 2003 relatif aux prescriptions techniques de conception et de fonctionnement pour le raccordement au réseau public de transport d'une installation de production d'énergie électrique	Ministerial order dealing with the specifications for the connection of generating units to the transmission grid. Main issues : connection schemes, active and reactive control capabilities, contribution to ancillary services, power quality, stability and protection issues, network operation and exchange of information, islanded operation, ...	This document is an abrogated ministerial order and it has been replaced by a new one in 2008 (see NOR : DEVE0808736A).
NF C 15-100, Installations électriques basse tension	Low voltage electric facilities	Enforced by law
NOR : INDI0608538A Arrêté du 6 octobre 2006 relatif aux prescriptions techniques de conception et de fonctionnement pour le raccordement au réseau public de transport de l'électricité d'un réseau public de distribution	Ministerial order dealing with requirements for the connection of public distribution grids on transmission network.	Rather general ministerial order that is complemented by RTE's technical reference guide currently available and updated.

NOR : DEVE0806640D Décret no 2008-386 du 23 avril 2008 relatif aux prescriptions techniques générales de conception et de fonctionnement pour le raccordement d'installations de production aux réseaux publics d'électricité	Government decree dealing with specifications for the connection of generating units installations to the public grids (transmission and distribution). This decree complements the previous one of June 27, 2003 (NOR INDI0301440D).	The following two ministerial orders complement this decree. RTE's technical reference guide currently available and updated complements this rather general government decree.
NOR : DEVE0808736A 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	Ministerial order dealing with the specifications for the connection of generating units to the transmission grid. Main issues : connection schemes, active and reactive control capabilities, fault ride through capability, contribution to ancillary services, power quality, stability and protection issues, network operation and exchange of information, islanded operation, ...	Rather general ministerial order that is complemented by RTE's technical reference guide currently available and updated.
NOR : DEVE0808815A Arrêté du 23 avril 2008 relatif aux prescriptions techniques de conception et de fonctionnement pour le raccordement à un réseau public de distribution d'électricité en basse tension ou en moyenne tension d'une installation de production d'énergie électrique	Ministerial order dealing with the specifications for the connection of generating units to the distribution grid. Main issues : voltage and reactive power regulation, power quality, decoupling protection, fault ride through capability, network operation and exchange of information, specific measures for island grids	Rather general ministerial order that will be complemented by the technical reference guide, which is being prepared by the distribution system operators.

Germany

Title	Purpose of the document	Outline of the protection requirements
Eigenerzeugungsanlagen am Niederspannungsnetz, Richtlinie für Anschluß und Parallelbetrieb von Eigenerzeugungsanlagen am Niederspannungsnetz, ISBN 3-8022-0646-0	Guideline of the VDEW (German Electricity Association, trade association of the electricity supply) for the connection of DG to the LV grid	Main guideline for connecting DG to the low voltage grid, no accessible switch required for small systems with a fail safe automatic disconnection device as specified in DIN VDE0126. Makes reference to: DIN EN 61000 3-2, DIN EN 61000 3- 3, DIN EN 61000 3-11, DIN EN 61000 3-12
Eigenerzeugungsanlagen am Mittelspannungsnetz, Richtlinie für Anschluß und Parallelbetrieb von Eigenerzeugungsanlagen am Mittelspannungsnetz, ISBN 3-8022-0584-7	Guideline of the VDEW (German Electricity Association, trade association of the electricity supply) for the connection of DG to the MV grid	

DIN VDE0126 Selbsttätige Freischaltstelle für Photovoltaikanlagen einer Nennleistung <= 4,6 kVA und einphasiger Paralleleinspeisung über Wechselrichter in das Netz der öffentlichen Versorgung	Requirements on the disconnection unit between the DG system and the grid. According to (1) with this device an accessible disconnection-switch is not needed.	Definition of a fail safe disconnection device for grid connected PV systems; in contrast to the title used for other DG, as well. Detection of unintended islanding using the impedance of the grid as a criteria. Is being revised to enhance European compatibility.
Technische Anschlußbedingungen für den Anschluß an das Niederspannungsnetz "TAB 2000", ISBN 3-8022-0627-4	General technical requirements for connecting loads and generators to the grid. For DG this regulation refers to (1). Published by VDEW (German Electricity Association, trade association of the electricity supply)	The master copy of this regulation has been published by the VDEW. Individual grid operators are free to use modified versions of this text.For DG this standard makes a reference to (1) which in references DIN VDE0126
TransmissionCode 2003 Netz- und Systemregeln der deutschen Übertragungsnetzbetreiber	Regulation for the access to the HV grid, published by "Verband der Netzbetreiber – VDN – e.V. beim VDEW"	
Bau und Betrieb von Übergabestationen zur Versorgung von Kunden aus dem Mittelspannungsnetz	General technical requirements for building coupling stations connecting loads and generators to the MV grid. Guideline of the VDEW.	This standard is referenced by (2)
Dezentrale Erzeugungsanlagen, Richtlinie für den Anschluss und Parallelbetrieb von dezentralen Erzeugungsanlagen am Hochspannungsnetz	Guideline of the VDEW for the connection of DG to the HV grid. Under consideration	

Greece

Title	Purpose of the document	Outline of the protection requirements
Distribution Directive 129 - Interconnection of generating facilities to the distribution network	Sets evaluation procedures, disturbance limits and interconnection technical requirements for connecting generating stations to the MV and LV network. It is therefore completely relevant to DG.	The evaluation methodologies established in the document regarding power quality disturbances due to the connection of DG to the distribution network are based on the IEC and EN standards, as well as on other national guidelines.
Transmission System Operating Code	Basic document, with fundamental technical, economic and legal provisions. Does not affect significantly technical aspects of DG, however, since DG is mostly connected at LV and MV level.	The current Transmission System Code is under revision. Nevertheless, it will continue to constitute an important document for technical and procedural issues. Very important are the provisions for the construction, financing and commissioning of the interconnection lines, equipment etc.

Italy

Title	Purpose of the document	Outline of the protection requirements
CEI 11-20	Electrical energy production system and uniterruptable power systems connected to I and II class network (i.e. LV and MV network)	
CEI 11-32	Electrical energy production systems connected to III class network (i.e. >132 kV network)	
DK5950	define rules and criteria for connecting PV plants to ENEL LV grid	

Spain

Title	Purpose of the document	Outline of the protection requirements
Ministerial Order 5/9/1985. Administrative and technical rules for the operation and interconnection to the grid of hydroelectric power plants up to 5 MVA and "autogeneration" plants.	General rules for the interconnection of RES and cogeneration plants to the grid. Utilities are bound to buy the surplus of electricity generated by these installations and to pay for that energy higher price.	Installation issues are related to grounding. Voltage variation limits in the grid are related to under voltage during interconnection. The present document gives general requirements and in some cases is not defining. Low voltage PV is not affected by this order. It should evolve to simplify the connection of small plants, as RD1663/2000 for PV
R.D. 1663/2000. Royal Decree, on interconnection of photovoltaic installations to the low voltage grid. Resolución 31/5/01rule, defines the contract model and the invoice model for low voltage connected PV installations.	Interconnection of PV installations to the low voltage grid: application, technical conditions, contract, connection and first verification	There is no reference made to inverter testing (a technical instruction is pending). It is not explained how can be assured the detection of islanding.
RD 842/2002. Royal Decree 842/2002, Spanish Low Voltage Code. ICT-BT 40: low voltage generating installations.	Complementary instruction applicable to generating installations, namely installations aimed at the transformation of any kind of non-electric energy into electric energy.	Technical requirements
RD 661/2007 regulates the activity of the Special Regime power production	The document modifies the legal and economical regime of the power production activity for the Special Regime, established in the previous RD 436/2004	It regulates technical aspects for the growing of Special Regime with security and quality, updates the incentive conditions based on experimented market prices evolution and translates legal changes in the European rules. Some protection requirements are included

The Netherlands

Title	Purpose of the document	Outline of the protection requirements
Dutch Netcode	Prescribes the requirements of the operation of the Distribution Grid and those connected to it	Dutch Netcode is very transparent and simple, generally does give barriers to DG

UK

Title	Purpose of the document	Outline of the protection requirements
The Distribution Code (of Great Britain)	The Distribution Code contains procedures to permit equitable management of day to day situations in the Electricity Supply Industry.	Normally it does not give limits, it addresses some Engineering Recommendations in the Annex 1 (considered as the source of requirements for the technical and design criteria) and other standards (EN 50160 and other electricity national standards). It also exist the "Distribution Code for Northern Ireland".
Engineering Recommendation G75/1	Recommendations for the connection of embedded generating plant to Public distribution systems above 20kV or with outputs over 5MW	Protection issues are mentioned in general terms and references are made to more specific recommendation in the Distribution Code, G59/1 and ETR113.
Engineering Recommendation G83/1	Recommendations for the connection of small scale embedded generators (up to 16A per phase) in parallel with public low-voltage distribution networks.	It is addressed in the Distribution Code.
Engineering Recommendation G59/1	Recommendations for the connection of embedded generating plant to the regional electricity companies' distribution system.	It is addressed in the Distribution Code. Associated technical report to be considered ETR113
Engineering Recommendation G77	UK technical guidelines for inverter connected single phase photovoltaic (PV) generators up to 5kVA.	Withdrawn superseded by G83/1

USA

Title	Purpose of the document	Outline of the protection requirements
IEEE Std. 1547-2003: "Standard for Interconnecting Distributed Resources with Electric Power Systems"	This document provides a uniform standard for interconnection of distributed resources with electric power systems (60 Hz). The inteconnection technical and testing specifications and requirements apply to all distributed resource technologies at the PCC.	Main worldwide reference regarding the connection of DR to electric power systems, presented (after 4 year development) in a single document of universal, technology neutral requirements for the interconnection itself and the interconnection testing. Valuable effort exclusively on technical issues; it does not address business, contract and tariff issues.
ANSI/IEEE Std. 929-2000: "IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems"	This recommended practice describes the interface, functions, and requirements necessary in the interconnection of a PV power system with an electric utility. It also describes the acceptable and safe practices for accomplishing those functions and meeting the requirements.	This recommended practice contains guidance regarding equipment and functions necessary to ensure compatible operation of photovoltaic (PV) systems that are connected in par-allel with the electric utility. This includes factors relating to personnel safety, equipment protection, power quality, and utility system operation. This recommended practice also contains information regarding islanding of PV systems when the utility is not connected to control voltage and frequency, as well as techniques to avoid islanding of distributed resources.

International

Title	Purpose of the document	Outline of the protection requirements
ÖVE/ÖNORM EN 61727 Photovoltaische (PV) Systeme - Eigenschaften der Netz- Schnittstelle (IEC 1727:1995)	This standard applies to utility interconnected PV power systems operating in parallel with the utility and utilizing static non-islanding inverters for the conversion of DC to AC. Specific recommendations for systems rated at 10 kW or less are described.	Specific recommendations for PV installations. So far only a framework document, next revision will probably published in 2004. In Austria, the document is not applied in practise. Instead the national standard ÖVE/ÖNORM E2750 is used for the installation of PV systems.
BS 61727/EN 61727 Photovoltaic (PV) systems: Characteristics of the utility interface	British standard version of the adopted European standard.	
PrENxxx Installation of Domestic Cogeneration	Addresses the interface requirements between micro-CHP system and DNO, and provides technical recommendations.	

A.3 Codes for Connection of Power Generators to Transmission Level in Several Countries

Country	Document ref.	Title	Reference, year	Scope
Austria	TOR	Technische und organisatorische Regeln für Betreiber und Benutzer von Netzen	E-Control 2004	Grid code for transmission & distribution
Australia	NER	National Electricity Rules, formed under the National Electricity (South Australia) Act 1996	Version 28 of NER issued March 2009.	Grid Code for Generation, Transmission & Distribution regulation,
Belgium	Royal Decree 19/12/2002 ELIA internal doc	Koninklijk besluit houdende een technisch reglement voor het beheer van het transmissienet van elektriciteit en de toegang ertoe Voorschriften en uit te wisselen informatie voor de aansluiting van productie-eenheden (Draft)	Staatsblad, 2002 ELIA, 2004	Transmission Code Wind connected to transmission level
Canada		Transmission provider technical requirements for the connection of power plants to the Hydro-Québec transmission system BC Hydro 69 kV to 500 kV Interconnection Requirements For Power Generators	H-Q, 2006 BC Hydro, 2002	Generation connected to transmission Generation connected to transmission
France		Référentiel technique de RTE	RTE 2005	Transmission Code

Germany	Transmission Code 2003 E.ON Grid Code	Netz- und Systemregeln der deutschen Übertragungsnetzbetreiber Grid code. High and extra high voltage	VDN, 2003 E.ON Netz, 2006	Transmission Code Grid code
	VDN Richtlinie	EEG Erzeugungsanlagen am Hoch- und Höchstspannungsnetz	VDN, 2004	Connection of renewable energy auto-production to the high-voltage level
Greece	Transmission Code, 30/5/2001	Transmission System Operation Code	HTSO	Transmission Code
Ireland	Grid Code	Grid Code, Version 1.1	ESB National Grid, 2002	Transmission Code
	WFPS1	Wind farm power station grid code provisions	ESB National Grid, 2004	Wind connected to transmission level
Italy	CEI 11-32	Impianti di produzione di energia elettrica connessi a sistemi di III categoria	Comitato Elettrotecnico Italiano	Connection of generators to HV (transmission level)
Netherlands	Grid Code	Netcode	DTE 2005	Grid code for transmission & distribution
Norway	guideline for wind farms >10MW (in preparation assisted by SINTEF)	guideline for wind farms >10MW (available on www. statnett.no from fall 2005	Stattnet	Connection of wind turbines
Poland		Instruction of Transmission System Operation and Maintenance	PSE-Operator, 2006	
Portugal		Regulamento do Acesso às Redes e às Interligações Regulamento da Rede de Transporte Decreto-Lei 312/2001 Guia Técnico das Instalações de Produção Independente de Energia Eléctrica Regulamento da Rede de Distribuição	. Entidade Reguladora do Sector Eléctrico (ERSE), 2001 2000 2001 1994 1999	Grid code for access to transmission & distribution

Spain	P.O. 12.1 P.O. 12.2 P.O. 12.3	Solicitudes de acceso para la conexión de nuevas instalaciones a la red de transporte Instalaciones conectadas a la red de transporte: requisitos mínimos de diseño, equipamiento, funcionamiento y seguridad y puesta en servicio Requisitos de respuesta frente a huecos de tensión de las instalaciones eólicas	MITYC	Grid code for transmission
Sweden	SvK	Affärsverket Svenska Kraftnäts föreskrifter om driftsäkkerhetsteknisk utformning av produktionsanläggningar	Svenska Kraftnät 2002	Decentralized generation connected to transmission level
UK	Engineering Recommendation G75/1	Recommendations for the connection of embedded generating plant to Public distribution systems above 20kV or with outputs over 5MW The grid code	Electricity Networks Association 2002 National Grid Electricity Transmission plc, 2007	Embedded generation (large systems) Grid code for transmission

A.4 Definition of Voltage Levels Used in this Report

France
French Transmission grid is composed of 400 kV, 225 kV, 90 kV and 63 kV networks. 30 kV, 20 kV and 15 kV networks belong to Distribution network.

Norway
Norwegian Transmission Network is composed of 420 kV, 300 kV, 132 kV and 66 kV networks. The 22 kV and 11 kV networks belong to Distribution Network.

Different voltage levels:

- 420kV, 300kV and 132kV – Extra High Voltage (EHV)
- 66kV – High Voltage (HV)
- 22kV and 11kV – Medium Voltage (MV)

Portugal
Portuguese Transmission Network is composed of 400 kV, 220 kV, 150 kV and the first busbar of 60 kV networks. The 60 kV, 30 kV and 15 kV networks belong to Distribution Network.

Different voltage levels:

- 400kV, 220kV and 150kV – Extra High Voltage (EHV)
- 60kV – High Voltage (HV)
- 30kV and 15kV – Medium Voltage (MV)

Spain
Spanish Transmission Network is composed of 400 kV and 220 kV. The 132 kV, 66 kV, 45 kV, 30 kV, 20 kV, 13.8 kV and 11 kV networks belong to Distribution Network.

Australia
Generally, Transmission is 110 kV and up, and (in terms of the NER) any voltage that allows a parallel connection or interconnection with systems at 132kV and up. Transmission voltages are 110kV, 132kV, 220kV, 330kV. There are areas where the 66kV system can be defined as "transmission" for regulatory purposes. The Electricity Act recognises Transmissioin Netwrok Service Providers (TNSP) and Distribution Network Service Providers (DNSP). The TNSPs are generally State-based, and the DNSPs are either State-based (having State Government ownership) or are privately owned. The ownership model varies by State.

Distribution is generally 33kV, 22kV, 11kV. Low voltage distribution is at 400V/230V nominally.

Other entities recognised by the legislation are Customers, Generators and Ancillary Service Providers. Day to day operation of the interconnected network and the energy market is by the National Electricity Market Management Company (NEMMCO).

<u>*UK*</u>

The following voltage levels are used in the UK power system: 400kV; 275kV; 132kV; 66kV; 33kV; 11kV; 6.6kV; and 0.4kV (LV). The use of these levels is not uniform across the country. Voltage levels (according to the UK Distribution code) are applied as follows:

- Transmission

  The major Power Stations are connected to the Transmission System (The Grid) which operates as a fully interconnected system within Scotland, England and Wales. The Grid operates at 275kV and 400kV. The 132kV network in Scotland is also classed as part of the Transmission System but this is not the case in England and Wales. The Transmission System provides a secure supply of electricity to Grid Supply Points, i.e. the Grid Exit Points, which are also the Entry Points to the Distribution System, and also to the Exit Points for Customers with large or special Demands.

- Distribution

  The Distribution System operates at nominal voltages of 66kV, 33kV and 22kV (EHV), 11kV and 6.6kV (HV) and 400 volts and 230 volts (LV). The 132kV network in England and Wales is also classed as part of the Distribution System but this is not the case in Scotland. The Distribution System provides a supply to the Exit Points to all remaining Customers for industrial, commercial and domestic purposes.

<u>*Voltage levels assumed in this report*</u>

Regardless of the precise definition for LV, MV, HV and EHV terms, as they can vary from country to country, the following voltage level definitions and the associated generation sizes have been assumed in this report:

- LV distribution network (< 1 kV). Small DG
- Local MV distribution network (1 to 35 kV radial). Medium DG.
- Regional MV subtransmsission network (35 to 100 kV mainly radial, but also meshed in some cases). Large DG
- HV subtransmission network (100 to 170 kV). Large DG.
- HV transmission network (170-345 kV). Large concentrations of DG (WF)
- EHV transmission network (>345 kV). Large concentrations of DG (WF)

Appendix B. Anti-islanding Protection Test Results – Commercial Relays

Scenario	ΔPgen	ROCOF Relay 1	ROCOF Relay 2	VS Relay
	[%]	[Hz/s]	[deg]	[deg]
1	-10	0.8	8	-
2	-5	0.4	8	-
3	-2.5	0.2	8	-
4	0	-	-	-
5	2.5	0.15	8	-
6	5	0.45	8	-
7	10	0.8	8	-

Table B-1. Maximum settings to ensure sensitivity (SM based generator)

Scenario	ΔPgen	ROCOF Relay 1	ROCOF Relay 2	VS Relay
	[%]	[Hz/s]	[deg]	[deg]
1	-10	10	24	12
2	-5	10	24	6
3	-2.5	10	24	3
4	0	1.1	16	-
5	2.5	10	24	3
6	5	10	24	7
7	10	10	24	15

Table B-2. Maximum settings to ensure sensitivity (DFIG based generator)

Scenario	Fault type	ROCOF Relay 1	ROCOF Relay 2	VS Relay
	[Position – connection]	[Hz/s]	[deg]	[deg]
8	1 – phase-to-ground	0.40	8	2
9	1 – phase-to-phase	0.50	8	3
10	1 – three-phase	1.35	8	2
11	2 – phase-to-ground	0.85	16	3
12	2 – phase-to-phase	2.55	24	2
13	2 – three-phase	8.90	16	19
14	3 – phase-to-ground	0.40	8	2
15	3 – phase-to-phase	3.70	24	3
16	3 – three-phase	10.0	8	14

Table B-3. Minimum settings to ensure stability (SM based generator)

Scenario	Fault type	ROCOF Relay 1	ROCOF Relay 2	VS Relay
	[Position – connection]	**[Hz/s]**	**[deg]**	**[deg]**
8	1 – phase-to-ground	0.10	24	3
9	1 – phase-to-phase	0.15	24	2
10	1 – three-phase	0.20	24	17
11	2 – phase-to-ground	0.10	12	7
12	2 – phase-to-phase	0.15	12	14
13	2 – three-phase	0.15	8	4
14	3 – phase-to-ground	0.10	8	4
15	3 – phase-to-phase	2.05	24	17
16	3 – three-phase	7.20	24	2

Table B-4. Minimum settings to ensure stability (DFIG based generator)

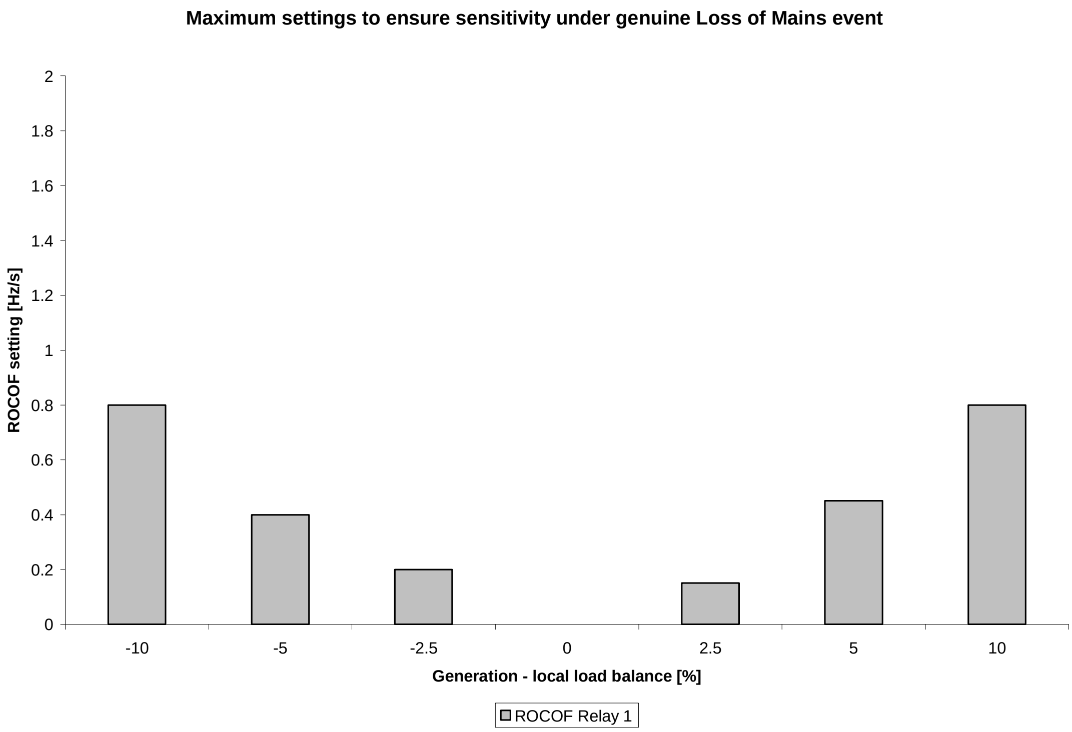

Figure B-1. Maximum settings to ensure sensitivity of ROCOF Relay 1 (SM based generator)

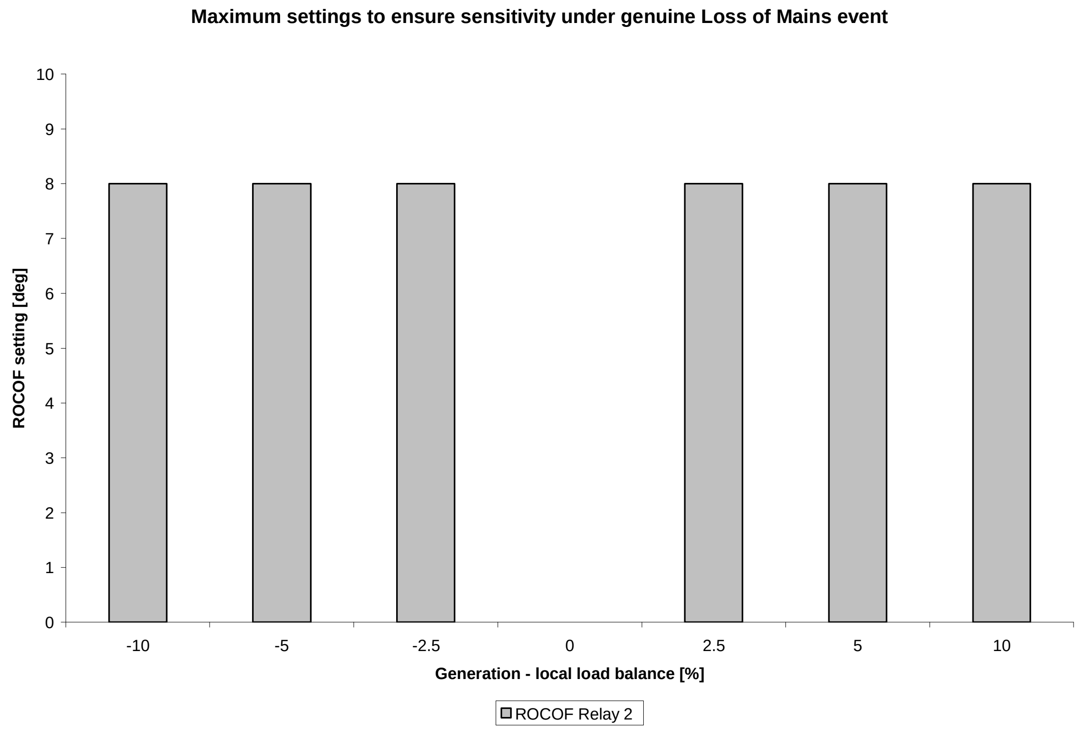

Figure B-2. Maximum settings to ensure sensitivity of ROCOF Relay 1 (SM based generator)

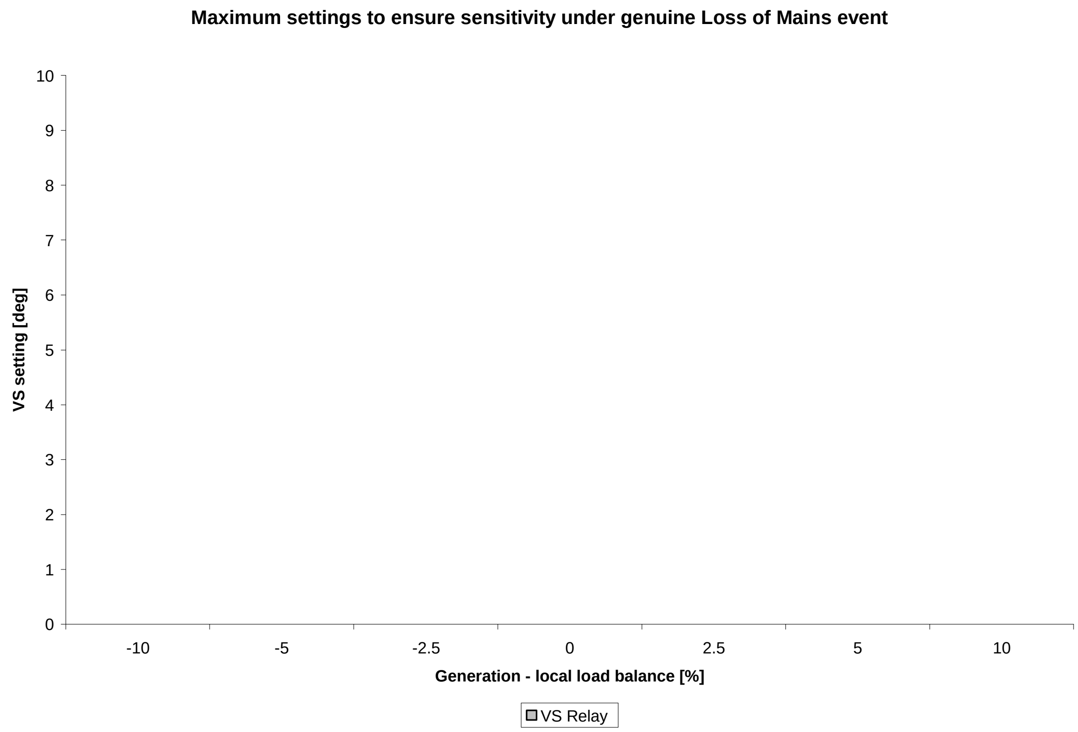

Figure B-3. Maximum settings to ensure sensitivity of VS Relay (SM based generator)

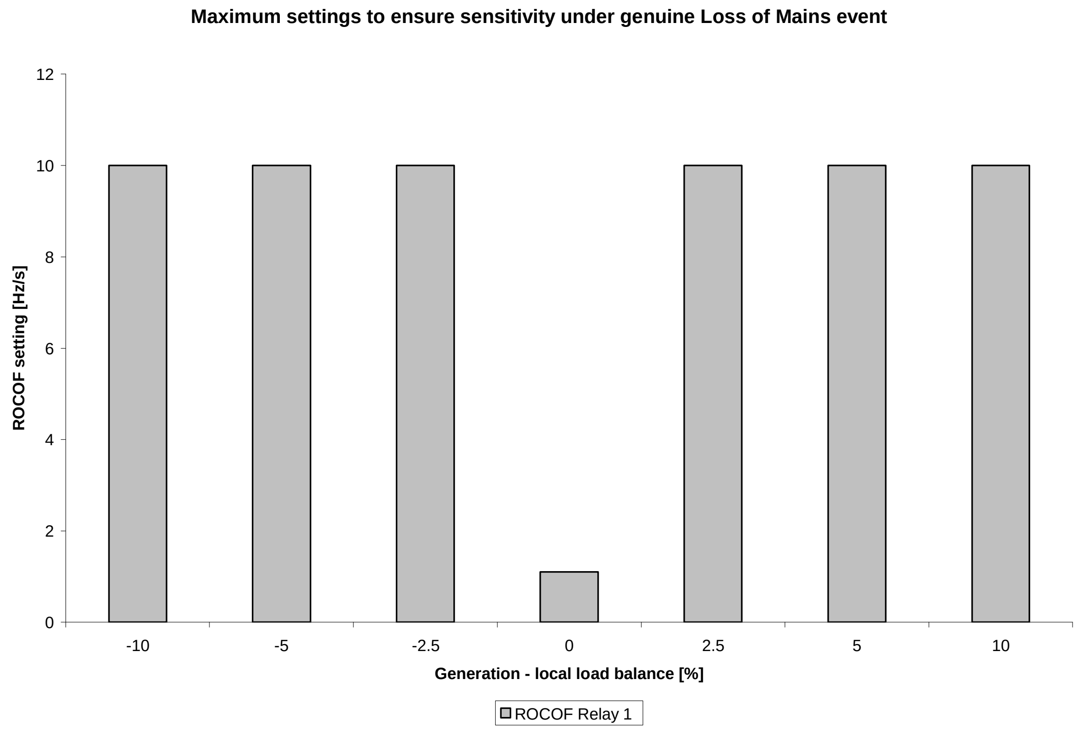

Figure B-4. Maximum settings to ensure sensitivity of ROCOF Relay 1 (DFIG based generator)

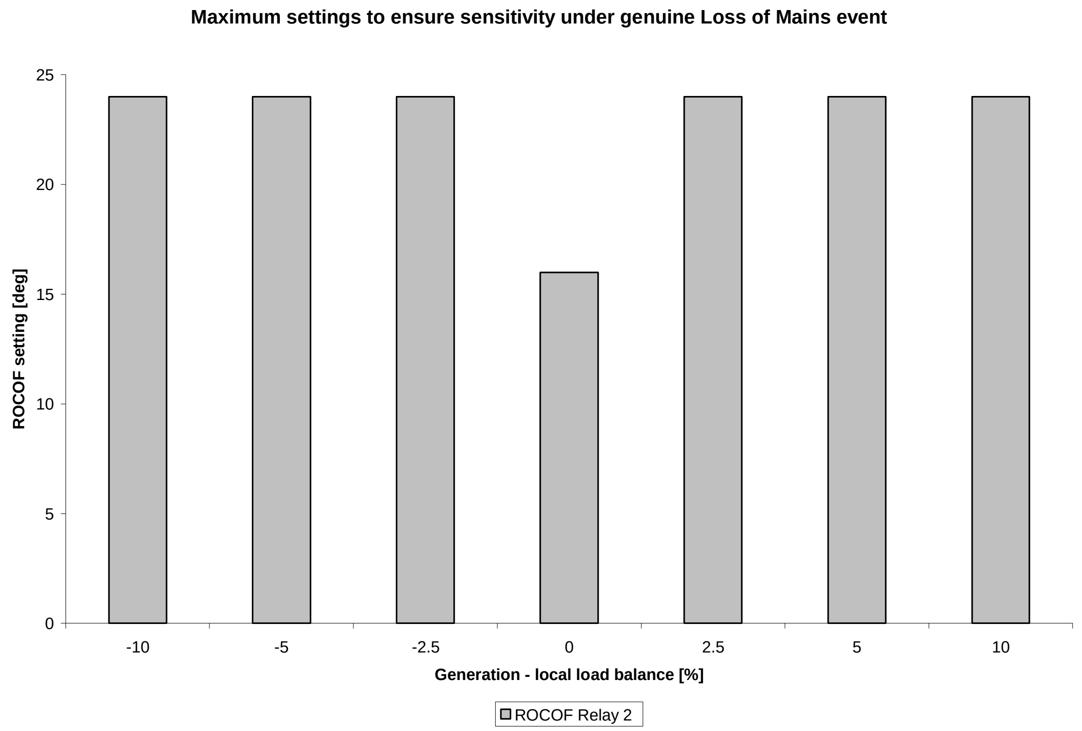

Figure B-5. Maximum settings to ensure sensitivity of ROCOF Relay 2 (DFIG based generator)

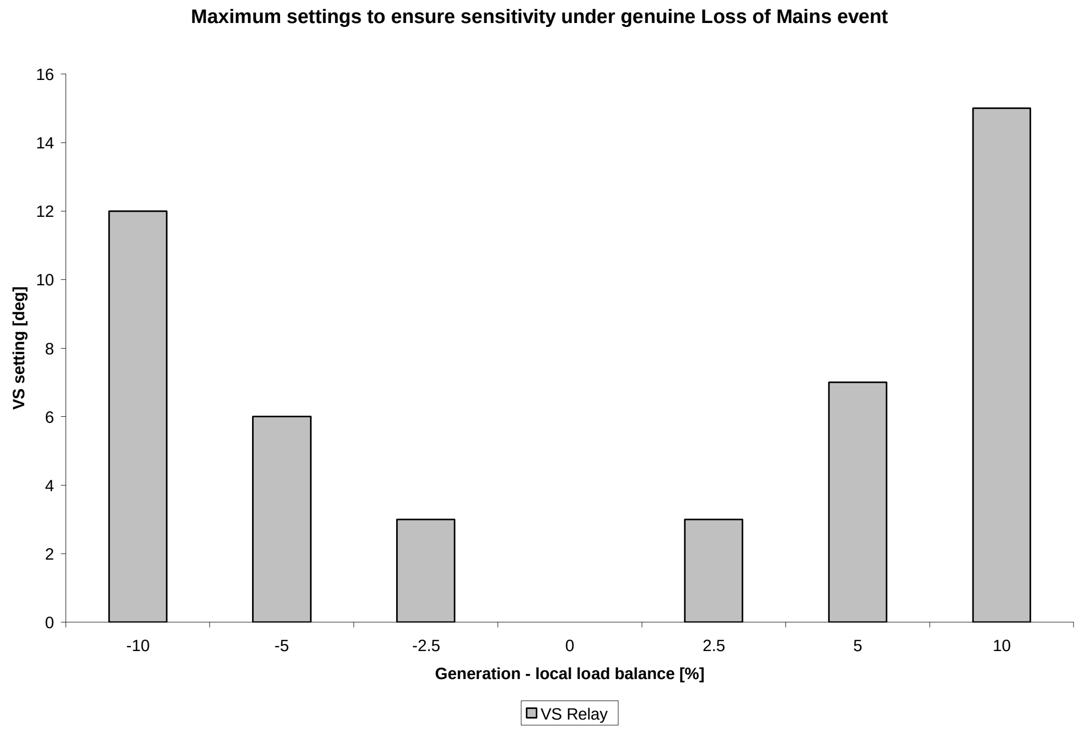

Figure B-6. Maximum settings to ensure sensitivity of VS Relay (DFIG based generator)

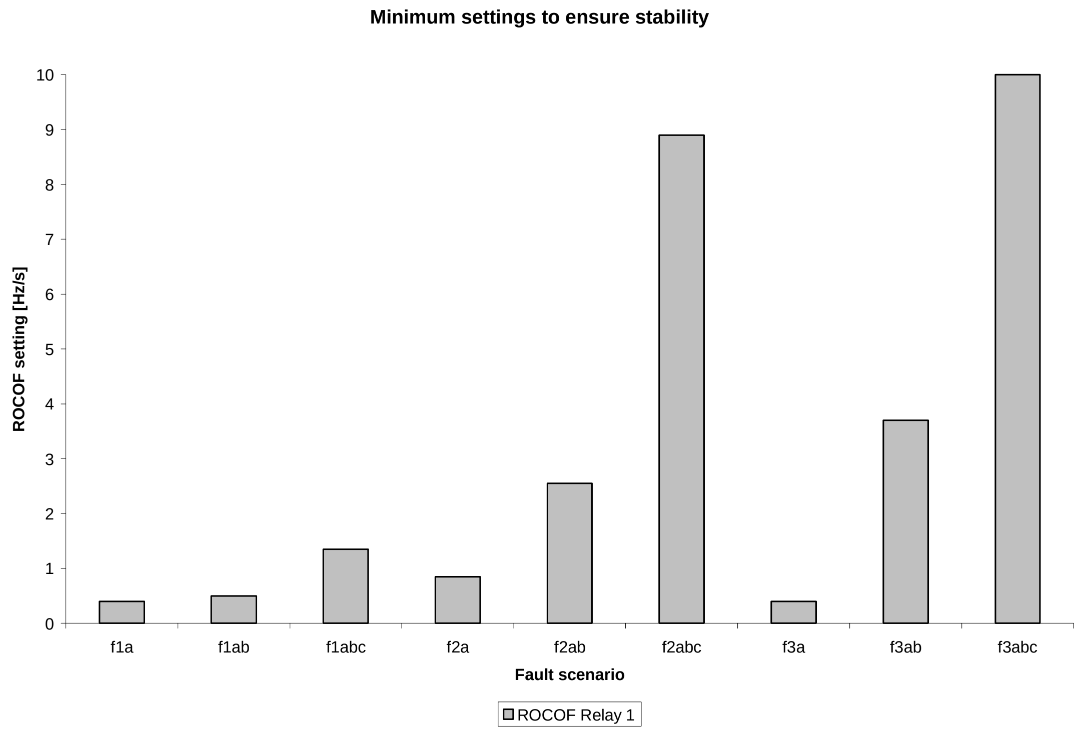

Figure B-7. Minimum settings to ensure stability of ROCOF Relay 1 (SM based generator)

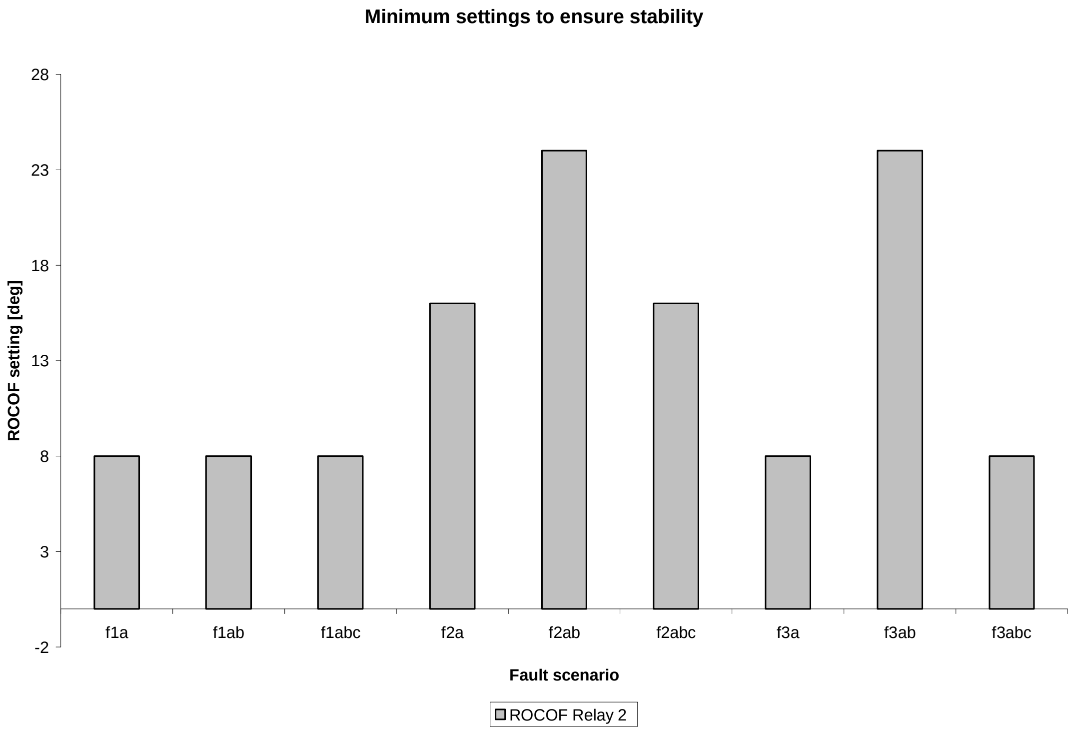

Figure B-8. Minimum settings to ensure stability of ROCOF Relay 2 (SM based generator)

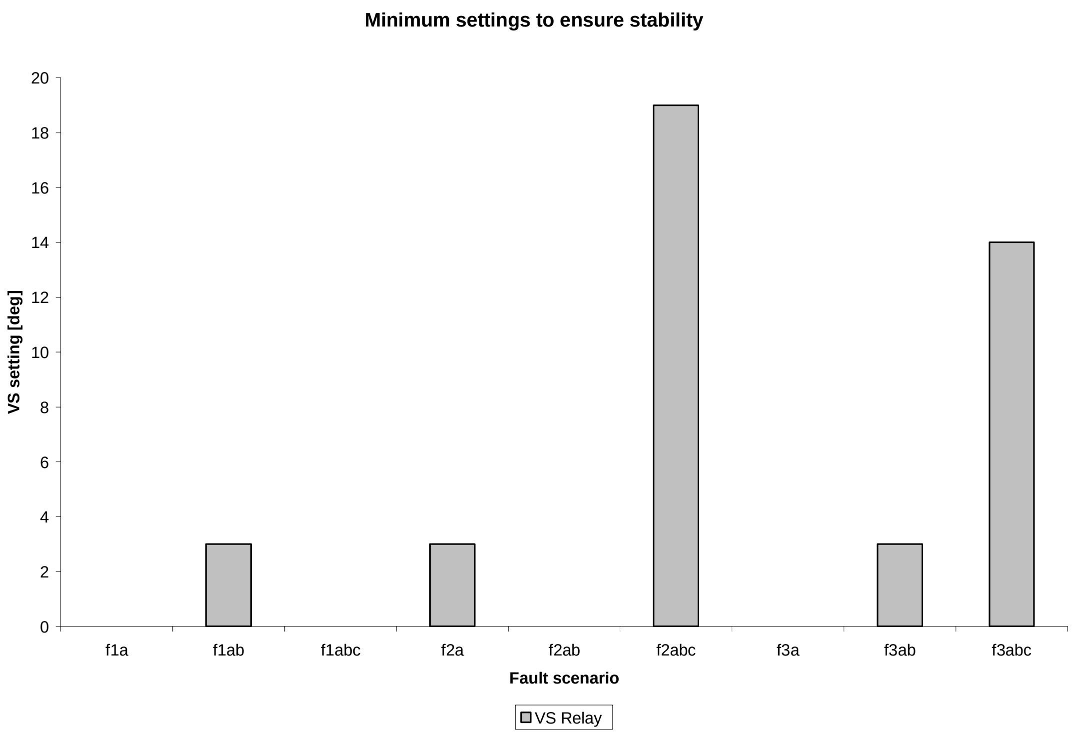

Figure B-9. Minimum settings to ensure stability of VS Relay (SM based generator)

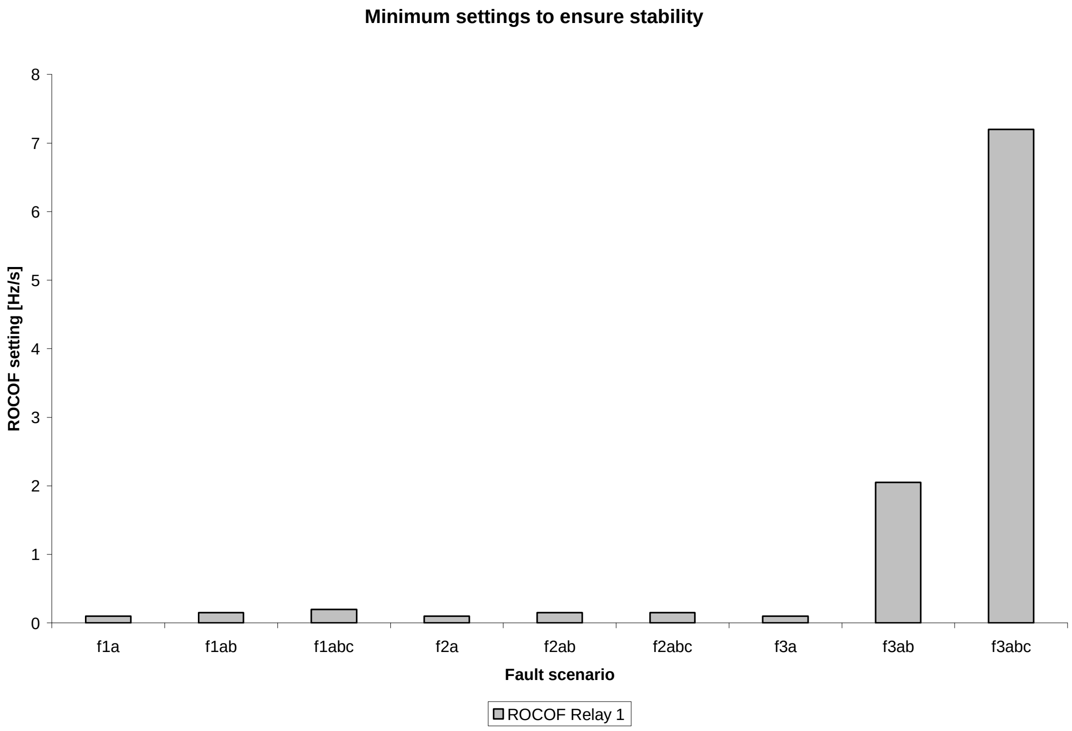

Figure B-10. Minimum settings to ensure stability of ROCOF Relay 1 (DFIG based generator)

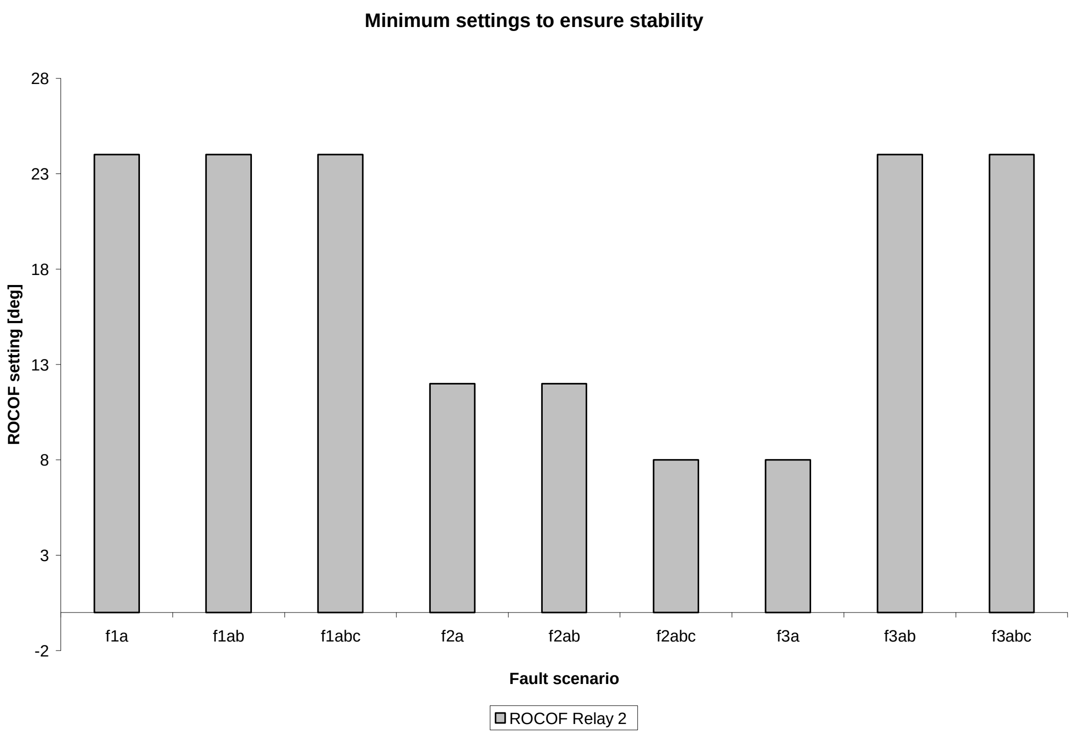

Figure B-11. Minimum settings to ensure stability of ROCOF Relay 2 (DFIG based generator)

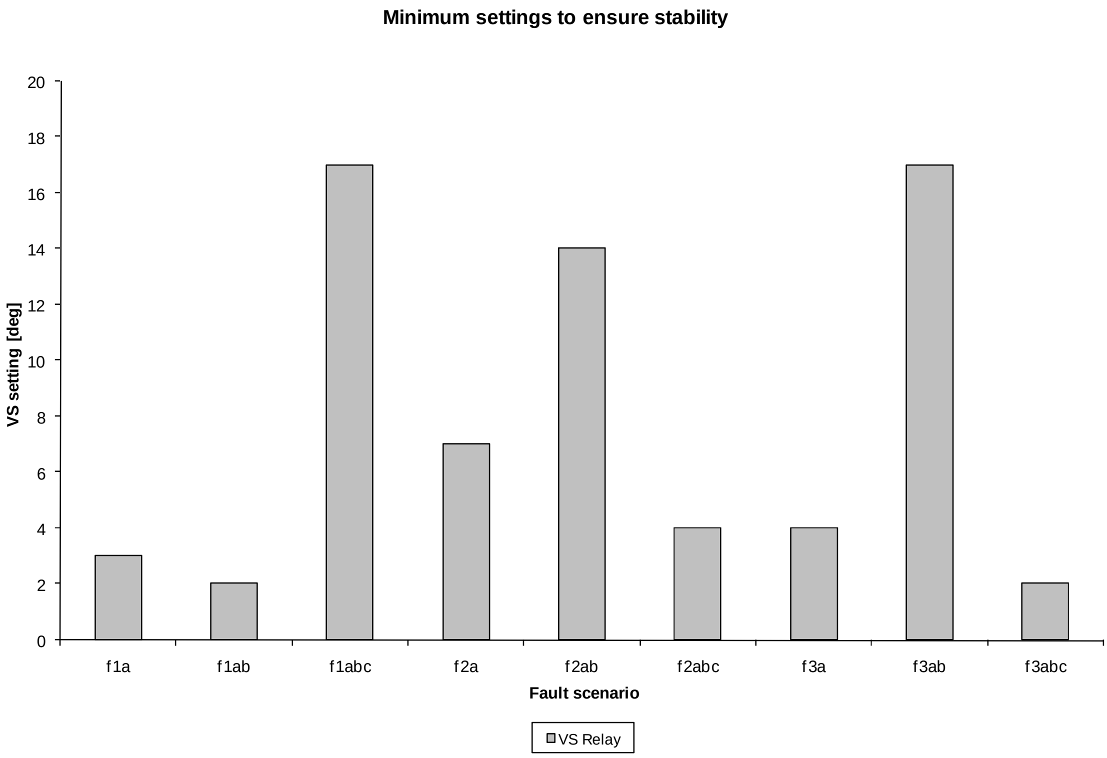

Figure B-12. Minimum settings to ensure stability of VS Relay (DFIG based generator)

Appendix C. Distributed Generator Data

Rated power, S_n [MVA]	11.2
Line-to-line voltage, V_n [kVrms]	33
Nominal frequency, f_n [Hz]	50
Number of pole pairs	4
Power factor	0.8
R_a [pu]	0.00656
X_L [pu]	0.081
X_d [pu]	1.43
X_q [pu]	0.93
X_d' [pu]	0.24
X_q' [pu]	0.20
X_d'' [pu]	0.1437
X_q'' [pu]	0.17
T_{do}' [s]	2.74
T_{qo}' [s]	3.5
T_{do}'' [s]	0.048
T_{qo}'' [s]	0.131
H [s]	2

Table C-1. Synchronous Generator data (on the machine rated power base)

Nominal power, S_n [MVA]	11.2
Line-to-line voltage, V_n [kVrms]	0.69
Nominal frequency, f_n [Hz]	50
R_a [pu]	0.00462
X_a [pu]	0.102
X_m [pu]	4.348
R_r [pu]	0.006
X_r [pu]	0.111
H [s]	2

Table C-2. DFIG Equivalent Generator data

Appendix D. Guidelines and Practices in Different Countries

D.1 Practices with Protection of DG in Australia

In Australia, DG is generally seen as having different requirements depending on its scale relative to the rest of the system to which it is connected. The draft national Code of Practice proposes the following classifications:

Technical Definition	Classification band
Having a nameplate (electrical) rating not greater than 2kW or AS4777 compliant and connected to the LV network	Micro
Having a nameplate (electrical) rating greater than 2kW but not more than 1MW and connected to the LV network but not compliant with AS4777	Small
Having a nameplate (electrical) rating greater than 1MW but not more than 5MW or not greater than 1MW but connected to the HV network	Medium
Having a nameplate (electrical) rating greater than 5MW	Large

Table D-1: Embedded Generation unit size definitions

Where the size band definitions include both nameplate rating capacity and connection voltage, this does not (necessarily) imply that the combination of connection voltage and size is acceptable – rather, that both the size and the voltage of connection (independently) represent connection constraints. For example, a DG unit will not be defined as a Small DG if it is connected at a voltage greater than LV – regardless of the nameplate rating of the DG unit.

Grid connected renewable generation still has a relatively low penetration in the market in Australia compared with some parts of the world, but it is growing. Some estimates put the penetration at about 10% of the market. A list of all operating and proposed renewable energy projects in Australia can be found at the Australian government Australian Greenhouse Office website http://www.agso.gov.au/renewable/

In addition, all generation no matter what type it is must meet the requirements of the National Electricity Rules (NER).

D.1.1 Prevailing generation technologies

Wind
A mix of small wind farms with a few turbines connected at the HV (generally 11kV) level, and a very few larger (> tens of MW) sites connected at transmission level.

Rubbish tip methane
These are generally made up of one or more 1-2MW size internal combustion driven machines connected to the HV system. But the total number of installations is still low (<100?)

"Peak lopping"

These are becoming viable mainly as a trading mechanism to deal with price spikes in the wholesale electricity market. These are either standby sets in large commercial buildings converted for grid parallel operation, or new installations of natural gas fired internal combustion engine machines.

Coal bed methane

A very few of these have been in operation for a number of years, utilising coal-bed methane burned in internal combustion engine driven machines of about 1MW size banked into 10-20MW sets.

PV / Solar

Low penetration of the low voltage market at the individual customer level. Standardised connection requirements are designed to reduced barriers to entry and inconsistency between Distributors. The most significant single installation is the roof-top PV arrays in the housing estate that was used for the Sydney 2000 Olympics Athlete's Village.

Other technologies

These include CHP with natural gas, which is being applied on an introductory basis. There are also Micro-hydro installations, but these are most often "off-grid" applications in rural areas not served by the grid.

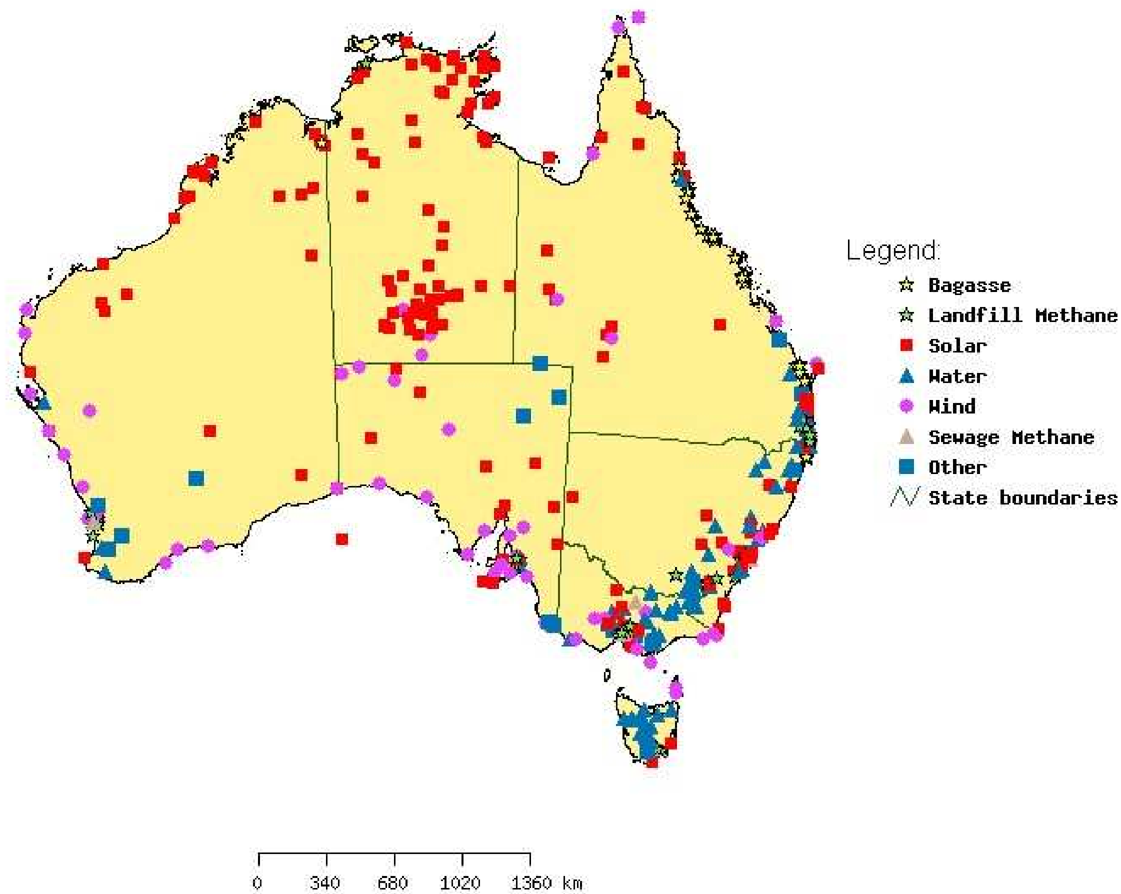

Figure D-1: Renewable Energy sources in Australia – Operating Plants (Source: http://www.agso.gov.au/renewable/)

D.1.2 Main challenges

Distributed and embedded energy systems are still relatively poorly represented in the Australian market. The low levels of such generation have resulted in a low demand for consistency in regulation up to now. As more developers begin to install systems, the call for consistent technical and commercial arrangements that do not introduce artificial barriers to entry increases. This is being addressed in the draft Code of Practice being drawn up under the auspices of the Federal government with input from State and Industry working groups.

The draft Code of Practice is a relatively high level document that provides policy guidance, rather than specific technical or engineering solutions. However, insofar as it does provide technical guidance, the protection systems tend to be dealt with in insufficient detail to cover specific connection arrangements. The challenge is to provide these more detailed guidelines so that any given project will be treated in the same way irrespective of jurisdiction.

D.1.3 Examples of typical connection arrangements

In general, the practices of individual electricity supply authorities are based on the practices and recommendations outlined in the UK documents:

- Energy Networks Association Engineering Recommendation G59/1(1991) Recommendations for the connection of embedded generating plant to the public distribution system.
- Energy Networks Association Engineering Recommendation G75/1(2002) Recommendations for the connection of embedded generating plant greater than 20kV or 20MW.
- Energy Networks Association Engineering Technical Report 113 (1995) Notes of Guidance for the protection of embedded generation plant up to 5MW.

Also, in addition to the draft Code of Practice, the Australian Business Council for Sustainable Energy Technical Guide for Connection of Renewable Generators to the Local Electricity Network provides some non-binding recommendations from the point of view of generators.

The NER does not in general treat wind and other intermittent generation sources differently from any other generation. It specifies for all generation the following technical requirements:

- VA – the plant must be able to absorb / supply 0.395 * watts at nominal voltage
- Quality of Supply – the limits are defined by AS61000-3.6 and 3-7 (same as IEC 61000). Limits are defined in terms of AS61000 for fluctuations in voltage, harmonics (waveform distortion) and frequency. Except as a consequence of a contingency event, the voltage of supply at a connection point should not vary by more than 10 percent above or below its normal voltage, provided that the reactive power flow and the power factor at the connection point is within the corresponding limits set out in the connection agreement.

Continuous uninterrupted performance is required for frequency, voltage and fault contingencies:

- Frequency variations: to the operating standards limits applicable to all market participants;
- Voltage variations:

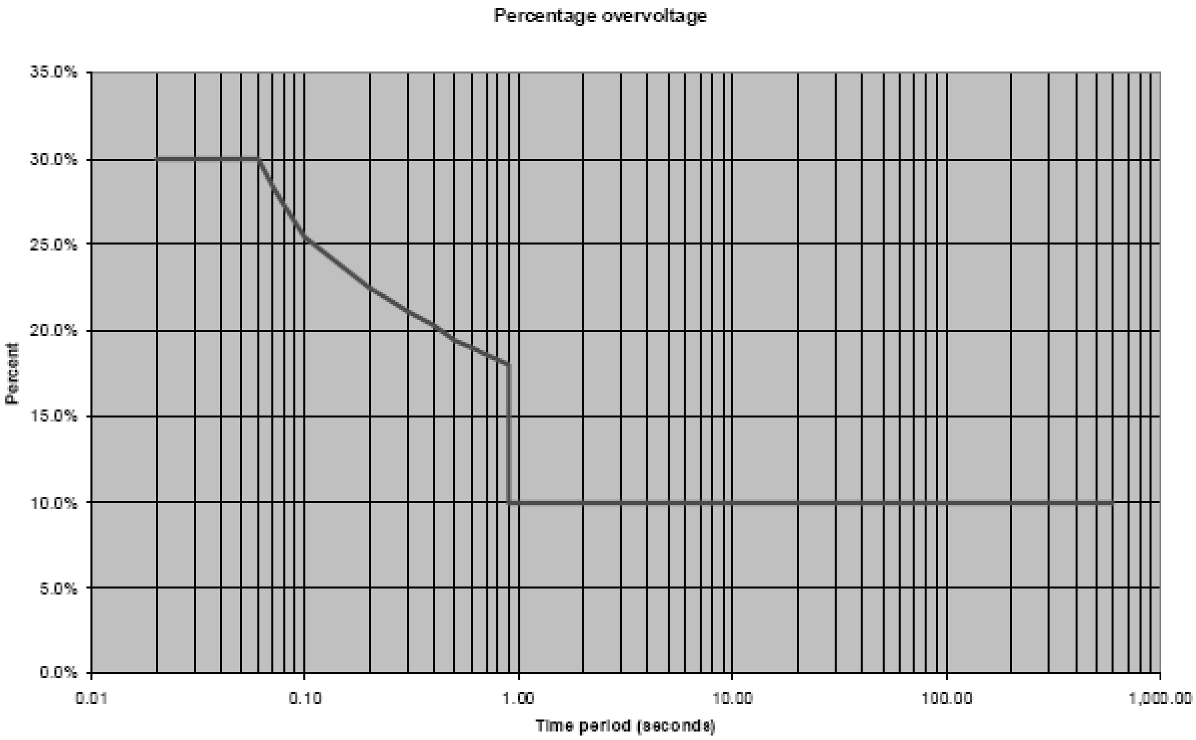

Figure D-2: Voltage Variations

- Faults: The voltage dip caused by a transmission system fault which causes voltage at the connection point to drop to zero for up to 0.175 seconds in any one phase or combination of phases, followed by a period of ten seconds where voltage may vary in the range 80-110 percent of the nominal voltage, and a subsequent period of three minutes in which the voltage may vary within the range 90-110 percent of the nominal voltage. There are variations to this basic requirement, but this is the default.

D.2 Practices with Protection of DG in Canada

D.2.1 Prevailing generation technologies

Canada possesses a diverse generation portfolio, covering a range of mature and emerging electricity-producing technologies (see Figure D-3). Hydro power produces the largest share at close to 60% of Canada's electrical production, followed by fossil fuels (coal, natural gas and oil) at 28% and nuclear at 12% (a number that is increasing due to planned refurbishments). Wind, bioenergy and other sources are now being considered as contributors to the overall portfolio, although combined, they currently provide only about 2% of Canadian electricity production [102].

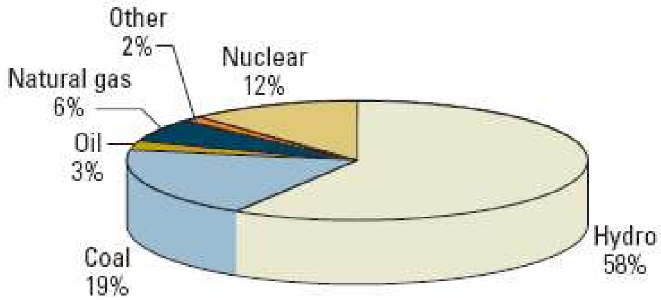

Figure D-3: Electric power generation, by source, in Canada[7]

D.2.2 Main challenges

It is estimated that electricity demand will continue to grow at an annual average rate of 1.5 to 2% percent. Utility energy efficiency and demand-side management (DSM) initiatives are helping to alleviate some of the pressures on the system, while also enabling consumers to better manage their electricity bills. Still, the significant scale of new generation required to meet growing demand was made apparent in a 2003 National Energy Board (NEB) report [103]. According to an average of two NEB scenarios, Canada's electricity supply will need to reach 814 TWh in 2020 to meet requirements. CEA (Canadian electricity Association) estimates that energy efficiency efforts could reduce this figure to 779 TWh. Yet with the anticipated retirement by 2020 of approximately 20% of facilities operating in 2000, the needed growth in supply must compensate for these requirements as well. Thus, a total of 314 TWh in 2020 will be generated by new facilities. Given a generating capacity of 111,000 MW in 2000 (20% of which is expected to retire by 2020), CEA projects that 60,000 MW will need to be added by 2020 to meet both system demand growth and plant replacement needs.

Hydro power already meets about 60% of Canada's electricity needs. It is assumed that the environmentally and socially acceptable potential for new facilities could double the current

[7] Net Electricity Generation in Canada, 2003. Total = 567 TW.h (*Source: CEA*).

installed capacity of hydro power. Fairly conservative estimates of the technical potential of electricity from coal, natural gas and nuclear energy were assumed – that is, 10,000 MW each in addition to existing plants. While nuclear energy is projected to last about 130 years at current uranium consumption rates, this fuel can also extend the use of nuclear fuel as it is able to run on "spent" fuel from other reactor types. Natural gas plant generation capacities are expected to increase over the coming years, but may be limited due to increasing prices, stagnating gas production and declining resource reserve levels in Canada. The role achieved by global liquid natural gas (LNG) supply and related pricing will have a significant impact on the future use of natural gas-fired generation.

Increases in oil-fired generation are expected to be minimal. Biomass capacities were estimated to be between 49 and 154 TWh by the Clean Air Renewable Energy Coalition (CARE 2004). This is seen as a high estimate by many, as much of the waste biomass from the forestry sector is already being used, and although there is large untapped potential in unused forest floor biomass from harvesting operations, additional resources cannot easily be transported cost-effectively to biomass facilities. More biomass could be gained from plantations, but this would increase electricity costs. The possible generation from all other sources was derived from the potentials, based on capacities and capacity factors for each technology. However, some resources have not been assessed in enough detail to be shown, such as offshore wind and wave power.

The potential for reducing electricity use from demand-side management (DSM) has been extrapolated from the 1,700 MW of potential (dependable winter peak capacity) determined for British Columbia and extrapolated for all of Canada. BC Hydro estimates that it can save about one-third, or 3,500 GWh of expected demand increases with its Power Smart Program by 2012. Given the uncertainty that more energy efficiency gains can be achieved successfully, the utility's strategy relies on new power sources for the remaining two-thirds of increased electricity demand. The same percentage is also targeted for demand-side measures within Manitoba Hydro's Power Smart Program.

Some efforts have been made to map emerging renewable resources, such as wind, run-of-river hydro power etc. BC Hydro has mapped several emerging resources, and the Ontario Ministry of Natural Resources has also mapped hydro power and other resources. B.C.'s wind resource is low, whereas the Prairies, eastern Quebec and a number of the Maritime provinces have fairly high wind speeds. Some Canadian utilities are public, whereas others work as private corporations in a deregulated market. As some of these utilities also export electricity to the United States, this will also influence the generation portfolio they wish to develop: for example, Hydro-Québec's strategy has been to develop large hydro power for export to the U.S.; Manitoba Hydro is now thinking of exporting wind power south of the border. In addition to cost considerations, historical, political and other preferences may determine the choice of power generation technologies in various provinces. While electricity can be transported over long distances using power lines, project economics often do not allow for the construction of transmission lines for a new facility that cannot be built near existing transmission lines. Hence, some resources can only be exploited where nearby transmission lines with free capacities already exist. Some governments try to overcome such barriers through public-private partnerships. Sometimes, sharing costs between several projects may be possible to finance new transmission lines or to upgrade existing lines. Only a few technologies can be employed cost-effectively in any province: for example, coal can be cheaply transported by rail and could therefore be used anywhere in Canada where good rail access is available. However, geothermal power plants are only economical in some places in British Columbia, where geo-thermal reservoirs are found near the earth's surface [102].

D.2.3 Examples of typical connection arrangements

For this section, interconnection requirements for power plants connected to the BC Hydro (BCH) transmission networks have been considered as reference [104]. Recommended settings for the interface protections for DG plants (only based on rotating machines) connected to BC Hydro Distribution network [105] are also presented for comparison. Protection requirements from other utilities, such as the Hydro-Québec transmission network, have been also analyzed [106] and they are similar to ones of BCH. The latter includes also supplementary requirements specifically to wind generation (FRT, overvoltage and over-/under-frequency relay settings, etc.).

A draft standard for the interconnection of DG to the MV network is being developed at present by the Canadian Standards Association.

D.2.3.1 Interface protection for connection in transmission network

- Entrance protection:

  Minimum relay requirements are three phase overcurrent relays (50/51) and one ground overcurrent relay (50/51N) of the inverse or very inverse type with instantaneous trip elements, selected and set such that they will co-ordinate with the respective phase and ground overcurrent relays at the BCH sources (Figure D-4).

  In fault current ranges where fully selective co-ordination is not possible, the DG plant's relays must trip their associated circuit breaker at the same time as BCH's line terminal trips, to assure that the DG plant has been tripped off prior to automatic or supervisory reclosing of the line terminals.

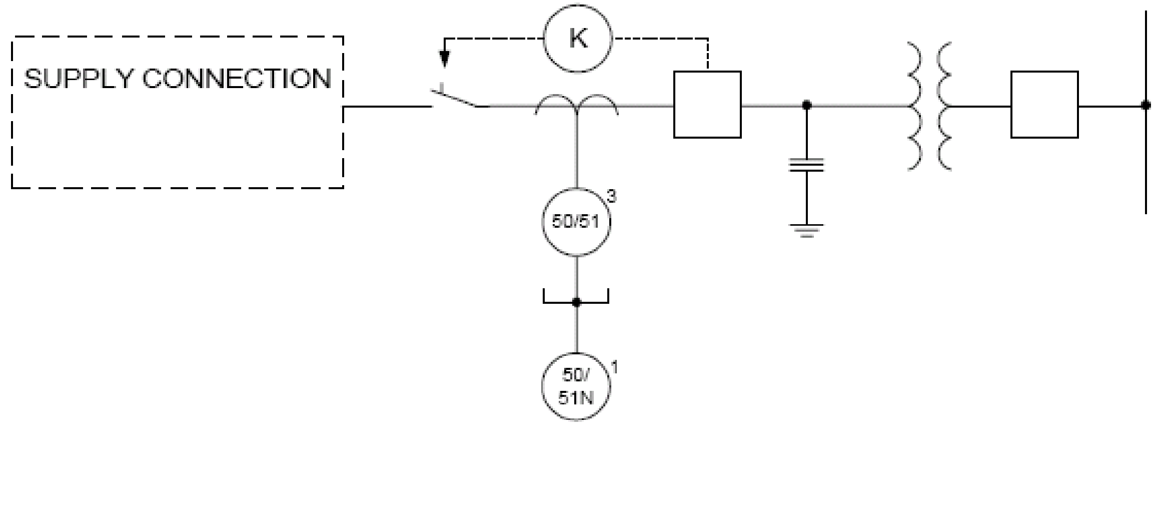

Figure D-4: Protective Relaying, Example 1

Another approach may be applicable (Figure D-5). The minimum relay requirement for this application consists of a transformer differential relay (87). In some instances BCH may also require the optional phase overcurrent relays (51) if the utility protection can detect faults on the secondary of the entrance transformer outside the differential zone - for example, a fault at location A.

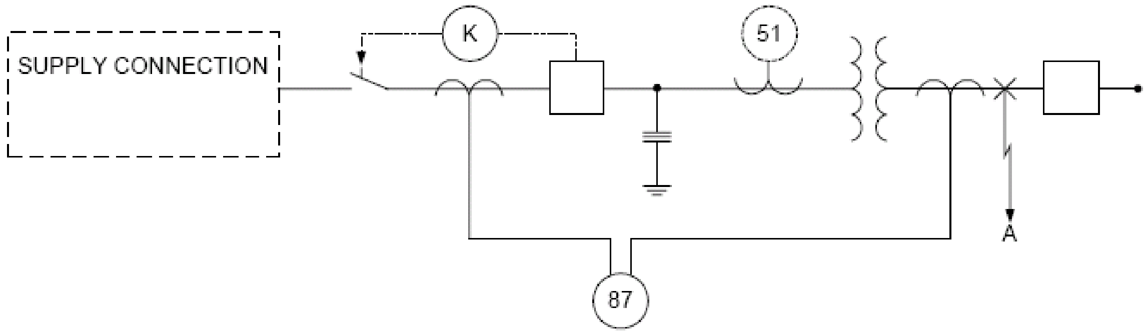

Figure D-5: Protective Relaying, Example 2

- Over/under frequency relays:

Generators must remain connected during frequency excursions both to limit the amount of load shedding required and to help the system avoid a complete collapse. Units susceptible to damage will follow the minimum criteria in Table D-2.

Underfrequency	Limit Overfrequency	Limit Minimum Time
60.0-59.5 Hz	60.0-60.5 Hz	Continuous
59.4-58.5 Hz	60.6-61.5 Hz	3 minutes
58.4-57.9 Hz	61.6-61.7 Hz	30 seconds
57.8-57.4 Hz		7.5 seconds
57.3-56.9 Hz		45 cycles
56.8-56.5 Hz		7.2 cycles
Less than 56.4 Hz	Greater than 61.7 Hz	0 cycles

Table D-2: Off-Nominal Frequency Minimum Performance

A generator that participates in a "local island" condition may have specific off-nominal frequency requirements to prevent power quality problems. Relays with inverse time vs. frequency operating characteristics are not acceptable.

- Under/Overvoltage relays:

Generating units connected to the BCH system should stay on-line without tripping for as long as possible during off-nominal voltage excursions to contribute to the restoration of normal system voltage. During a severe system disturbance, the DG plant must not disconnect before all BCH over-/under-voltage tripping schemes take effect (undervoltage relay settings must coordinate with the undervoltage load shedding program).

Overvoltage	Undervoltage	Minimum Delay
<1.10 pu	>0.90 pu	Continuous
-	≤0.90 pu	10.0 seconds
≥1.10 pu	-	5.0 seconds
≥1.20 pu	≤0.80 pu	2.0 seconds
≥1.25 pu	≤0.75 pu	0.8 seconds
≥1.30 pu	-	0 seconds

Table D-3: Off-Nominal Voltage Minimum Performance

D.2.3.2 Interface protection for connection in distribution network

The recommended relays and settings for plants rated 500 kW and up are as follows:

Relay function	Threshold (%Un)	Time (sec)
Undervoltage	< 60 60-90	Instant. 1.0
Overvoltage	>140 110-140	Instant. 1.0
Underfrequency	59.5 Hz	0.5
Overfrequency	60.5 Hz	0.5

Table D-4: Recommended relay settings in Canadian distribution system

If the under/over voltage and under/over frequency relay settings result in too many nuisance trips, it may be necessary to use more elaborate relaying such as rate of change of frequency, change of reactive power or voltage-vector magnitude and phase.

D.2.3.3 Line protection

Since DG plant will contribute to faults on the BCH system, the DG plant shall provide redundant equipment to clear all phase and ground faults on the utility transmission line.

As well as providing protection to detect transmission line faults and prevent ungrounded energization, the DG plant shall provide breaker failure protection for the entrance circuit breaker.

The DG plant must provide a method to prevent energization of the ungrounded transmission line to the DG plant, as could happen if the DG plant's transformer has a delta connected HV winding and the line is open at the BCH terminal(s). Depending on the specific circumstances, redundant equipment may be required. Depending on the location and method of connecting to the BCH system, communications assisted line protection may be required to provide acceptable fault clearing times.

For ground faults, Possible methods include zero sequence voltage detection (using a voltage relay, 59N, connected to the broken delta secondary connection of primary voltage instrument transformers) or zero sequence current detection (using a current relay, 51N, to measure zero sequence current flow from the DG plant to BCH).

For phase faults, dedicated phase fault protection shall be provided by the DG plant to clear isolated multi-phase faults on the BCH transmission system. Appropriate to the installation, this protection will consist of under-voltage relaying (27), directional inverse time over-current relaying (67), impedance relaying (21), or inverse time over-current relaying (51).

D.2.3.4 Prevention of energization of ungrounded transmission line and reclosing co-ordination

An acceptable method to prevent energization of a line that is open at the BCH terminal(s) is to send a transfer trip signal from the open BCH terminal(s) to the DG plant. Hydro-Quebec requires the installation of a remote tripping system in these cases:

- If the line reclosing time is less than 2 sec
- When unwanted islanding may occur
- To ensure adequate protection for faults on the H-Q network if DG's protections are not effective
- If self-excitation may occur, as when islanding a power plant with a capacitive load (capacitor bank, filters, etc.)

Reclosing of BCH lines could connect an islanded DG system to the BCH system when the two systems are out of synchronism. To prevent the DG plant from being damaged by such reclosing operations, the plant may need to be disconnected from the transmission system prior to the reclose or BCH may provide a means of preventing reclosing.

D.2.4 Islanding

BC Hydro does not generally allow islanding conditions to exist except for a controlled (temporary, area-wide) grid separation.

Relaying that responds to frequency and voltage fluctuation will trip the generator for the large voltage and frequency deviations that would tend to occur during an island condition.

In the case where a DG plant remains connected because of a balanced load situation, the generation affected in the local island must be disconnected prior to synchronizing to the main BCH system.

D.2.4.1 Typical connection schemes

The connection to the BCH system will generally take one of two forms as shown in Figures D-6 and D-7.

For these installations, a delta connected HV winding is generally recommended. For installations that connect to a substation, wye-connected HV windings are recommended together with appropriate ground fault protection for the connecting transmission line.

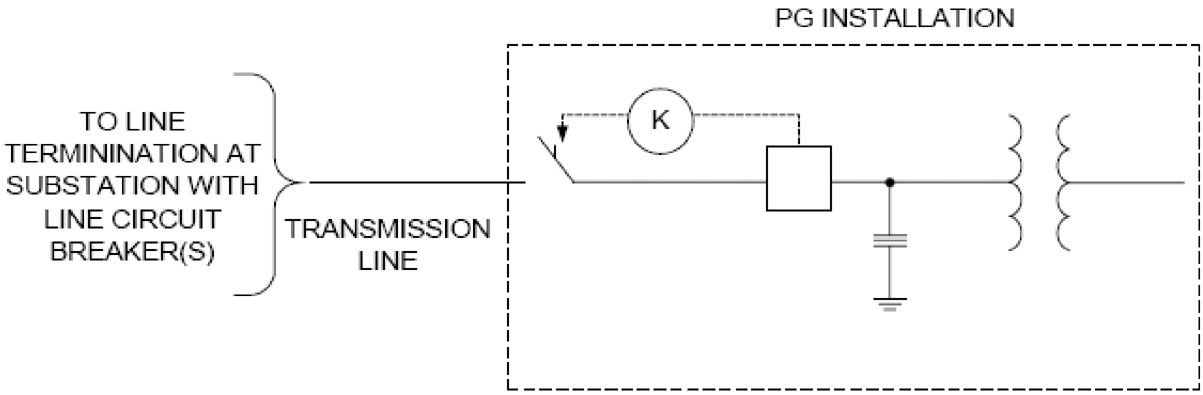

Figure D-6: Radial Line

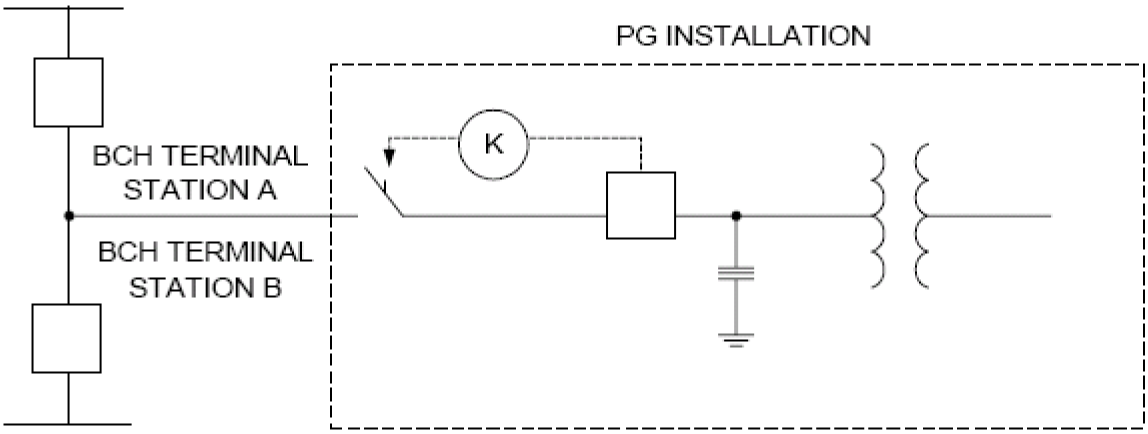

Figure D-7: Tap into Transmission Line

D.3 Practices with Protection of DG in Denmark [107]

D.3.1 Prevailing generation technologies

For many years Denmark have had an environmental and energy policy with ambitious goals. This has resulted in large subsidies for the construction and the operation of small-scale Combined Heat and Power (CHP) plants and Wind Turbines (WT).

Energy 21 published by the Danish government in 1996 sets up overall goals of reducing CO2-emissions by 20 per cent in 2005 compared to 1988, and as a long term goal to halve CO2-emissions by 2030 by making one third of the energy use sustainable energy and by making the rest of the energy use more effective.

Accession to the Kyoto protocol defined the goals on an EU level to be an 8 per cent reduction of greenhouse gas emissions from 1990 to 2008-2012. The national Danish goal is under certain conditions a 21 percent reduction.

Danish energy policies have in the Western part of Denmark led to the building of 1.570 MW Combined Heat and Power plants (CHP) and 2.315 MW Wind Turbines (WT) by the end of 2002. These units are distributed all over the network. At the end of 2002, 55% of the production capacity was placed in the distribution networks. This tendency will probably continue. From Table D-5 it can be seen that the production capacity in the distribution network, are now higher than the peak load.

The production of electric energy in 2002 was 23.5 TWh.

Energy consumption, including losses	20.858 GWh
Peak Load	3.685 MW
Off-peak-load	1.189 MW
Utilization time	5.660 h

	MW	**GWh**
Combined heat and Power, central Units	3.196	12.928
Combined heat and Power, local Units	1.570	6.723
Wind Turbines	2.315	3.825
Total	7.081	23.476

Table D-5: Key figures from 2002

Power lines are connecting the German main grid system in a way that makes the system power less dependant of the wind power fluctuation.

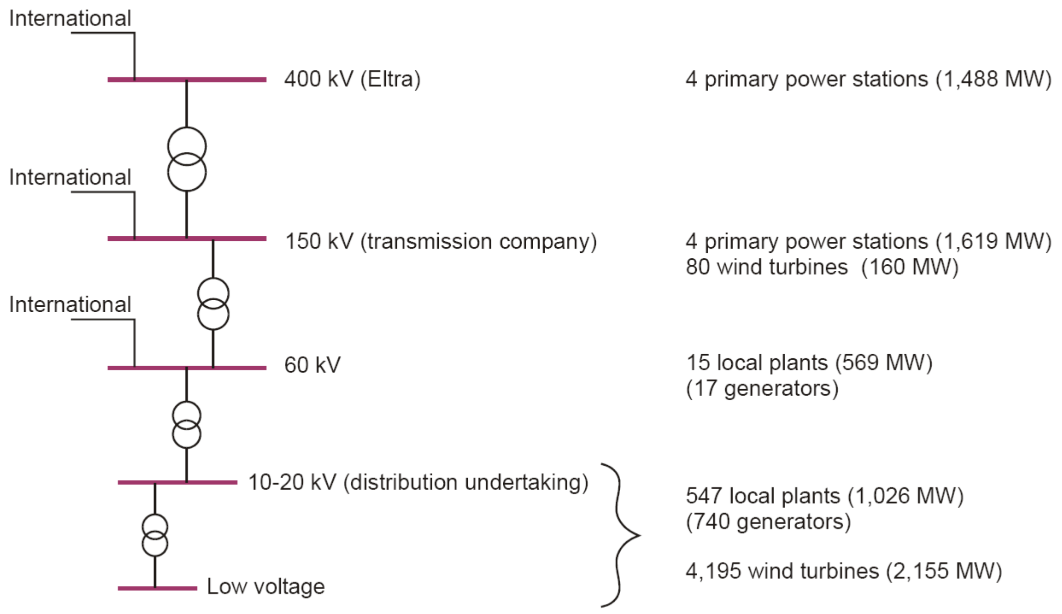

Figure D-8: Production capacity at each voltage level

About 50 per cent of the production is now bound production. The production from the CHP units is bound to the demand for district heating and the Wind Turbines are bound to the wind.

D.3.2 Main challenges

The situation for wind power is more complex. The development in the early 90's was quite relaxed heading for a total of 1,500 MW for Denmark as a whole in year 2005.

From 1995 the increase was larger than expected and the increase in year 2000 was enormous. The result was 2,315 MW of onshore wind power in the western part of Denmark by the end of 2002.

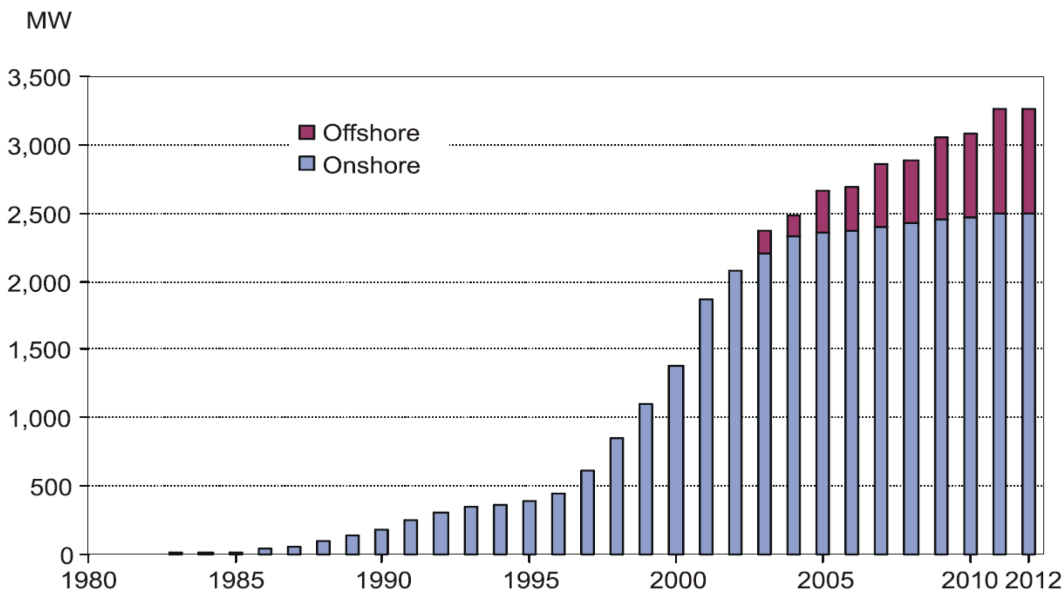

Figure D-9: Wind turbines capacity in the ELTRA system.

As the development of wind power is basically determined by rules of subsidy, it is not possible to forecast a level of stabilisation. Due to the rules now in force, we expect onshore wind power to stabilise at 2,500 MW in Denmark West.

The amount of onshore wind power is determined by a replacement rate decided by the government. The replacement will add approx. 400 MW.

The amount of offshore wind power shown in Figure D-9 is decided in the government development plan. The instruction to the Danish electricity companies is to build five wind farms with a total capacity of 750 MW offshore.

During the 90's the development of technical properties regarding wind turbines has been significant. From unit sizes in the range 55-600 kW we now installing turbines in the range of 1.5 to 2.0 MW. This development is expected to continue.

Being the System Operator in the western part of Denmark, ELTRA faces a great number of new challenges derived from an ambitious energy and environmental policy and a new market concept due to the liberalisation. New paradigms characterise the electricity market for generation and the transmission system since the framework and the conditions have changed dramatically within a few years.

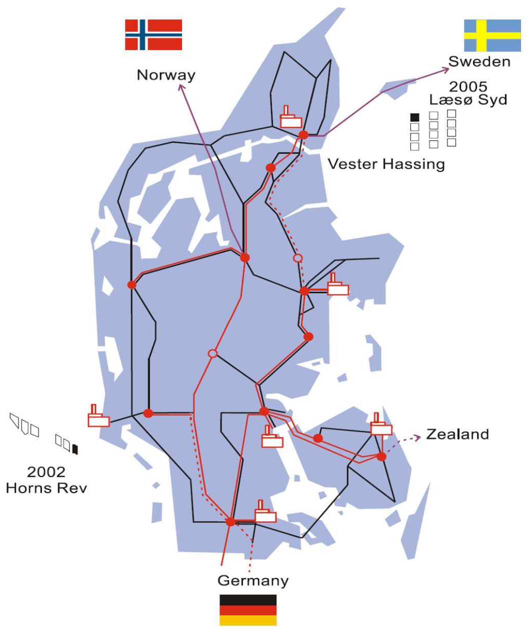

Figure D-10: Structure of the transmission grid in Eltra area.

ELTRA has the job of balancing the power system taking into consideration that:
the wind power production is unpredictable

- the CHP production is based on the district heating
- congestion must be managed in a transparent way
- the security of supply is ensured
- the market must function well, based on correct pricing.

Non-dispatchable production in Denmark may influence the market in the Nord Pool area by the amount of bound production.

The transmission grid in the Eltra area covers 712 km of the 400 kV lines and 1,739 km of the 150 kV lines. The Eltra area is connected to Norway and Sweden by HVDC links and to Germany by AC links (400 kV, 220kV, 150 kV, 60kV).

D.3.2.1 Economic Impacts

<u>*Network reinforcement*</u>
The appearance of local CHP units has influenced the network expansion of recent years. At 10 kV and 60 kV level the task of the network is no longer just to distribute energy - the CHP units and wind turbines also mean that the network must be able to collect the energy where it is produced. All things considered, this has increased the network expansion at the 10 kV level, and in a few cases also at the 60 kV level.

<u>*Socialized costs*</u>
In the ELTRA area some of the costs for network reinforcement due to connection of CHP and WT (with a capacity greater than 1.5 MW) are socialized (publicly owned). In the period from 1992 to 2002 these socialized costs amount to 706 MDKK.

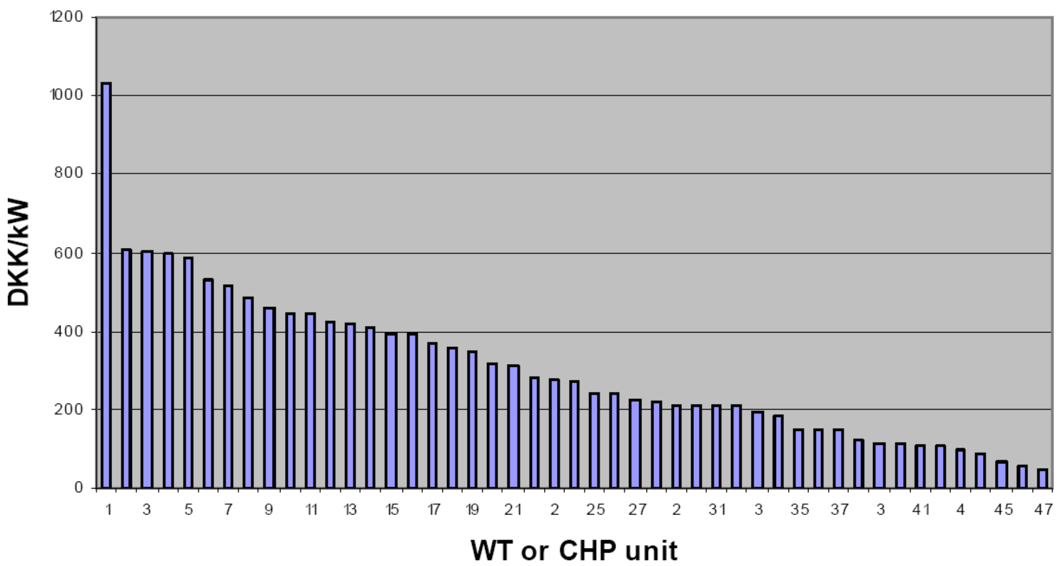

Figure D-11: Connection Costs 2001

<u>*Cost models*</u>
The socialized costs were in the beginning based on the real project costs, but the administration of this system was connected with high costs. It was then decided to estimate the project costs by a cost model. The accuracy of this model is +/- 20%. The model has been calibrated by use of 156 real cases. The connection costs for 2001 can be seen in Figure D-11.

D.3.2.2 Operational Challenges

Flow in 150/60 kV transformers
The flow towards the transmission system level causes problems with regards to regulating tap changes of the transformers and with regard to voltage profiles in the distribution network having lower voltages, at the points of transformation than at the points of infeed of the

Distributed Generators. Network Operators therefore often connect the generators at separate outlets where consumption is not connected.

Offshore Wind farms

The energy efficiency is expected to be much better for offshore wind farms than for onshore wind farms. Measurements indicate that the same amount of energy can be produced by half the capacity offshore than onshore. Utilisation time in the order of 4,000 hours is expected. The control functions for an offshore wind farm in the Eltra area are as follows:

- **Production limitations** set output to a maximum
- **Reserve** operate with a certain reserve downward and/or upwards
- **Balance control** set output downwards or upwards in steps
- **Grid protection interventions** set output to a lower value, in critical situations
- **Gradient limitations** adjust the output gradient limit upwards and/or downwards

Each turbine handles its own frequency control. In addition, the reactive power can be controlled locally or centrally so that the wind farm's total consumption/intake of reactive power is kept within certain limits. Disconnection of the turbines in case of grid faults or too strong winds is also controlled individually.

Regulating power

Wind power and local CHP plants have displaced central units which are being decommissioned, as there is no longer a commercial basis for them. It means that the regulating units are disappearing in areas where the need for regulating capacity is growing.
The regulation must then be effected by the local CHP plants and the wind power.
Eltra is therefore working on getting these services from the DGs.

Short circuit power

The short-circuit power level has been reduced. The result has been:

- increased limitations on the use of HVDC links especially to Sweden
- increased risk of harmonics
- increased risk of voltage steps when connecting and disconnecting lines
- a risk that faults can be seen at a longer distance.

Priority to CHP and WT production

The energy policy has resulted in approximately 50 per cent of the energy production in the Eltra area now being prioritised. This means that the Danish small-scale CHP production and the wind power cannot be regarded as secondary production and it cannot be closed down when needed.

Complex system

An obvious price for the Danish energy and environmental policy has been a very complex power system to operate. Balancing a power system like ELTRAs can for the time being only be done if it is connected to areas with other types of production. This is not a situation that can be accepted in the long run.

CHP generation

From the very start the direct coupling of heat and power production was a major concern of the power utilities. A situation in which many CHP units made the base load electricity production and the large extraction and condensing power stations were to be dispatched by the power pool at peak load was not considered a satisfactory solution, neither by the utilities nor by society. The planning tool to overcome this problem has been a three-rate tariff.

D.3.3 Examples of typical connection settings

Dimensioning voltages and frequencies

A wind farm shall be dimensioned to produce at voltages and frequencies that deviate from rated values in the minimum hours indicated. Voltages and frequencies for which Figure D-12 states time-limited operation will occur is less than ten hours per year. Voltages above the upper limit for the full-load voltage range (U_{hf}) will be very rare, for instance by re-establishment of the supply after a major operational disturbance. Abnormal voltages and frequencies shall not result in a production decrease larger than one indicated in Figure D-12.

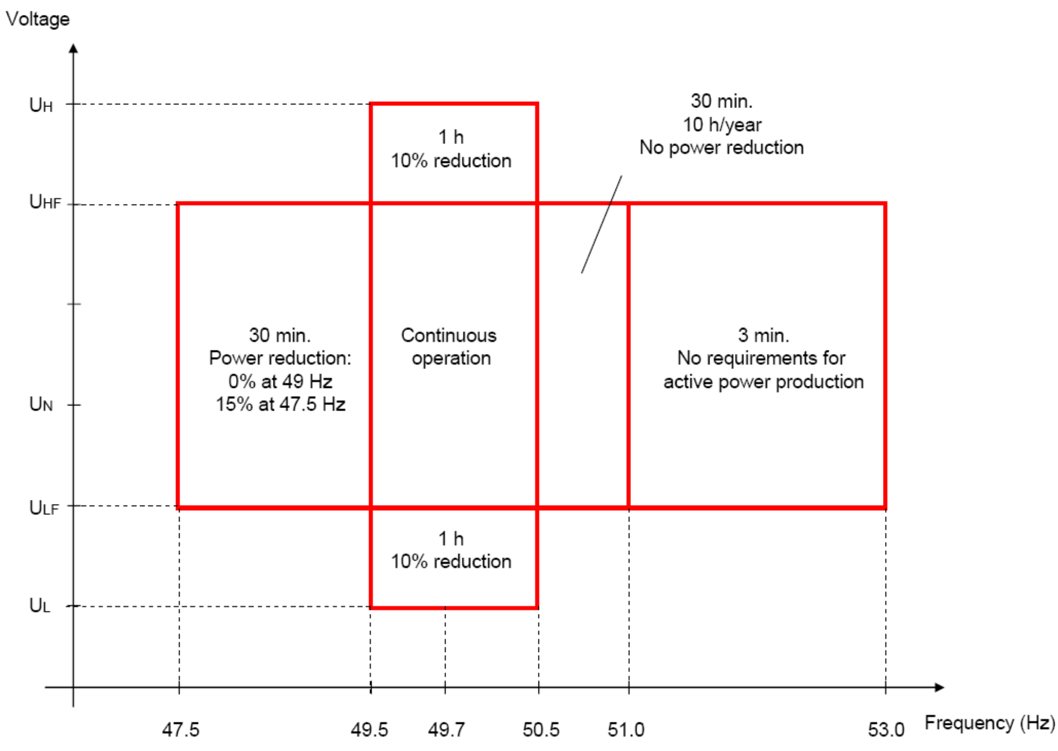

Figure D-12: Definition of abnormal voltages/frequency conditions

Nominal voltage U_N	Lower voltage limit, U_L	Lower voltage limit for full-load range, U_{LF}	Upper voltage limit for full-load range, U_{HF}	Upper voltage limit, U_H
400 kV	320 kV	360 kV	420 kV	440 kV
150 kV	135 kV	146 kV	170 kV	180 kV
132 kV	119 kV	125 kV	145 kV	155 kV

Table D-6: Voltages in the transmission grid

The full-load range indicates the voltage range within which the wind farm shall be able to supply its nominal power.

<u>*Protection Practices*</u>

On the basis of experience, Eltra has set some requirements on relay equipment and settings at local CHP units. Units ranging from 0 to 50 MW must satisfy the requirements.

However, in case of fast 3-pole re-closure local CHP units may be islanded during the dead time, and to avoid unit damage affected units are tripped before re-closure (0.3s). It is impossible to apply time selectivity. Therefore, as primary protection an undervoltage relay is used, which measures the positive-sequence voltage, possibly supplemented with a ROCOF relay.

The ROCOF relay has given rise to quite a lot of forced outages of local CHP units. The reason is partly that some types of relays are sensitive to the phase shift resulting from short circuits and couplings in the network and partly that Eltra originally recommended too sensitive settings on the ROCOF relay (df/dt > 1.5 Hz/s and df/dt< -0.7 Hz/s)

However, the strategy for system protection may have to be revised. 10-12 times per year Eltra experiences simultaneous forced outages of many local CHP units.

The wind farm shall be equipped with voltage and frequency relays for disconnection of the wind farm at abnormal voltages and/or frequencies. The relays shall be set according to agreement with the regional grid company and the system operator. The protective functions of the wind farm turbine shall have settings and time delays meeting the requirements:

The wind farm shall remain connected after the below faults in the transmission grid. Likewise, compensation plants shall remain connected.

On the basis of experience, Eltra has set some requirements on relay equipment and settings at local CHP units. Units ranging from 0 to 50 MW must satisfy the requirements shown in Table D-7.

Type of relay	Settings	Trip Time
Positive-sequence undervoltage	$U_1 < U_{1n} + 30\%$	t<= 50 ms
Three-phase overvoltage	$U > U_n + 10\ \%$	t<= 50 ms
	$U > U_n + 6\ \%$	t: 30-60 s
Three-phase undervoltage	$U < U_n + 10\ \%$	t: 2-10 s
Overfrequency	f> 53.0 Hz	t= 300 ms
Underfrequency	f< 47.0 Hz	t= 300 ms
Overcurrent	I>>	t<= 50 ms

Table D-7: Required relay protection at dispersed CHP units in the 0-50 MW range within the Eltra service area

The above relays protect consumers and the network against unacceptable influences from the generator and the generator against out-of-phase reclosure in case of reclosure after network faults.

As additional protection in order to further protect the generator the following types of relays (as shown in Table D-8) may be used, provided that the specified settings are satisfied.

Type of relay	**Settings**	**Trip Time**
ROCOF	df/dt > 2.5 Hz/s df/dt < -2.5 Hz/s	80-100 ms
Phase shift	U> 8^0 3-phase U> 30^0 1-phase	momentary
Negative-sequence current/voltage	I_2 > 5-20 %	3-10 s
Zero-sequence voltage	20 %	60 s

Table D-8: Additional protection of local CHP units ranging from 0 to 50 MW

The risk of damage to units is minimised by protecting the unit against islanding and against out-of-phase re-closure. Eltra practices 3-pole fast re-closure in case of most multi-phase short-circuit faults in the 400 kV, 150 kV and 60 kV transmission systems.

The positive-sequence under-voltage relay functions before islanding occurs, and dependent on the type of fault and the relevant coupling and operational situation a large number of local CHP units may be tripped even though they would not all have entered into island operation.

D.4 Practices with Protection of DG in Finland

D.4.1 Prevailing generation technologies

The electric power consumption of Finland in 2008 was about 87 TWh with a decline of 3.8 percent compared to previous year. As the total consumption reduced, year 2008 has been described exceptional. The decline was due to the impact of economic recession on industrial sectors. It was also noted that the decline accelerated towards the end of year 2008. Sectors other than industrial power rose by 1.2 percent. Figure D-13 presents the electricity production by energy sources in 2007. [108]

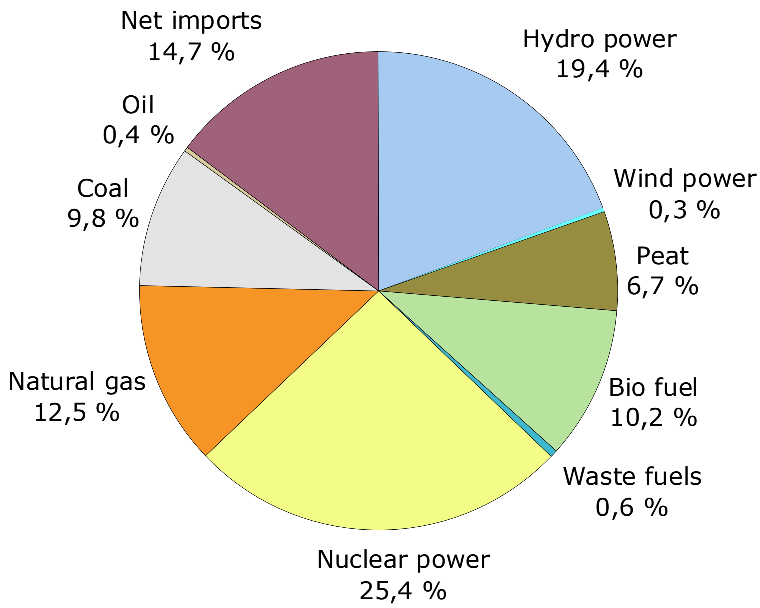

Figure D-13: Electrical power generation 2008 in Finland [108]

As it can be seen from Figure D-13, nuclear power forms one quarter of production. The import is from Sweden, Norway, Russia and Estonia.

The contribution of renewable energy sources in electrical power generation is dominated by hydropower and wood/biomass. Most of the biomass consists of residues from the wood industry. Figure D-14 illustrates the situation in 2007.

The proportion of wind power in Finland is minor at the moment. At the end of 2007 there were 107 wind turbine units with an aggregated production capacity of 110 MW. The total wind power production in 2007 was 190 GWh, which accounted for 0.2 % of the total consumption.

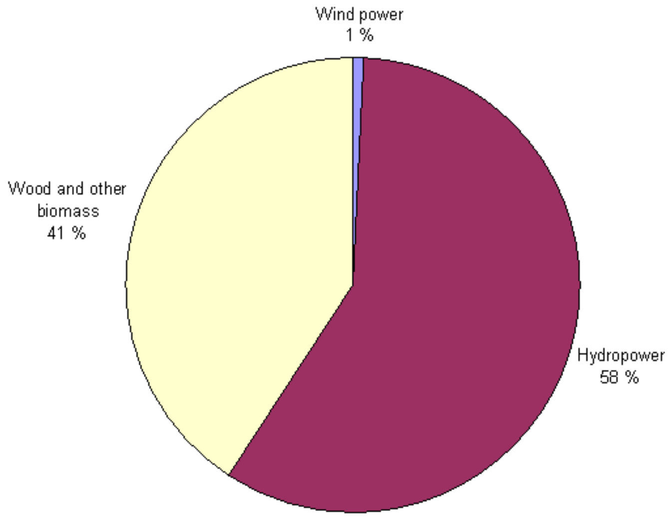

Figure D-14: Renewable energy sources for electrical power generation 2007 in Finland [108]

When considering the renewable energy sources in the whole energy production, thus including heating, industrial processes etc., the share of wood-based biomass becomes much more significant. This is illustrated in Figure D-15.

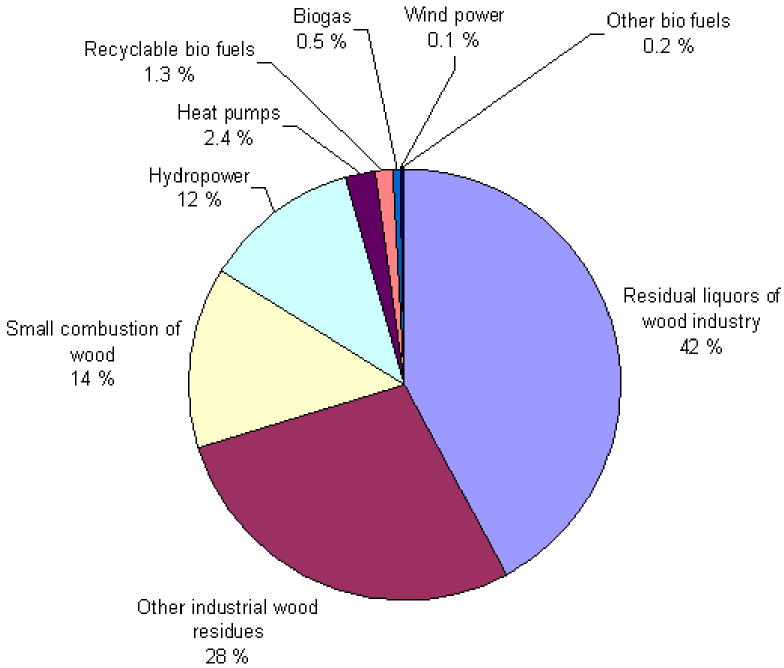

Figure D-15: Renewable energy sources for overall energy production 2006 in Finland (data: [109])

D.4.2 Examples of typical connection arrangements in Finland

The Finnish transmission system is operated by Fingrid Plc mostly on voltage levels greater or equal to 110 kV. Fingrid has defined their own requirements for connecting generators. [26] These requirements are based on the Nordel's Nordic Grid Code.

The Finnish distribution system is operated mostly as a 20 kV network, although some networks with 10 kV or 45 kV "sub-transmission" levels exist as well. At the moment there are around 100 distribution network operators ranging from some major companies to very small local operators. Currently there are no generally applied requirements for connecting generators to the distribution level. However, many companies have defined – or are currently defining – their own requirements. Recommendations [110] published by the Finnish Electricity Association Sener have been applied in many cases as a guideline. Motiva Oy has also published recommendations [111] for connecting small-scale generation.

The following chapters describe the requirements and/or recommendations in each voltage level.

D.4.2.1 Arrangements on the transmission network level (≥110kV)

The operation limits of frequency required in transmission networks are established in Fingrid Plc [26].

The grid frequency is defined to be in the range 49.5…50.5 Hz during normal operation. The unit must be able to operate at the full output power within a frequency range of 49…51 Hz and voltage between 90…105 %. However, between 50.3…51 Hz, power reduction of 10 % is allowed and the required operation time is limited. While the frequency is within the normal operation area, one hour of operation is required with voltages within ranges 85…90 % and 105…110 % with an allowed output reduction of 10 %.

During low frequencies between 49…47.5 Hz, 30 minutes of operation is expected with an allowed output reduction. Below 47.5 Hz the unit may be disconnected. During overfrequencies the unit must operate with strongly reduced power between 51…53 Hz. Disconnection from the network is allowed above 53 Hz and required above 55 Hz.

Figure D-16 presents the requirements during varying system frequency.

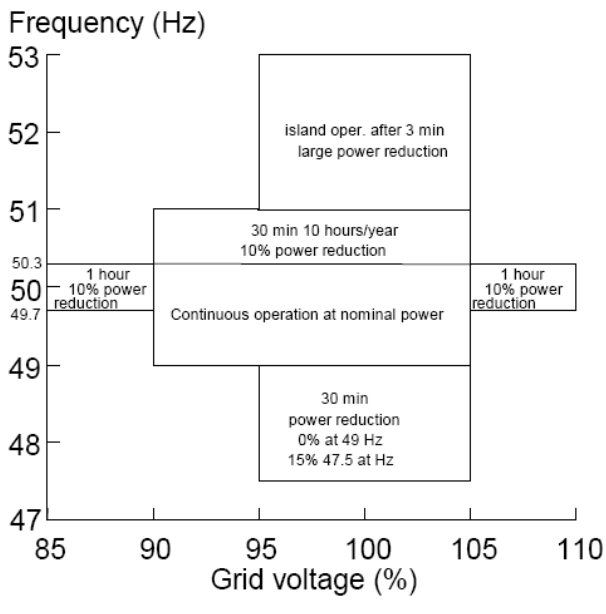

Figure D-16: Requirements for power production when the grid frequency and voltage vary. Disconnection is allowed outside the lines. ([26])

D.4.2.2 Arrangements on medium voltage level (<110kV)

Presently there are no general requirements for interconnecting DG on medium voltage levels. The distribution network operators define their own requirements for interconnections to their network. These requirements may vary significantly depending on the DNO, which is natural as the network circumstances vary as well.

However, recommendations for the interconnection have been published by the national association of energy companies. These recommendations are applied as such especially in minor network companies. It can be said that all major companies have formed their own requirements which follow the recommendations in many aspects as well. In the following, the protection recommendations are considered.

The recommendations defines some basic requirements for the operation of DG protection:

- The DG unit must be disconnected whenever the network is not fed from another source or when the voltage is lost totally or partially
- After a distribution interruption it must be possible to re-energize the network without any actions on the DG unit
- The DG unit must not result in a failure to reclose by maintaining the voltage in the network
- The DG unit must be disconnected during abnormal voltages or frequencies
- The DG unit may not be connected to the network unless all phases are live
- Unnecessary disconnections of other customers must be avoided. The DG protection must operate selectively with network protection. The DG unit itself should not be unnecessarily disconnected.

The recommendations describe the typical DG-related protection problems on medium-voltage levels. These include:

- Failure of autoreclosure
- Unnecessary disconnection of healthy feeders (sympathetic tripping)
- Disturbance of the the overcurrent protection on the DG feeder (blinding)
- Impacts of faults occurring on higher voltage levels
- Substation faults

D.4.2.3 Protection practices

There are no general guidelines for units on transmission network. However, wind power and other renewable energy sources need to fulfil same requirements as other large-scale units on transmission level. Units are typically connected through own substation. The protection equipment is similar to other units on transmission level, including for instance under-/overvoltage, under-/overfrequency and ground fault protection. The behaviour during abnormal conditions has been defined in the connection requirements.

The basic protection devices of a DG unit connected distribution network are presented in recommendations as follows:

Relay type	3U <>	f <>	I >	U_0 >
Loss of mains	x	x		
Overcurrent protection for network faults			x	
Ground fault protection for network faults				optional
Overcurrent protection for DG unit internal faults			x	
Unsymmetrical connection	x			
Device protection against abnormal voltage and frequency	x	x		

Table D-9: The basic protection functions for a DG unit.

For the voltage and frequency protection the following settings are given:

Relay	Operation limit	Operation time
Overvoltage	230 V + 10 % 230 V + 6 %	50 ms 30…60 s
Undervoltage	230 V – 10 %	2…10 s
Overfrequency	51 Hz	200 ms
Underfrequency	47 Hz	200 ms

Table D-10: Suggested protection settings at the medium voltage level.

In addition to the Table D-10 above, other protection functions are often used especially relating to loss of mains and ground fault protection. It is also quite common to apply a faster undervoltage protection with an operation limit as low as -50 % and operation time between 50…100 ms. Voltage relays must be three phase in order to detect unsymmetrical situations. One phase operation is adequate for frequency protection. The operation time of the lower overvoltage threshold has to be coordinated with the tap changer of the main transformer. Overcurrent protection can be provided with relays or fuses depending usually on the voltage level.

Ground fault protection may be necessary depending on the application. Practically all larger DG installations are equipped with zero-sequence voltage relays for disconnecting the unit during ground faults.

No different recommendations are given for DG units connected via dedicated lines or connected directly to the substation. However, different settings can be used in these applications.

D.5 Practices with Protection of DG in France

D.5.1 Prevailing generation technologies

Currently, there is around 116GW of electricity generation in France. Total annual consumption amounts to about 480TWh and the winter peak demand is about 88GW. The relative composition of the generation mix is presented in Table D-11.

FACILITIES	Maximum installed capacity			GENERATION		
	As of 31st DECEMBER 2005 MW	As of 31st DECEMBER 2006 MW	Trend MW	2005 GWh	2006 GWh	Trend %
France						
NUCLEAR	63 260	63 260	+ 0	429 978	428 665	- 0.3
CONVENTIONAL THERMAL	25 354	24 578	- 776	59 650	53 848	- 9.7
HYDRO-ELECTRIC	25 451	25 681	+ 230	56 179	60 987	+ 8.6
Renewable energy sources but hydro	1 679	2 547	+ 868	4 322	5 602	+ 29.6
Of which, wind	*752*	*1496*	*+ 744*	*985*	*2 257*	*+ 129.1*
Total France	115 744	116 066	+ 322	550 129	549 102	- 0.2

Table D-11: Developments in generating resources in France

The main renewable technologies in France are hydro, for many years, wind, biomass and waste.

D.5.2 Main Challenges

The NREs (new and renewable energies) are a fundamental component of French energy policy in two respects: as a means to diversify its energy mix and to improve its security of supply, and as a means to protect the environment because they neither emit CO2 nor pollute, and they eliminate problems of waste management. Here we look at how generating electricity with renewable energies can contribute to the global targets for NREs.

As part of its drive to diversify France's energy mix, the country's energy policy has targeted 10% of whole amount of primary energy needs to be supplied from renewable sources by 2010. France already generates a substantial quantity of renewable energy thanks to hydroelectricity. One of the means by which France plans to achieve its goals of satisfying 10% of its energy needs from renewable sources lies in the development of electricity generated from renewables. Pursuant to Directive 2001/77/EC, France has set a goal of generating 21% of its gross domestic electricity consumption from renewable sources by 2010.

This ratio has been affected considerably by the low levels of hydroelectricity generation since 2003, combined with the hefty share of hydroelectricity in total electricity generated from renewables (94% in 2004), even though electricity consumption continued to climb, albeit at a more moderate pace. Because of the dwindling number of suitable sites, produceable hydroelectricity is now nearing its upper limit.

Therefore further progress toward the targets set for NRE-generated electricity will necessarily entail the development of other renewable forms, *wind power* foremost among them. Recently wind power has grown considerably (it was multiplied by 3.5 between 2002 and 2005), although the quantity of electricity produced is still insufficient for its expansion to increase the share of NREs significantly. But past trends do point to an increase in the future importance of these types of energy, given the scale of France's wind power potential and the incentives put in place. For this, however, it will be necessary to remove certain obstacles such as the need to fit into the local environment or connection to the networks.

D.5.3 Examples of typical connection arrangements

RTE's Transmission grid is composed of 400 kV, 225 kV, 90 kV and 63 kV networks. 30 kV, 20 kV and 15 kV networks belong to Distribution network.

RTE uses single pole tripping to eliminate intermittent phase-to-ground faults on 400 kV and 225 kV networks.

In France, every power generator is equipped with at least

- Over and Under voltage protection
- Over and Under frequency protection.

The legal text regarding how to connect power plants on RTE's grid mentions requirements on frequency and voltage levels. Frequency requirements are defined between [47-52] Hz. Power plants have to remain connected within these frequency bounds.

Voltage requirements are defined as follows:
Low level voltage: power plants have to remain connected as long as the grid's voltage is higher or equal than 0.8Un.

High level voltage:

- the legal text defines the maximum level of voltage (440kV for 400kV grid ; 250kV for 225kV grid and so on...)
- the legal text requires the power plants to remain connected and to deliver, at least, 95% of the active rated power.

The French grid code is (of course) just in accordance with these requirements.

Scheme 1 – Interconnection through a dedicated 400kV line

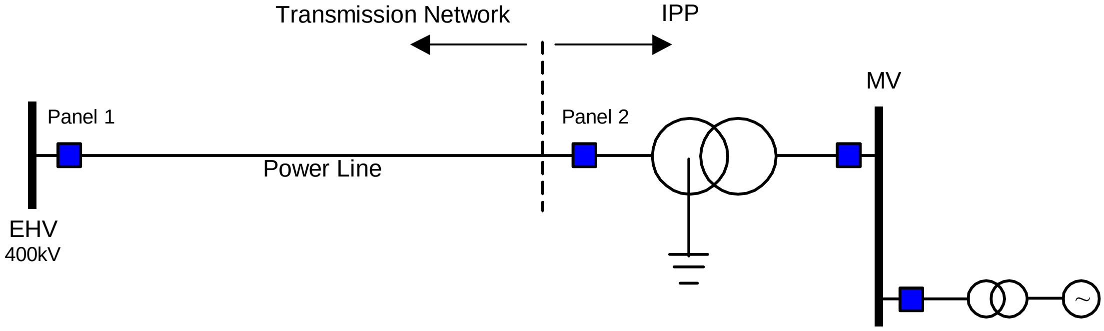

Figure D-17: Interconnection through a dedicated 400kV line in Transmission Network

Line Protection System:

Panel 1 (RTE)

- Line differential protection (one communication channel)
- Distance protection including
    - Power Swing blocking function
    - teleprotection aided scheme (PUTT[8] or BOP)
    - directional ground-fault protection : zero-sequence directional power[9], inverse time delayed
- Breaker failure protection
- Single and Three-pole autorecloser

Panel 2 (DG)

- Line differential protection (one communication channel)
- Distance protection including
    - Power Swing blocking function
    - teleprotection aided scheme (PUTT or BOP)
    - directional ground-fault protection
- Weak infeed function is needed to preserve the autorecloser's single phase cycle if the generator is off. A specific equipment exists for 20 years in the EDF panel (based on undervoltage relays 27).
- Breaker failure protection (DG's option)

Single and Three-pole autorecloser

Most of these 400 kV interconnection schemes are currently between RTE and EDF, that means similar panels at both ends. But there are now projects with independent producers.

Scheme 2 – Interconnection through a dedicated 400kV short line

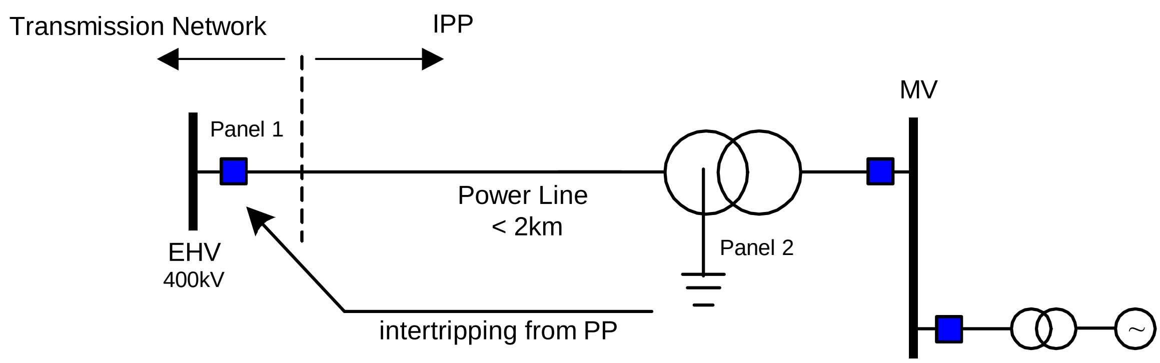

Figure D-18: Interconnection through a dedicated 400kV short line in the Transmission Network

8 Permissive underreach transfer trip, blocking overreach protection

9 Specific equipment based on Vo*Io measurement (32N).

Line Protection System:

Panel 1 (RTE)

- Distance protection including
    - Power Swing blocking function
- Distance protection including
    - Power Swing blocking function
    - directional ground-fault protection : zero-sequence directional power, inverse time delayed
- Breaker failure protection

Panel 2 (DG)

- Overcurrent delayed relay

Most of these 400 kV interconnection schemes are currently between RTE and EDF. Recently (end of 2007), for security reasons, new projects have to be connected in priority with scheme 1.

Scheme 3 – Tap connection to two ends of a 225 kV line

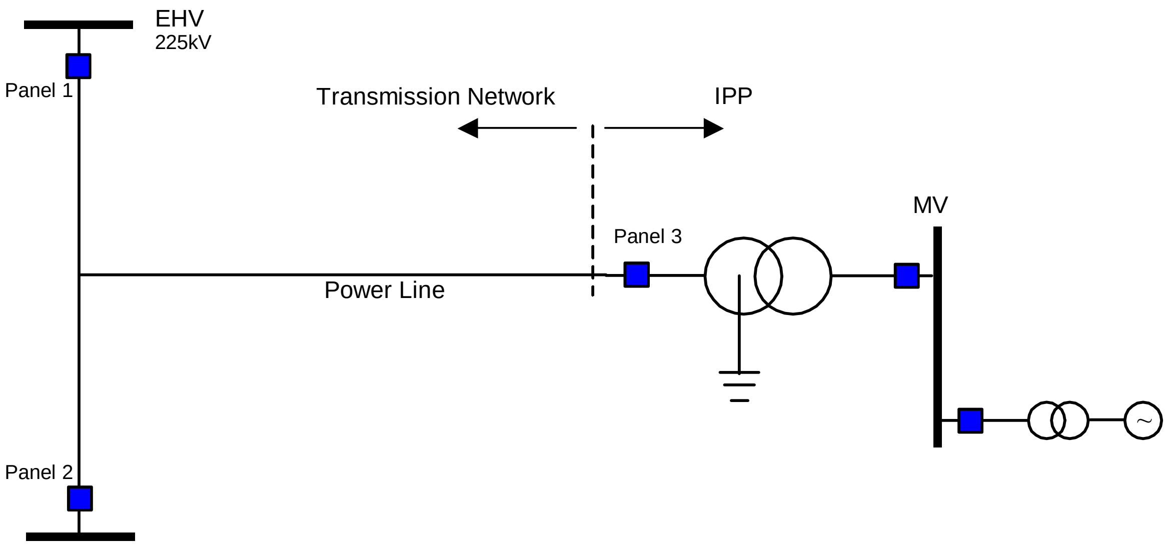

Figure D-19: Tap connection to two ends of a 225 kV line in the Transmission Network

Line Protection System:

Panel 1 and 2 (RTE)

- Distance protection including
    - Power Swing blocking function
    - teleprotection aided scheme on short line (<15km, BOP)
- Distance protection including
    - teleprotection aided scheme on short line (<15km, BOP)
    - Power Swing blocking function
    - directional ground-fault protection : zero-sequence directional power, inverse time delayed
- Breaker failure protection
- Single and Three-pole autorecloser

Panel 3 (example of RTE's equipment)

- Distance protection including
  - teleprotection aided scheme on short line (<15km, BOP)
  - Power Swing blocking function
  - directional ground-fault protection : zero-sequence directional power, inverse time delayed
- Weak infeed function : specific device, based on undervoltage and zero-sequence current relay, accelerated by remote distance protections (panel 1 or 2)
- Breaker failure protection, sends intertripping to CB via panel 1 and 2
- Single and Three-pole autorecloser

Note: DG tap connection is prohibited on the 400 kV grid.

Scheme 4 – Interconnection through a dedicated HV line in the Transmission Network

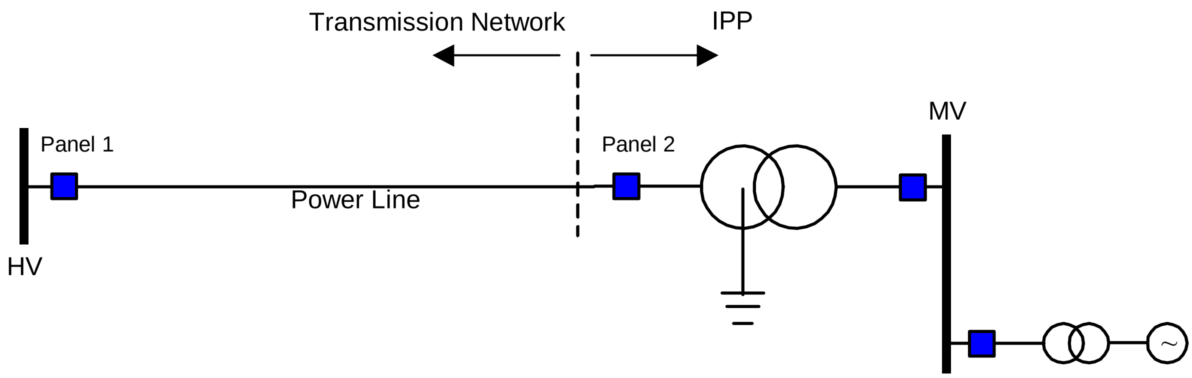

Figure D-20: Connection to a dedicated HV line in the Transmission Network

2 HV levels exist on RTE's grid : 63 kV and 90 kV.

Line Protection System:

Panel 1

- Distance protection including
  - Power Swing blocking function
  - directional ground-fault protection : zero-sequence directional power, inverse time delayed
- back up impedance relay
- Breaker failure protection
- Three-pole autorecloser

DG/Network Interconnection protection (associated to **Panel 2**):

Zero-sequence Overcurrent protection

If the HV/MV transformer is not grounded on the HV side, a zero-sequence overvoltage relay is used.

Scheme 5 – Tap connection to two ends of a HV line in the Transmission grid

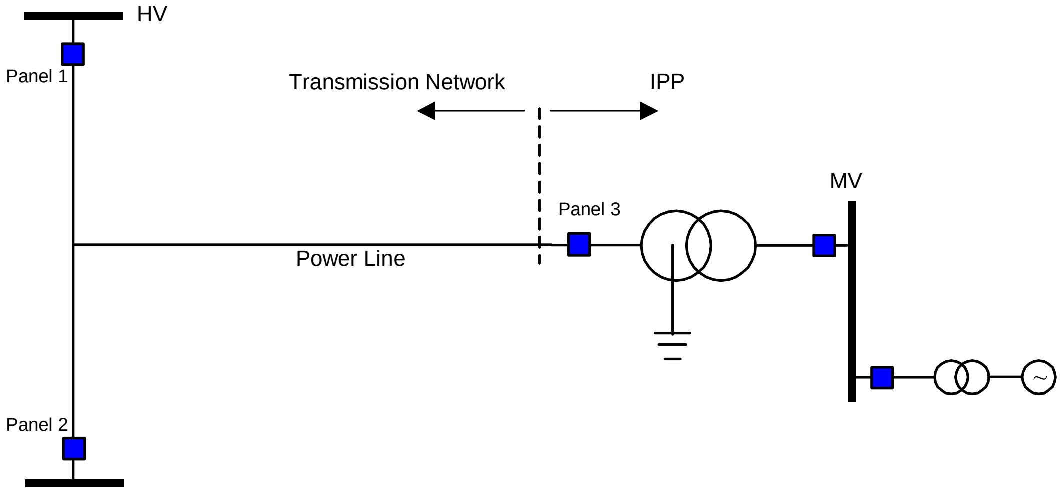

Figure D-21: Tap connection to two ends of a HV line in the Transmission Network

Line Protection System:

Panel 1 and 2 (RTE)

- Distance protection including
  - teleprotection aided scheme on a short line (<15km, BOP)
  - Power Swing blocking function
  - directional ground-fault protection : zero-sequence directional power, inverse time delayed
- back up impedance relay
- Breaker failure protection
- Three-pole autorecloser

DG/Network Interconnection protections (associated to **Panel 3**):

- Zero-sequence Overcurrent protection
- If the HV/MV transformer is not grounded on the HV side, a zero-sequence overvoltage relay is used.

Scheme 6 – Interconnection through a HV substation in the Transmission Network

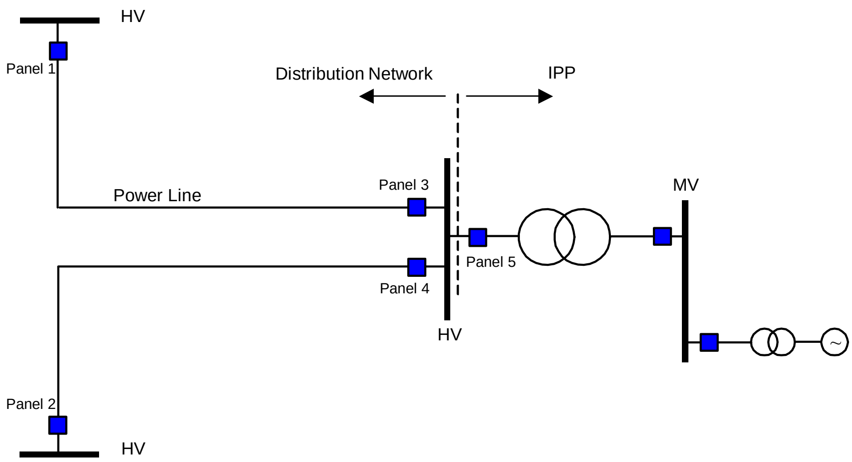

Figure D-22: Connection to dedicated HV substation in the Transmission Network

<u>Line Protection System:</u>

Panel 1 and 2 (RTE)

- Distance protection including
  - teleprotection aided scheme on a short line (<15km, BOP)
  - Power Swing blocking function
  - directional ground-fault protection : zero-sequence directional power, inverse time delayed
- back up impedance relay
- Breaker failure protection
- Three-pole autorecloser

Panel 3 and 4 (RTE)

- Distance protection including
  - teleprotection aided scheme on short line (<15km, BOP)
  - Power Swing blocking function
  - directional ground-fault protection : zero-sequence directional power, inverse time delayed
- back up impedance relay
- Three-pole autorecloser

<u>DG/Network Interconnection protections (associated to **Panel 5**):</u>
Zero-sequence Overcurrent protection
If the HV/MV transformer is not grounded on the HV side, a zero-sequence overvoltage relay is used.

D.5.4 Connection of power generators to distribution networks

D.5.4.1 Legal requirements

The following paragraphs summarize requirements to connect power generators on French distribution networks (30kV, mainly 20kV, 15kV, also 220V for domestic purposes), according to the most recent legal text (Ministerial order NOR DEVE0808815A 23/04/08) [17]. This text is relevant for all kinds of power generators (including RES).

The choice of the voltage at the connection point depends on the generator's rated power, in accordance with Table D-12.

Voltage	Generator's Rated power
One phase 220V	<= 18kVA
Three phases 220V	<= 250kVA
20kV (15kV, 30kV)	<= 12MVA

Table D-12. Voltage levels for connection of various sizes of DG

All generators must be able to detect faults on the distribution networks and to disconnect in case of :

- Ground fault on 20kV (15kV, 30kV) network
- Phase to phase fault on 20kV (15kV, 30kV) network
- Fault between phases on cables on the 220V network
- Internal isolated network.

All generators connected on the 220V distribution network must not absorb reactive power.

All generators connected on 30kV, 20kV or 15kV distribution networks must be able to send or absorb reactive power when the voltage at the connection point remains within [095-1.05]V_n, where V_n is a nominal rated voltage.
Send : up to 0.4 of active rated power,
Absorb : up to 0.35 of active rated power.

The distribution operator has to determine which kind of regulation and which level of reactive power it wants the generator to provide, with respect to the operator‘s grid code.

All generators above 5MW must remain connected on the distribution networks in accordance with Table D-13.

Frequency (Hz)	Duration	Loss of power (%)
49.5-49	5 hours	10
49-48	3 minutes	10
48-47.5	3 minutes	15
47.5-47	20 seconds	20
50.5-51	1 hour	10
51-51.5	15 minutes	To be determined with the distribution operator
51.5-52	20 seconds	

Table D-13. Operation frequency requirements for generators above 5MW

Producers are allowed to disconnect their generators if the grid frequency is above 52Hz. If they remain connected, generators must cope with frequencies up to 55Hz for 60 seconds.

All generators on distribution networks must remain connected at least 20 minutes above 0.95 of active rated power when voltage U at the connection point is within the following:

0.9Uc <= U < 0.95Uc or
1.05Uc < U <= 1.1Uc

When there is both frequency and voltage swing, generators above 5MW must remain connected at least for the shortest duration required in the above paragraphs, loss of power should be added.

FRT is required for all generators above 5MW. The FRT characteristics are included in chapter 2 in Figure 2-9 (page 43).

Power generators which fulfil at least one of the three following points must be linked with the Distribution Control Centre :

- Power generator is above 5MW,
- Power generator shares a feeder with other customers and the power is larger than 25% of the total consumption of this feeder,
- Power generator is connected on a dedicated feeder and the power is larger than 25% of the transformer’s rated power in the distribution substation.

These power generators have to exchange information regarding voltage at the connection point, management of active or reactive power, scheduled outages, scheduled power production etc.

D.5.4.2 How to protect generators on distribution networks

According to the French Distribution System Operator (eRDF), the requested protection features are :

- Anti islanding,
- Grounded fault on 15kV, 20kV and 30kV grids,
- Phase-phase fault on 15kV, 20kV and 30kV grids, or faults between conductors on the 220V grid,
- Risk of wrong coupling, especially on overhead lines with a fast auto reclosing device,
- Faults on the transmission grids (63kV and 90kV) if the sum of the generator's power on the same distribution substation is more than 12MW.

In order to achieve these requirements, the following relays have to be provided:

- Zero sequence overvoltage protection (on 15kV, 20kV 30kV grids),
- Phase-phase overvoltage protection,
- Phase-phase under voltage protection,
- Under and over frequency protection.

These relays may include a remote tripping of power generator(s) in case of loss of the transmission feeder (63kV or 90kV) and risk of islanding the distribution network, the ability to detect faults on the transmission grids (63kV or 90kV) in some distribution substations with more than 12MW of embedded generators. This functionality is not relevant for the generators but for the Distribution System Operator.

In order to avoid wrong coupling, 3 phase under voltage relays (27) are sometimes requested on the distributor's panel. The aim is to detect voltage sustained by the generators during an auto reclosing cycle and to delay, if necessary, the fast cycle reclosing.

D.5.4.3 Example

Protections and settings relevant to generators connected on an overhead 15kV, 20kV or 30kV line are listed in Table D-14.

	Relay	*Measure*	*settings*	*delay*
Single phase fault protection	Over V_0 (59N)	V_0	10 % V_n	delayed 1 to 2s[10]
Phase-phase fault protection	Under U (27)	3 phase-phase voltages	85% U_m	delayed 1 to 2s
Deep voltage drop protection (on producer request)	Under U (27)	3 phase-phase voltages	25% U_m	instantly
Anti islanding	Under U (27)	3 phase-phase voltages	85% U_m	delayed 1 to 2s
	Over U (59)	1 phase-phase voltage	115% U_m	instantly
	Under f (81U)	1 phase-phase voltage	49.5 Hz	instantly
	Over f (81O)	1 phase-phase voltage	50.5 Hz	instantly
	Under U (27)	1 phase-phase voltage	25% U_m	instantly

Table D-14. Protection specifications for DG connected to overhead lines (12kV, 20kV or 30kV)

[10] Depending on the distribution substation

D.6 Practices with Protection of DG in Germany

D.6.1 Prevailing generation technologies

Currently, the annual electrical power consumption in Germany is about 630 TWh. As can be seen from Figure D-23 half of Germany's electrical power generation is based on coal. Renewable energy sources such as wind and hydropower represent only about 10 %.

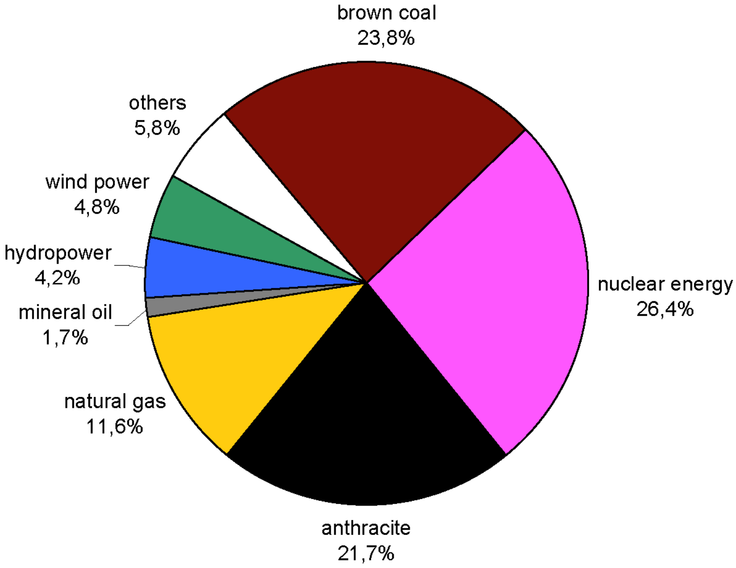

Figure D-23: Structure of Electrical Power Generation 2006 in Germany [112]

The structure of the renewable energy sources in Germany can be seen from Figure D-24. Almost half of the renewable electrical energy is produced from wind power. At the moment photovoltaic energy is the sector with the most subsidies – even though Germany is not the ideal place for this energy source.

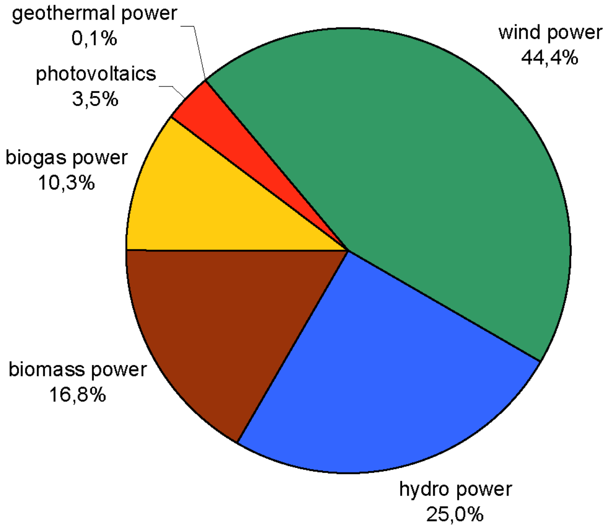

Figure D-24: Structure of Renewables in Electrical Power Generation 2007 in Germany [113]

Germany is currently planning to build huge offshore wind farms in the North Sea and some smaller ones in the Baltic Sea. At the moment wind farms with a total power of 22.9 GW are licensed and 2.6 GW are undergoing the licensing procedures in the North Sea. In the Baltic Sea wind farms with a total power of 2 GW are licensed and 0.9 GW are undergoing the licensing procedures [114].

The typical wind power input for onshore wind farms is about (200…15) MVA (100…20 generators).

D.6.2 Main challenges and potential benefits

The German political environment is such that there is a desire to switch off all nuclear power stations – and at the same time, try to reduce CO_2 production. Figure D-23 shows clearly that this challenge cannot be met within the next years. Therefore, the German government has created laws to subsidise almost all kinds of renewable energy sources (especially wind and photovoltaics).
The northern high voltage and medium voltage networks are not able to transport the planned amounts of wind energy and new high voltage transmission lines are planned and there are also ideas of DC-transmission systems.

Potential benefits of this development might be the reduction of the need for fossil energy sources (natural oil and gas) as well as jobs in the field of building and services for wind farms/generators.

D.6.3 Examples of typical connection arrangements in Germany

At the moment a German working group is developing a guideline for connecting distributed generators to the medium voltage[11] (MV) network. The following figures are part of this guideline (draft).
Figure D-25 shows the recommended protection system if the generator / wind farm is directly connected to the substation busbar system. If the generator is connected to the MV network the proposed protection system can be seen from Figure D-26. In both cases the following protection systems should be implemented:

Generator protection system:

- Over- and undervoltage protection (different speeds)
- Over- and underfrequency protection

DG/Network protection system:

- Over- and undervoltage protection
- Underimpedance protection
- Combined protection: undervoltage and reactive power flow towards the generators

The most interesting concept is the combined protection system, which trips the circuit breaker if there is a fault in the system and the wind farm is consuming reactive power instead of supplying. This feature should be implemented in both connection-cases to the main circuit breaker.

[11] Typical medium high voltage levels in Germany are: 10 kV, 20 kV, 110 kV.

Besides this guideline the following structures are implemented in the German distribution network.

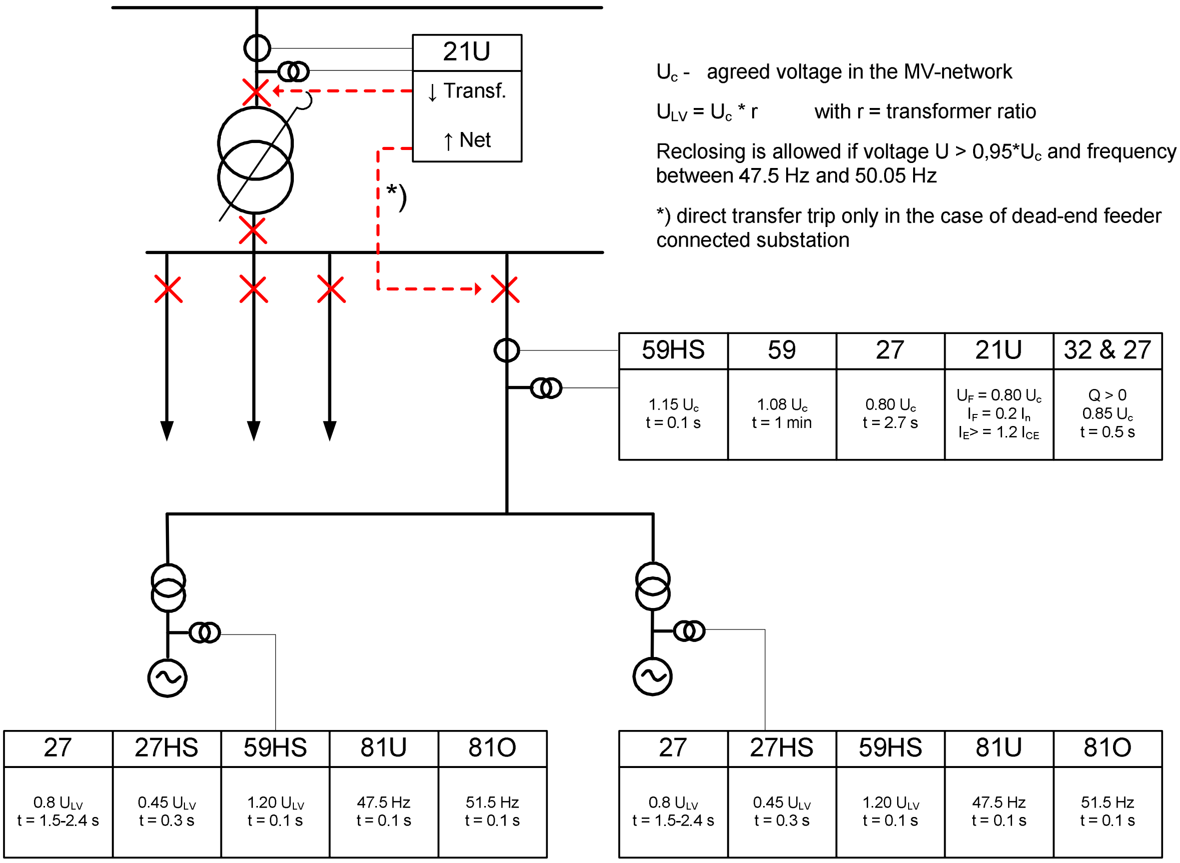

Figure D-25: Protection application if generator is connected to the substation busbar [115]

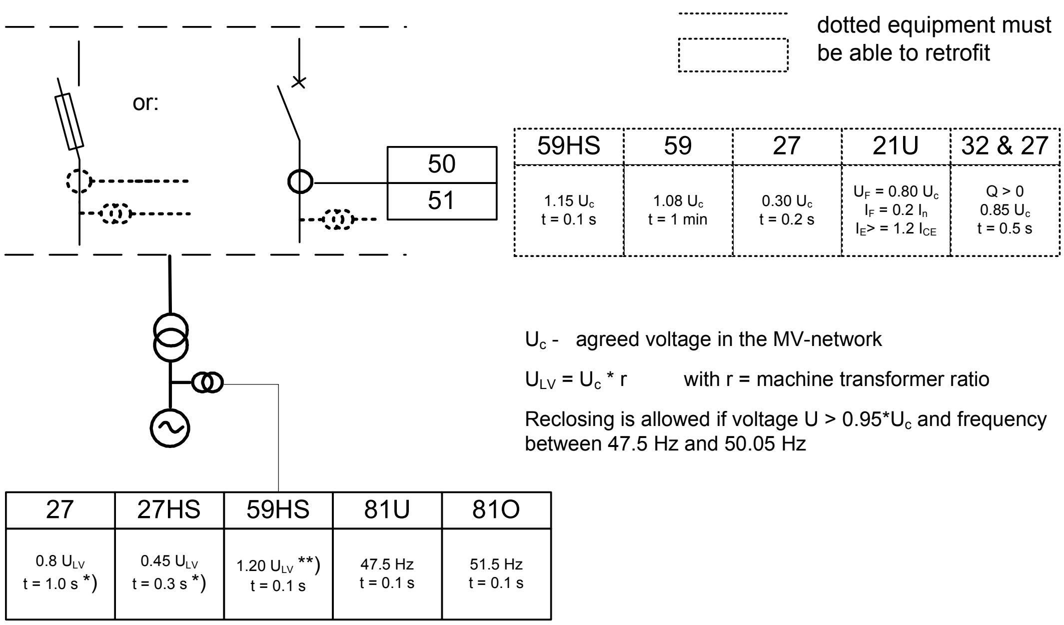

Figure D-26: Protection application if the generator is connected to the MV-network [115]

D.7 Practices with Protection of DG in Norway

D.7.1 Prevailing generation technologies

Production and consumption of electric energy

The production of electric energy in 2007 was 137.7 TWh, approximately the same as in 2005. 98.5% of the production was hydropower. The energy content of the reservoirs at the end of 2008 was 57 TWh, which is 67.0% of the total capacity. During the past 10 years (1998-2008) an average annual increase in production of 1.5% is observed.

At the end of 2009, the production from the Norwegian hydropower system is estimated at 135 TWh. Domestic gross consumption was 125TWh in 2008. The gross general consumption increase by 0.9% in average. Adjusted for temperature conditions, the general consumption increase by approximately 1.0% pr. year. Average annual increase over the past 10 years has been 0.9%. The maximum system power load in 2008 related to domestic consumption was approximately 22000 MW.

In 2008, the power station installed capacity increased by 400 MW, an increase of 1.4%. Average annual increase in installed capacity over the past 10 years has been 0.5%. As of 31 December 2008, the total installed capacity of the Norwegian power system (hydro, wind and thermal power stations) was 31000 MW, of which 98.0% is hydropower.

The figures for 2006 are based on preliminary data from Statistics Norway and other sources, and must be regarded as approximate values. The table on oil and gas resources is based on information from the Directorate of Petroleum. Statistics Norway is also the source for the tables giving district heating, production of important forms of energy, domestic deliveries of petroleum products, final energy consumption and the energy balance.

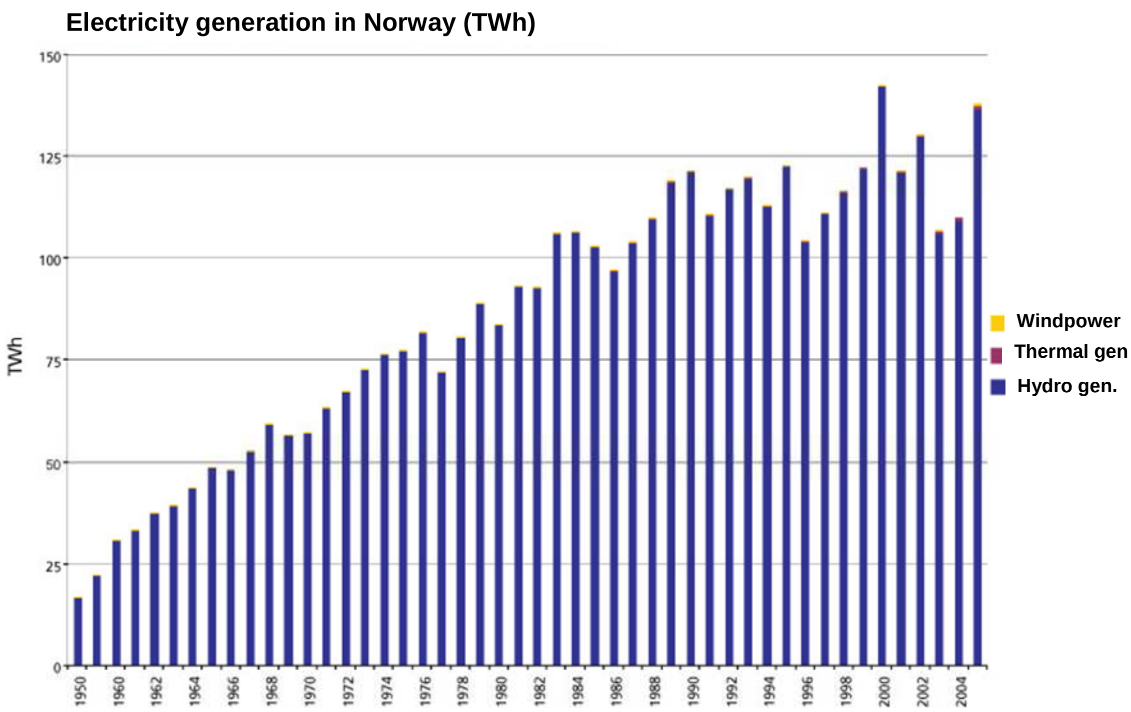

Figure D-27: Generation technology mix in Norway

It can be seen from Figure D-27 that Norway has electricity generation mainly based on hydro. This means that the power system is dependant on the available hydro reservoir level in the relevant season. In the last few years power lines connecting the system to the main grid of other countries is making the power system less dependant on the hydro power reservoirs.

The main renewable technologies in Norway are wind, biofuels and hydro. The growth of electricity generation from renewables since 1950 is presented in Figure D-27.

There is also an intention to include tidal power in the future as this could provide a contribution to the electricity generation mix. So far only a test plant is running.

It would seem that there will be a rapid growth in the number of DGs over the next few years. The obvious reason for this is the great potential for small wind and hydro generating units and the fact that electricity energy prices have been rapidly increasing over the last few years.

Hydroelectric power plants
During the last 5-10 years there is a growing interest from private landowners to build small power plants. This is mainly small hydroelectric power plants (1-10 MVA) connected to the high voltage distribution grid (11 / 22 kV). The number of plants is rapidly increasing and the weak transmission network will have more such power plants connected. Power usually flows from the substation to the consumer in this type of grid. With more DG connected the power flow will change direction most of the time.
Other than the small hydroelectric power plants the most common hydroelectric power plants consist of units of more than 20 MVA each. The biggest unit is about 400 MVA. These generators are without exception connected to the grid at voltages above 66kV.
There is no more potential for new hydro plants so there will be a need for alternatives to hydro power generation in the future. Up to 2008 the energy generation from hydroelectric energy has grown to approximately 5% since 2004.

Wind power
Wind power has become a popular addition to Norwegian power production. The Norwegian coastline is suited for wind power production. From single wind turbines connected to the distribution grid, the tendency now is that “parks” with a large number of wind turbines are built. The power is mostly fed into the transmission grid (>66 kV).
Public opinion is less favourable for wind turbines due to the visionary impact.

So far Norway has 4 big wind farms at a size of 40-150 MW. Smøla Wind farm, on the northwest coast, has an energy capacity of 150 MW. In addition there are 10 smaller farms in operation.

Further status:

- 10 Wind farms from 3 - 250 MW have got a concession from the authorities but are not yet in operation.
- Approximately 50 Wind farms from 1-800 MW apply for a concession.

In 2008 the power generation from wind farms are about 900 GWh as a total.

<u>*Alternative electricity generation*</u>
The climate CO_2 influence from the fossil fuel plants will affect which will be the next energy generating source. This is a political issue in Norway as well as in all EU nations.

So far it seems to be that gas turbine power plants will provide the dominant part of the capacity needed to fill the energy gap over the next few years. Politically there has been a concession restriction connected to CO_2 storage for gas turbine plants. This means that new gas turbine plants must have a solution for CO_2 storage before a permanent concession will be given. Total thermal energy generation was about 1500 GWh in 2008.

D.7.2 Main challenges

The Norwegian distribution grid is mainly not prepared to deal with the increasing amount of DG. The transmission network capacity has to be increased.

The public utility network was originally designed for the distribution of energy. The grid capacity is suitable for the consumption of electricity in dedicated areas. Voltage control is done by means of the automatic control of the tap changer in the next transformer at higher voltage level. Planning of new DG units is normally done without a total view of how the existing grid capacity can cope with the amount of generation from all DGs. This situation is due to a number of reasons. Rural utility network owners have not made it clear what is the momentary capacity limitation and the legislative framework is not clear. The authorities say that when no more network capacity is available the next DG unit must pay for all the required grid capacity. Some areas have come to a situation with very high level of utilisation of the existing capacity. Due to this there are very high energy losses and the voltage control has become a challenge.

More dynamic analysis of the power system has to be done. Voltage control must be modified. In addition to automatic tap changing some units need to be able to take part in voltage control by operation in lagging and leading mode. We need a more dynamic power system to be able to take full advantage of the new production.

In the 11 /22 kV grid there is an additional challenge that will have to be dealt with concerning a new direction for the distribution network quality. This direction says clearly which amount of over- and under-voltage is acceptable compared to nominal value. The DG shall not cause the EPS service voltage to go outside the quality requirements of the distribution network. Also, the quality requirement is clear concerning flicker requirements.

Grid owners have to fulfil the legislative framework connected to the refund of tariff money when delivery to the consumers is out for more than 3 minutes. This means that authorities stimulate the grid owner to have a sufficient grid quality at any time. This thinking is based on the fact: Lack of grid quality means a growing possibility of grid failure. This direction has led to the fact that the distribution network grid owners have become more aware about what is going on and affecting the grid and what has to be done to prevent grid failure.

Protection of DG connected to the transmission network is definitely an important issue. This is due to possible energy flow in two directions, varying infeed from the DG units and dealing with failure in the actual and neighbouring grid connected to the same busbar. Co-ordination between protection and the DG to prevent unnecessary grid failure is an important issue. This is affecting the DG units ride through capability.

The balance between the transmission capacity and the production capacity is another interesting area. From this point of view wind power is a challenge. The greater the amount of generation from wind turbines and the smaller the DG units are compared to the total need, the more complicated the momentary load dispatch control will be. A solution for this challenge has not been found yet.

There is a strong pressure from the public opinion to limit the penetration of wind energy in Norway. The reason for this is mostly connected to the aspects that big windmills will change the view of the costal landscape in a negative way. At the moment we see that a few concentrated wind parks will get a concession to build new installations.

D.7.3 Examples of typical connection arrangements

Requirements to DG connections
Voltage regulation:
The DG facility does not actively regulate the voltage at the Point of
Common Coupling, or PCC.
Synchronization:
The DG facility shall not cause a voltage fluctuation at the PCC greater than
+/-5% of the prevailing voltage level related to the EPS at the PCC.
Inadvertent energizing of the area EPS:
The DG facility shall not energize the Area EPS when it is already de-energized.
Monitoring:
If the DG facility is more than 1000 kVA, the unit must monitor its connection status, real power output, reactive power output, and voltage at the point of DG connection (at the PCC).
Isolation device:
A readily accessible, lockable, visible-break isolation device shall be located between the EPS and DG unit only if required by the EPS operating practices.
Surge withstanding and paralleling device:
The interconnection system shall be able to withstand voltage and current surges in accordance with IEEE Standard.
These are typical requirements for the DGs.

Protection Practices
There are several protection practices that are advised in the IEEE Standard 1547. The three main factors are voltage, frequency, and harmonics.
Wind farms normally are equipped with over voltage, over current and ground fault protection. Outgoing cables from wind farms connected to transmission network have protection for over current, ground fault and directional ground fault.

<u>*Voltage*</u>
The protection functions of the interconnection system shall detect the effective (rms) or fundamental frequency value of each phase-phase voltage. In the case of a transformer connecting the local EPS to the area EPS it is a grounded wye-wye configuration. The phase-neutral voltage shall be detected.
The DG facility shall cease to energize the EPS within a clearing time. This clearing time is the time between the start of the abnormal condition and the DG ceasing to energize the EPS.
For DG less than or equal to 30 kW in peak capacity, the voltage set points and clearing times shall be either fixed or adjustable to co-ordinate with the grid protection plan. For DG greater

than 30 kW, the voltage set points shall always be adjustable to co-ordinate with the grid protection plan.

Frequency

If the frequency falls within the range (48>f <51), the DG shall cease to energize the EPS within a clearing time of 0.2s. As stated above in the voltage protection, the clearing time is the time between the start of the abnormal condition and the DG ceasing to energize the EPS. If the DG is less than or equal to 30 kW in peak capacity, the frequency set points and clearing times shall either be fixed or adjustable. Otherwise, for DG greater than 30 kW, the frequency settings shall be adjustable.

Harmonic Distortion

The maximum harmonic distortion for a DG facility is according to the IEC 61000-3-6 standard.

Islanding

Islanding is typically not allowed for any Distributed Generation. For unintentional islanding, the DG facility that energizes the Area EPS through the Point of Common Coupling, the safety inter connection equipment must be able to detect this island. Rate of change of frequency has become the most common use of protection in this case. Within two seconds, the DG facility must cease to energize the Area EPS.

The Norwegian Transmission Network is composed of 420kV, 300kV, 132kV and 66kV networks. The 22kV and 11kV networks belong to the Distribution Network.

Different voltage levels:

- 420kV, 300kV and 132kV – Extra High Voltage (EHV)
- 66kV – High Voltage (HV)
- 22kV and 11kV – Medium Voltage (MV)

So far the connections of EHV(132kV) and HV(66kV) wind farms are only connected as radial lines.

Settings are intended for a quick disconnection of the generators in HV and MV to prevent islanding operation, so instantaneous trip for relays and transfer trip are specified. Typical setting values are given in Table D-15.

Relay function	Threshold	Time [s]
Undervoltage	V < 85% of Vn V < 50% of Vn	1.5 0.2
Overvoltage	V > 115% of Vn V > 105% of Vn	0.2 1.5
Underfrequency	48 Hz	0.2
Overfrequency	51 Hz	0.2

Vn: rated voltage at connection point of the network

Table D-15: Typical voltage and frequency settings in Norway

Transfer trip from the remote utility breaker is the most used system at the moment. An anti-islanding system could be unnecessary when, if, due to the characteristic of the generator (i.e. asynchronous generator without capacitor banks for reactive compensation, photovoltaic plants with inverters assisted by the network, etc.), there is not a possibility for islanded operation. A line voltage check for autoreclose blocking and synchrocheck can be installed as complementary preventive measures when necessary.

The protection schemes used for a typical connection of DG to the HV network is illustrated in the figures D-28 and D-29.

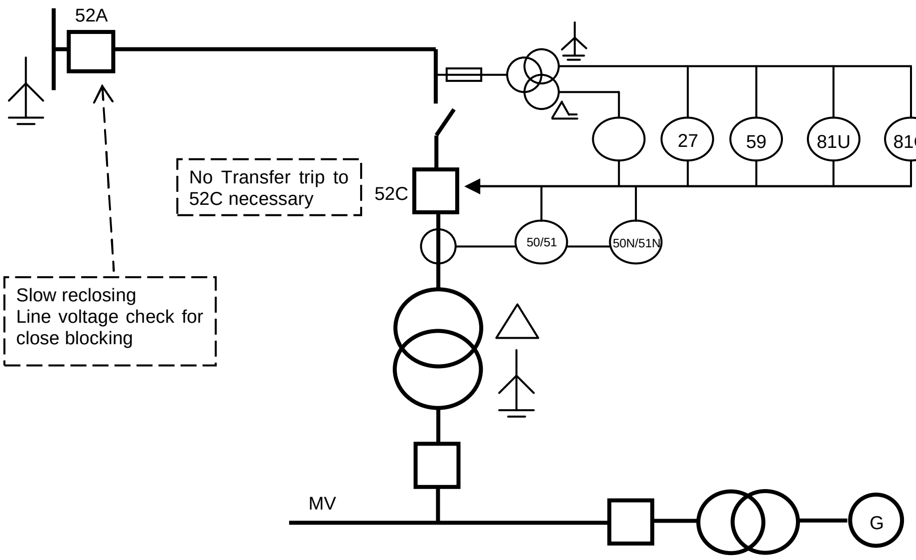

Figure D-28: Connection to a dedicated line

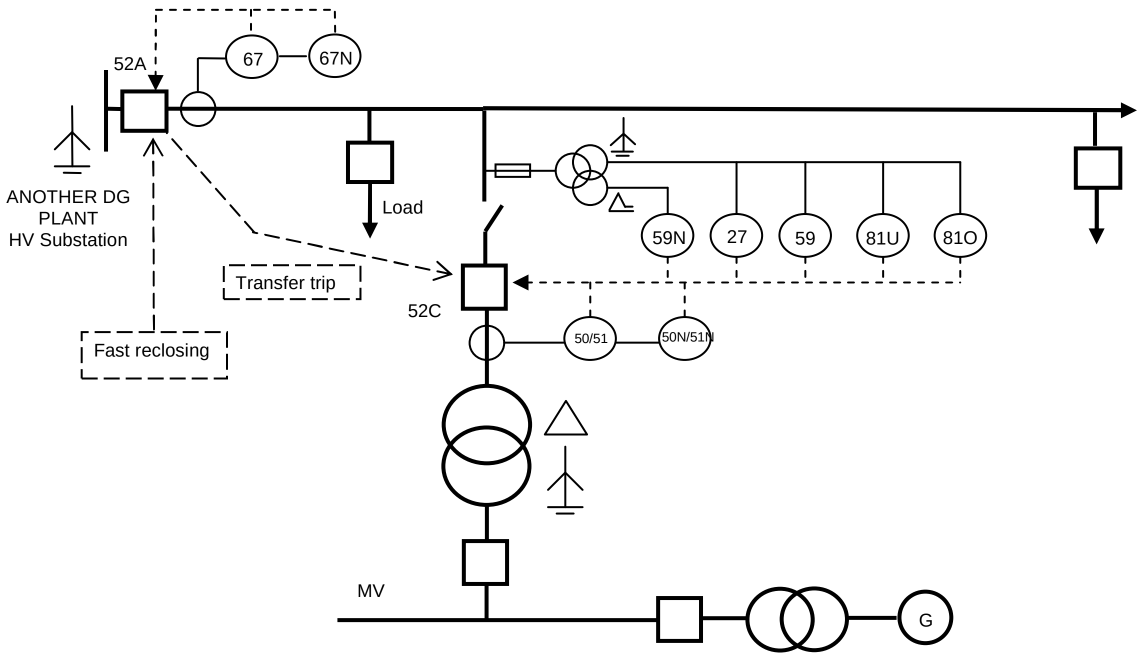

Figure D-29: Connection to a radial non dedicated line.

D.8 Practices with Protection of DG in Portugal

D.8.1 Portuguese national goals for renewable generation and prevailing generation technologies

Independent Power Production in Portugal is called *Special Regime Production* as opposed to the *Ordinary Regime* that includes the greater conventional power plants. In Portugal, the Special Regime Production includes all generation from renewable energy sources (like wind, photovoltaics , small hrydro and others), cogeneration, biomass and solid wastes.
For Special Regime Production there are special technical and economical conditions for grid connections. The great wind potential and the technological development, and some incentives pushed significantly the use of the Special Regime Production in Portugal, which has experienced a rapid growth in the last years.

The Kyoto Protocol and the connected goals established by the European Union in the Directive 2001/77/CE to promote the electricity obtained from renewable energy sources (RES), defining a target for Portugal of 39% of generation from RES in 2010 (nowadays, the new target is 45% in 2012), imposed a big change in the development of the generation system and of the electrical transmission and distribution grids.

The Portuguese power generation system has always had an important amount of RES contribution because of its important large hydro installed capacity. Portugal has approximately 4600 MW of large hydro, capable of supplying 25% of the annual total electric energy demand (48 TWh in 2005) for a current peak load of 8500 MW.

Most of that hydro power was commissioned during the 50's, 60's and 70's. The construction of new large dams has decreased in the last two decades, because of their cost and growing environmental restrictions.

The load which is growing at a steady 4 to 4.5% each year, one of the highest in the European Union, has been controlled by thermal generation construction. Recently, two new natural gas combined cycle power stations (2170 MW) were constructed, adding to the pre-existing fuel (1710 MW – 2 plants) and coal (1780 MW – 2 plants) generation components.

Nowadays, the only effective way to complete successfully the 39% objective by 2010 with the existing technologies is to increase the component of wind power generation in the order of several thousand MW starting only from 120 MW of wind power in operation at the end of 2001.

The national objectives for the expansion of power generation from RES aren`t limited to wind generation but also include some new large hydro stations (800 MW) as well as the increase of installed power in existing plants (410 MW) and the construction of new small hydro, biomass and photovoltaic plants.

However, wind will be, by far, the most important renewable component to increase in the near future, with a present target of about 6000 MW in 2013, probably approaching 4500 MW by 2010. We can say that, in relative terms, taking as reference the forecasted peak demand in the system of 11,000 MW in 2010, Portugal has one of the highest wind targets among the European Union countries. At the end of June 2008 there are 2450 MW in operation and 900 MW in construction. Considering the different wind turbine technologies, taking into account the installed capacity in construction and assignment until end of 2006, Portugal has 4% for DCIG

(Directly Connected Induction Generator), 43% of VSSG (Variable Speed Synchronous Generator) and 53% of DFIG (Double Fed Induction Generators).

The next figures and tables present the electricity generation (Supply) and the installed capacity evolution in Portugal.

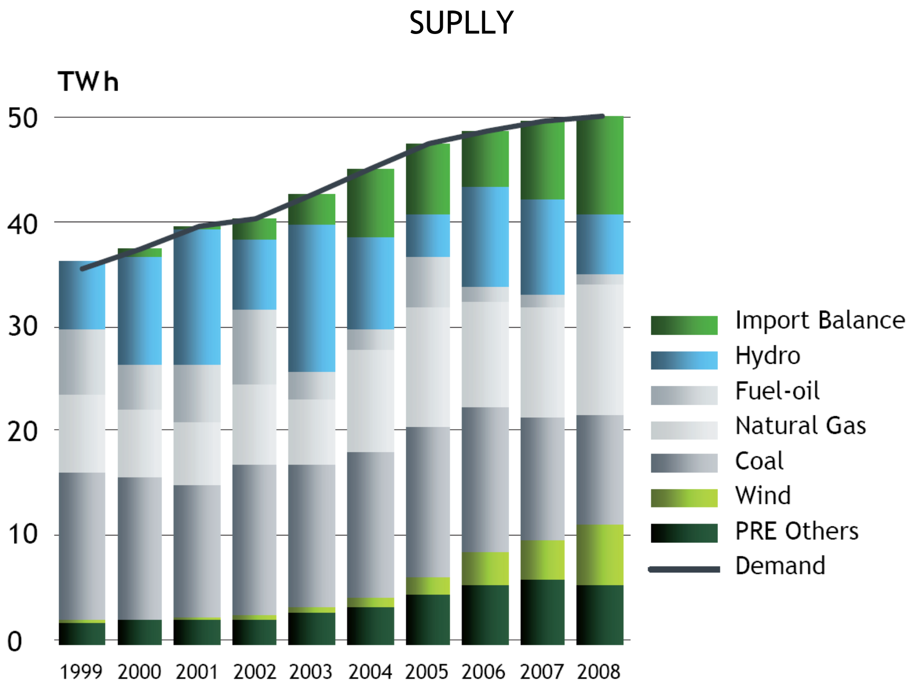

Figure D-30: Generation technology mix in Portugal

POWER GENERATION

Net Demand

GWh	**2008**	**2007**	Variation **[%]**
TOTAL GENERATION	**30 232**	**32 948**	**-8**
HYDRO GENERATION	**6 436**	**9 523**	**-32**
THERMAL GENERATION	**23 797**	**23 425**	**2**
Coal	10 423	11 663	-11
Fuel-oil / Gas-oil	800	1 268	-37
Natural Gas	12 573	10 494	20
SPECIAL STATUS GENERATION	**11 551**	**10 163**	**14**
Hydro	663	694	-4
Thermal	5 160	5 437	-5
Wind	5 694	4 012	42
Photovoltaic	33	20	64
Waves	0	-	-
IMPORT BALANCE	**9 431**	**7 488**	**26**
Import (trade values)	9 478	9 088	4
Export (trade values)	40	1 591	-97
HYDRO PUMPING	639	541	18
TOTAL DEMAND	**50 574**	**50 059**	**1,0**
(corrected by temperature and working days)			**1,1**

Table D-16: Power generation evolution in Portugal (years 2008 and 2007)

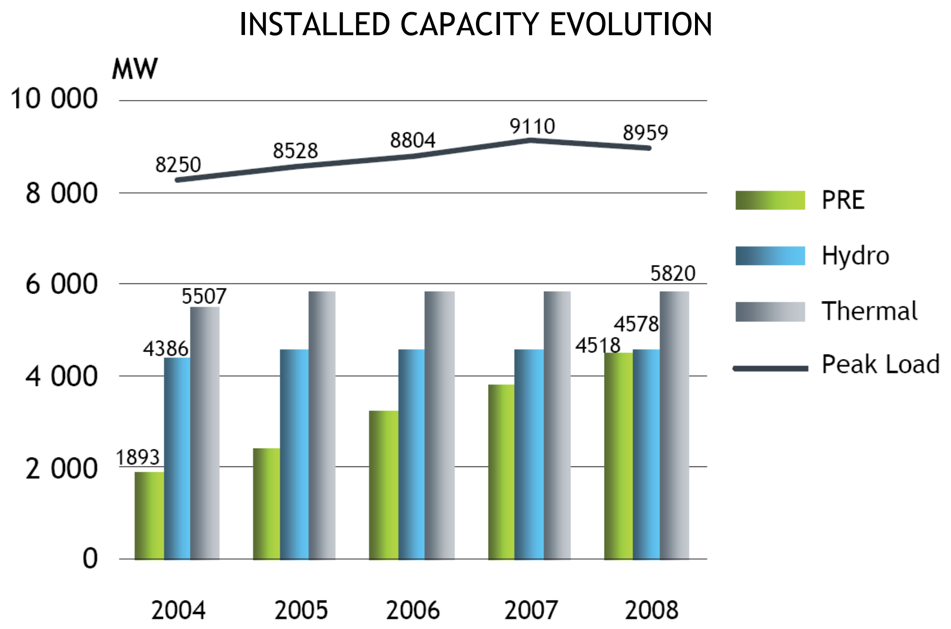

Figure D-31: Installed capacity evolution in Portugal

GENERATING EQUIPMENT

Installed Capacity at End of Year

MW	2008	2007	Variation
INSTALLED CAPACITY	**14 916**	**14 198**	**718**
HYDRO POWER PLANTS	**4 578**	**4 578**	**0**
THERMAL POWER PLANTS	**5 820**	**5 820**	**0**
Coal	1 776	1 776	0
Fuel-oil	1476	1476	0
Fuel-oil / Natural Gas	236	236	0
Gas-oil	165	165	0
Natural Gas	2 166	2 166	0
INSTALLED CAPACITY SPECIAL STATUS PRODUCERS P. R. E. [(1)]	**4 518**	**3 800**	**718**
Thermal	1 463	1 365	98
Hydro	379	374	5
Wind	2 624	2 048	576
Photovoltaic Generators	50	13	37
Wave Energy Producers	2	0	2

[(1)] Connected Power Supply to the Public Grid or Installed Thermal Power in accordance to M. Order 399/2002

Table D-17: Generating equipment (installed capacity) in Portugal (years 2008 and 2007)

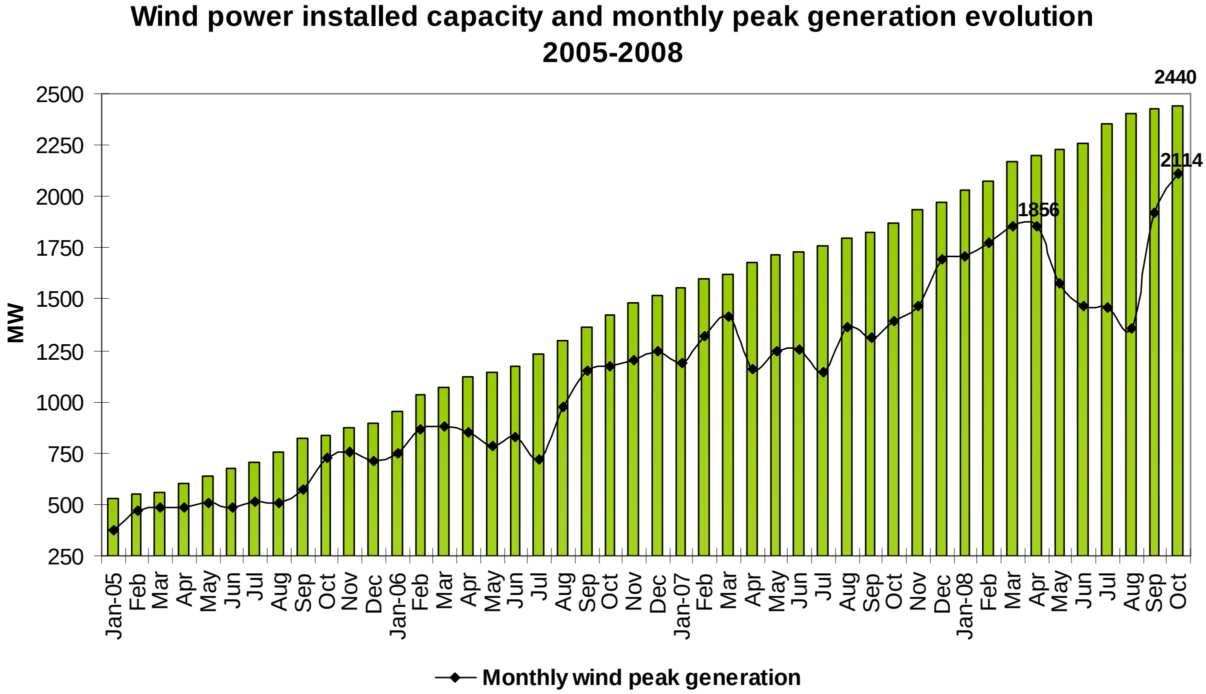

Table D-18: Wind power installed capacity and monthly peak generation evolution in Portugal (years 2005 to 2008)

D.8.2 Main challenges and potential benefits

Portugal is a country clearly importing electrical energy. The development of RES reduces the external dependency degree and contributes actively to the supply security. It also gives other benefits such as saving in CO2 emissions, improved efficiency (losses) due to the distributed characteristic of RES (plants are located in many cases close to the consumption points (for example: cogeneration)) and the possibility of employment creation and rural development.

The integration of a large amount of RES in the Portuguese Grid is an important national challenge. The challenge at a first level is for the Ministry of Economy and Innovation (MEI), and its General Directorate for Energy and Geology (GDEG), entities responsible for the process. The challenge at a more technical level is for the TSO, REN - Rede Eléctrica Nacional SA (REN) and also for the DSO, EDP Distribuição Energia, S.A. (the majority of wind farms will be connected to its distribution grids), because the necessary changes must be dealt with special care in order to take benefit of the advantages of this kind of generation keeping the necessary manageability and network security levels.

D.8.2.1 Legal proceedings for generation connection

Between the years of 1997 and 1998, even before Directive 2001/77/CE, a new liberalised power sector legal framework and some measures to promote power generation from RES led to a significant number of promoters to present applications to connect wind farms to the transmission grid and especially to the distribution grids.

At this point, with the perspective of a fast increase in the number of wind farm projects, the TSO had to review and change not only the transmission grid development plan but also the transmission grid planning process too.

The previous paradigm of transmission grid planning was based on a few number of well known large new power stations. This was no longer applicable because it was not possible any more to give individual connection solutions for each project coherent with all the others and assure the future security and adequate operation of the transmission grid.

The institutional arrangement and administrative rules to manage and process the application for transmission and distribution grids connection of new power projects were reviewed and redefined in 2001 in the Decree-Law 312/2001. The most important guidelines of the framework set in this document relevant for the purpose of this report are as follows:

- TSO defines (and makes public) future capacities at the different areas/substations in the transmission grid according to their development plans. This grid investment plan will have to respect and be coherent with the national global RES objectives.
- During the first half of January, May or September, promoters present their applications for new generation projects to GDEG.
- GDEG sends the applications to the TSO (if above 50 MVA) and the DSO (if below 50 MVA) who will give "pre-viability information" (PVI). At this point, each application is seen independently from the other applications received but taking in account the capacity already reserved previously. It's important to tell large power stations (conventional power station), the TSO usually studies the possibility of specific non planned grid reinforcements to create acceptable connection conditions to the transmission grid.
- GDEG sends the PVIs, issued by the TSO and DSO, to the promoters. If the promoters want to keep on, they will contact GDEG again, asking for capacity reserve. At this level, promoters need to present the technical projects and the results of the first environmental viability studies and point out other administrative procedures.
- GDEG will then attribute reserve capacity for the project. If there is an excess of demand capacity for a certain grid area, GDEG will classify and organize the projects according to the specific criteria defined in Decree-Law 312/2001 and/or attribute capacity on a proportional ("prorata") basis to respect maximum grid capacities. From 2005 on, MEI and GDEG can also promote auctions of grid capacity.
- Once the capacity is reserved, promoters have 24 months (36 in the case of small hydro) for their plants to become operational. If not, reserve capacity may be annulled by GDEG.

Most of the wind generation reserve capacity (around 3500 MVA, so far) has been attributed on a proportional basis, because of the large excess of demand for new projects in all the transmission grid areas with significant wind resources. In the second half of 2005, MEI/GDEG made an auction of two blocks of 1000 and 800 MW of wind power.

D.8.2.2 New technical requirements for wind power generation

The previous technical requirements for wind generation in Portugal were established in the past, considering a very small share of wind power generation penetration. Because of that, in the light of the results of the stability studies, a review is required to adapt them to the future situation of a high penetration of wind power. A proposal, that is under debate by the MEI, is presented in Chapter 2.

Taking into account the importance of having a high share of wind turbine generators complying with the new requirements, both proposed standards for wind turbine generators connected to transmission and distribution grids establish obligations for the new wind farms and for part of the ones already in operation. However, compensatory economic mechanisms are considered for existing wind farms, such as a small increase in installed capacity. In case these technical modifications, necessary for existing wind farms to comply with the new requirements, prove not to be technically or economically viable, the GDEG may exempt them from this obligation.

D.8.3 Typical interconnection schemes between DG and Network in Portugal

The Portuguese Transmission Network is composed of 400kV, 220kV, 150kV and the first busbar of 60kV networks. The 60kV, 30kV and 15kV networks belong to the Distribution Network.

In Portugal the different voltage levels are considered and presented below:

- 400kV, 220kV and 150kV – Extra High Voltage (EHV)
- 60kV – High Voltage (HV)
- 30kV and 15kV – Medium Voltage (MV)

D.8.3.1 Typical interconnection schemes between DG and Transmission Network

Scheme 1 – Interconnection through a dedicated EHV line in the Transmission Network

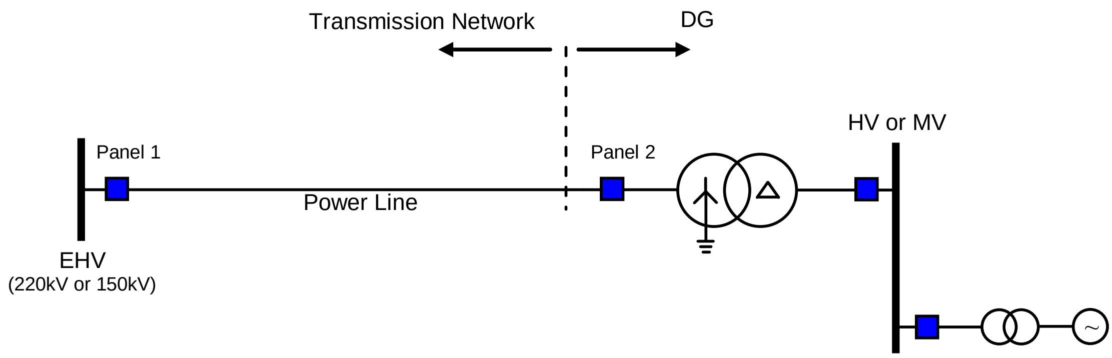

Figure D-32: Interconnection through a dedicated EHV line in the Transmission Network (typical scheme)

NOTE: This scheme is the most used in the 220kV and 150kV voltage levels of the Portuguese Transmission Network.

<u>Line Protection System:</u>

Panel 1

Main Protections System 1

- Line differential protection (dual redundant communication channels)
- Step distance protection (instantaneous zone 1 is blocked if Line differential protection is operational)
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (PUTT) which is blocked if Line differential protection is operational
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Single and Three-pole(1) autorecloser

Main Protections System 2

- Step distance protection
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (POTT)

- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Single and Three-pole(1) autorecloser

(1) with dead-line supervision

Breaker failure protection (which may be integrated in a decentralized busbar protection). On a breaker-and-a-half substation topology, Breaker failure protection sends a remote unconditional trip to the DG breaker.

Panel 2

Main Protections System 1

- Line differential protection (dual redundant communication channels)
- Step distance protection (instantaneous zone 1 is blocked if Line differential protection is operational)
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (PUTT) which is blocked if Line differential protection is operational
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Single and Three-pole(2) autorecloser

Main Protections System 2

- Step distance protection
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (POTT)
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Weak-end Infeed (trip and echo)
- Emergency phase time delayed overcurrent
- Single and Three-pole(2) autorecloser

(2) with live-line and dead-bus or synchrocheck (depending on DG own decision) supervision

Breaker failure protection (busbar protection is optional).

<u>DG/Network Interconnection protections (associated to **Panel 2**):</u>

- Over and Undervoltage protection (September 2007, the General Directorate for Energy and Geology (GDEG) published the standards document which allocates these protections to Panel 2 and specifies that the Over and Undervoltage protection of the generators must be regulated for values according to Fault Ride through Capability of the generators)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protections of generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for the Under/Over frequency protection is between 0 to 0.15sec.)
- Overcurrent protection
- Zero-sequence Overvoltage protection (September 2007, the GDEG published the standards document which allocates this protection to Panel 2)

Scheme 2 – Tap connection to two ends of the EHV line in the Transmission Network

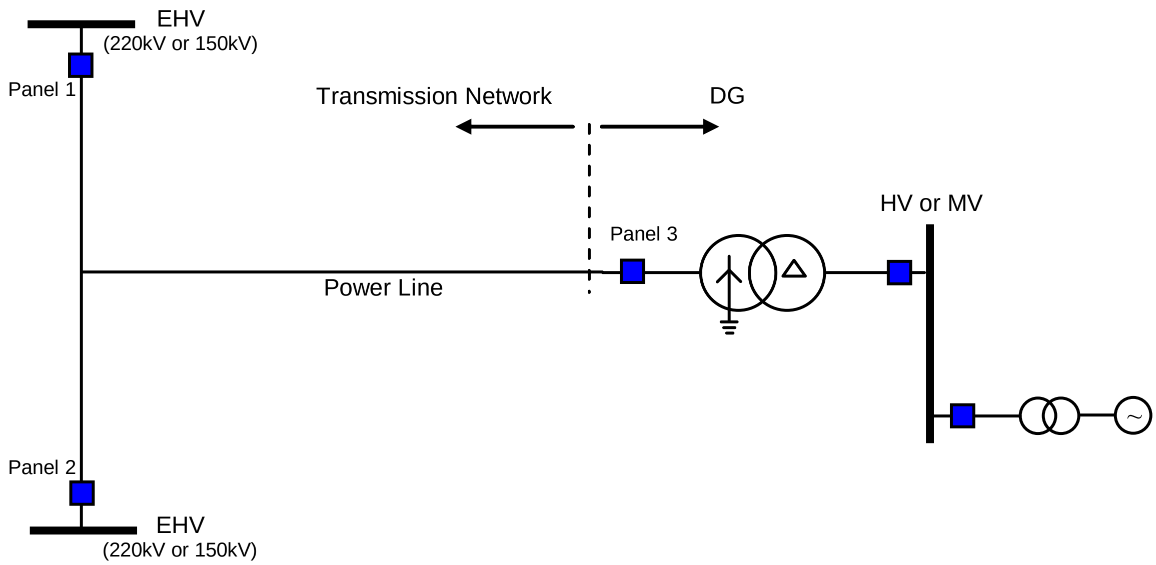

Figure D-33: Tap connection to two ends of the EHV line in the Transmission Network (non typical scheme)

NOTE: This scheme is used in the Portuguese Transmission Network (220kV and 150kV) one or two times.

Line Protection System:

Panels 1 and 2

Main Protections System 1

- Line differential protection (ring topology communication channels)
- Step distance protection (instantaneous zone 1 is blocked if Line differential protection is operational)
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (PUTT) which is blocked if Line differential protection is operational
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Single and Three-pole(1) autorecloser

Main Protections System 2

- Step distance protection
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (POTT)
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Single and Three-pole(1) autorecloser

(1) with dead-line supervision

Breaker failure protection (which may be integrated in a decentralized busbar protection). On a breaker-and-a-half substation topology, Breaker failure protection sends a remote unconditional trip to DG breaker.

Panel 3

Main Protections System 1

- Line differential protection (ring topology communication channels)
- Step distance protection (instantaneous zone 1 is blocked if Line differential protection is operational)
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (PUTT) which is blocked if Line differential protection is operational
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Single and Three-pole(2) autorecloser

Main Protections System 2

- Step distance protection
- Distance protection trip Power Swing Blocking
- Distance protection with teleprotection aided scheme (POTT)
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Weak-end Infeed (trip and echo)
- Emergency phase time delayed overcurrent
- Single and Three-pole(2) autorecloser

(2) with live-line and dead-bus or synchrocheck (depending on DG own decision) supervision

Breaker failure protection (busbar protection is optional).

<u>DG/Network Interconnection protections (associated to **Panel 3**):</u>

- Over and Undervoltage protections (September 2007, the General Directorate for Energy and Geology (GDEG) published the standards document which allocates these protections to Panel 2 and specifies that the Over and Undervoltage protection of the generators must be regulated for values according to the Fault Ride through Capability of generators)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protection of the generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for Under/Over frequency protections is between 0 to 0.15sec.)
- Overcurrent protection
- Zero-sequence Overvoltage protection (September 2007, the GDEG published the standards document which allocates this protection to Panel 2)

Scheme 3 – Interconnection through a dedicated HV line in the Transmission Network

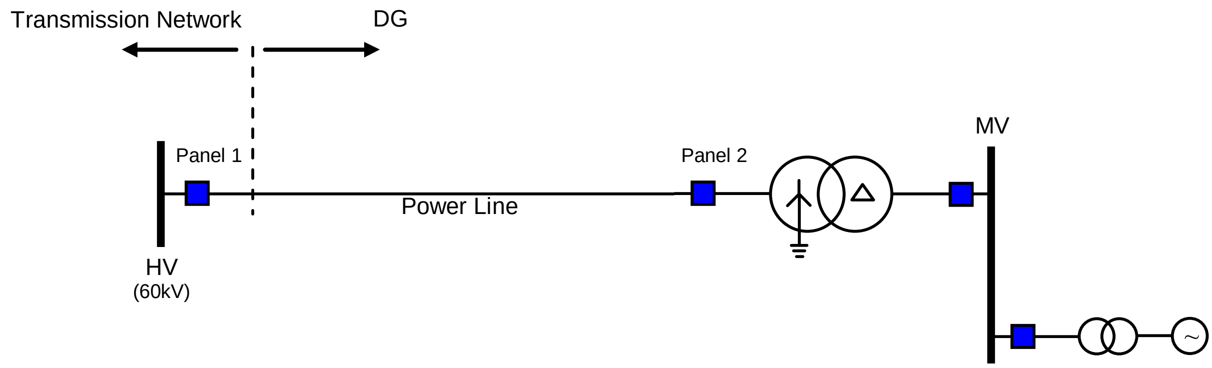

Figure D-34: Connection to dedicated HV line in Transmission Network (typical scheme)

NOTE: This scheme is the most used in the 60kV voltage level of the Portuguese Transmission Network.

Line Protection System:

Panel 1

Main Protections System 1

- Step distance protection
- Distance protection trip Power Swing Blocking
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Three-pole autorecloser (with dead-line supervision)

Main Protections System 2

- Step distance protection
- Distance protection trip Power Swing Blocking
- Zero-sequence directional time overcurrent (Directional ground-fault protection)
- Emergency phase time delayed overcurrent
- Three-pole autorecloser (with dead-line supervision)

Breaker failure protection

DG/Network Interconnection protections (associated to **Panel 2**):

- Over and Undervoltage protections (September 2007, the General Directorate for Energy and Geology (GDEG) published the standards document which allocates these protections to Panel 2 and specifies that the Over and Undervoltage protection of the generators must be regulated for values according to the Fault Ride through Capability of generators)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protection of the generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for Under/Over frequency protections is between 0 to 0.15sec.)
- Overcurrent protection
- Zero-sequence Overvoltage protection (September 2007, the GDEG published the standards document which allocates this protection to Panel 2)
- Zero-sequence Overcurrent protection (ground-fault protection) (recently, 3rd of September 2007, the GDEG published the standards document which allocates this protection to Panel 2)

D.8.3.2 Typical interconnection schemes between DG and Distribution Network

Scheme 4 – Interconnection through a dedicated HV line in Distribution Network

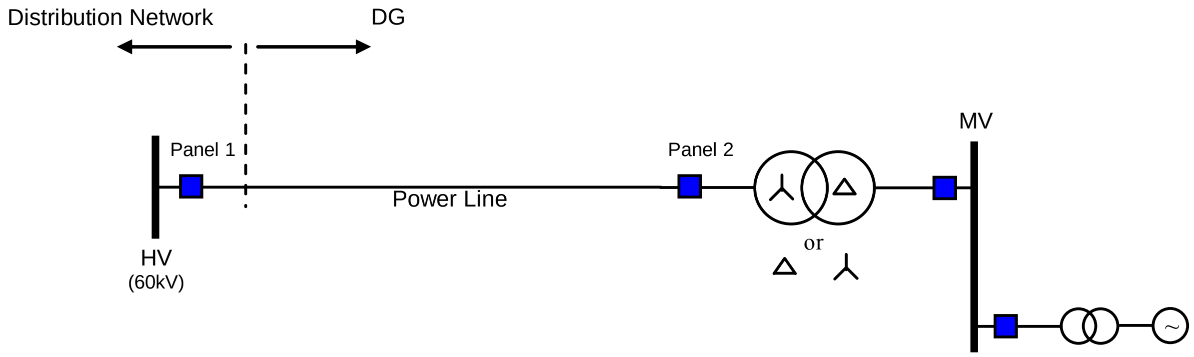

Figure D-35: Connection to dedicated HV line in Distribution Network (typical scheme)

NOTE: This scheme is the most used in the 60kV voltage level of Portuguese Distribution Network.

Line Protection System:

Panel 1

- Distance protection
- Overcurrent protection
- Directional ground-fault protection
- Three-pole autorecloser

DG/Network Interconnection protections (associated to **Panel 2**):

- Over and Undervoltage protections (September 2007, the GDEG published the standards document which specifies that these protections on Panel 2 must be regulated to 1.15Un-1sec. and 0.85Un-1sec., respectively)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protection of the generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for Under/Over frequency protections is between 0 to 0.15sec.)
- Overcurrent protection
- Zero-sequence Overvoltage protection
- Zero-sequence Overcurrent protection (ground-fault protection)

Scheme 5 – Interconnection through a dedicated HV substation in the Distribution Network

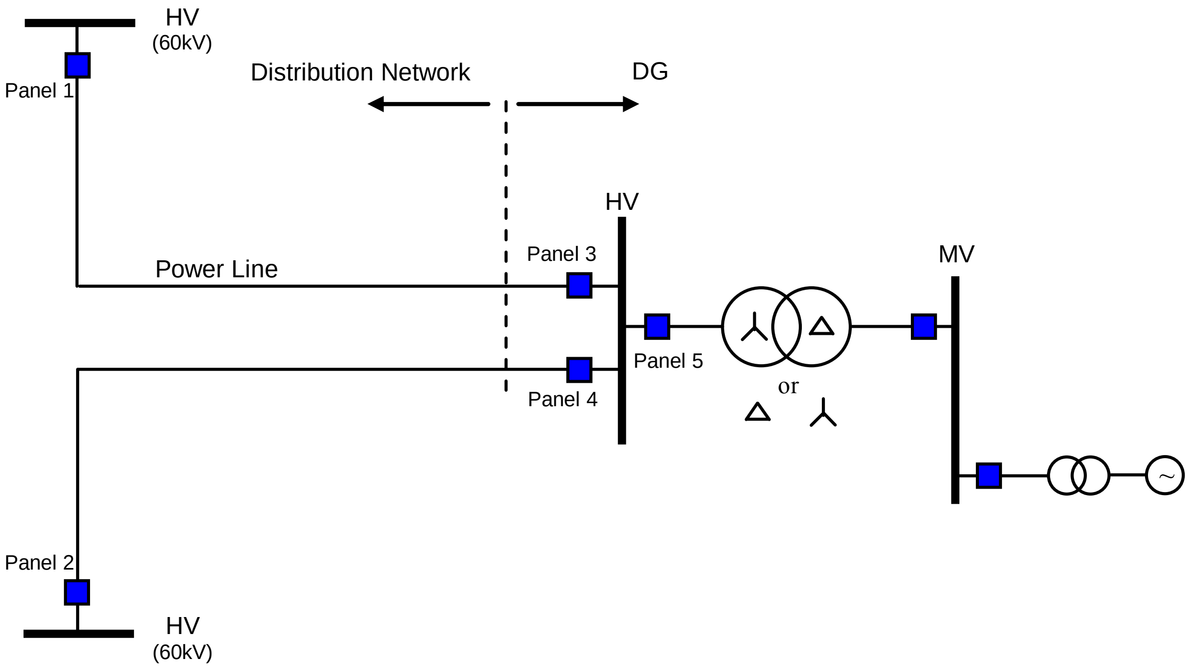

Figure D-36: Connection to a dedicated HV substation in the Distribution Network

Line Protection System:

Panels 1, 2, 3 and 4

- Distance protection
- Overcurrent protection
- Directional ground-fault protection
- Three-pole autorecloser

DG/Network Interconnection protections (associated to **Panel 5**):

- Over and Undervoltage protections (September 2007, the GDEG published the standards document which specifies that these protections on Panel 2 must be regulated to 1.15Un-1sec. and 0.85Un-1sec., respectively)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protection of the generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for Under/Over frequency protections is between 0 to 0.15sec.)
- Overcurrent protection
- Zero-sequence Overvoltage protection
- Zero-sequence Overcurrent protection (ground-fault protection)

Scheme 6 – Interconnection through a radial non dedicated HV line in the Distribution Network

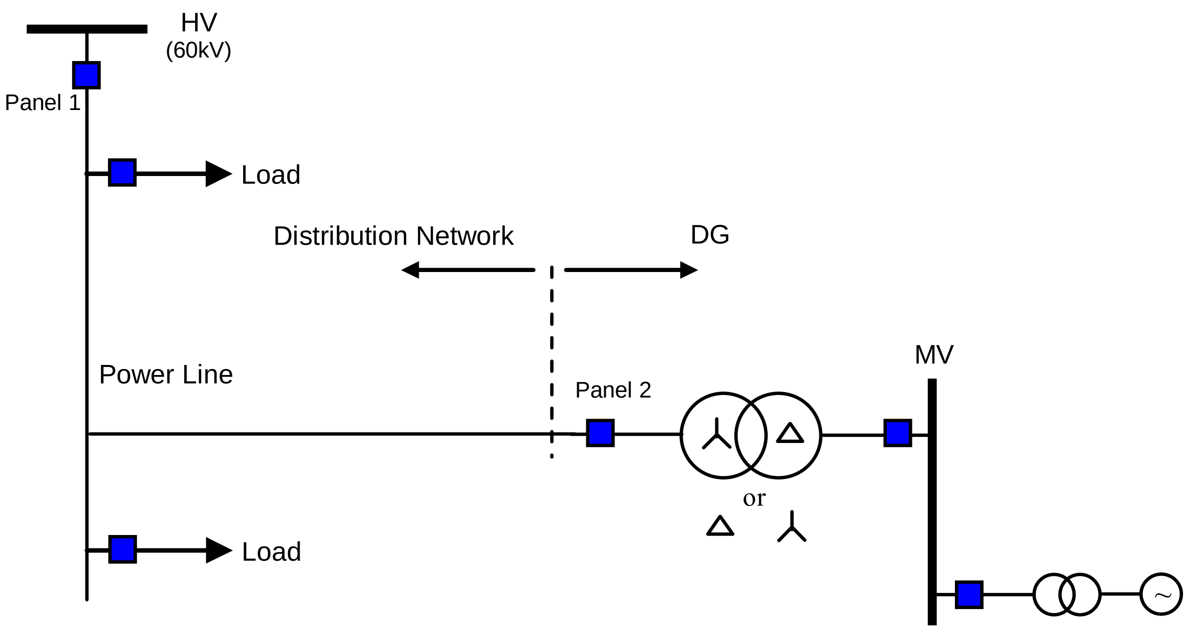

Figure D-37: Connection to a radial non dedicated HV line in the Distribution Network

Line Protection System:

Panel 1

- Distance protection
- Overcurrent protection
- Directional ground-fault protection
- Three-pole autorecloser

DG/Network Interconnection protections (associated to **Panel 2**):

- Over and Undervoltage protections (September 2007, the GDEG published the standards document which specifies that these protections on Panel 2 must be regulated to 1.15Un-1sec. and 0.85Un-1sec., respectively)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protection of the generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for Under/Over frequency protections is between 0 to 0.15sec)
- Overcurrent protection
- Zero-sequence Overvoltage protection
- Zero-sequence Overcurrent protection (ground-fault protection)

Scheme 7 – Interconnection through a dedicated MV line in the Distribution Network

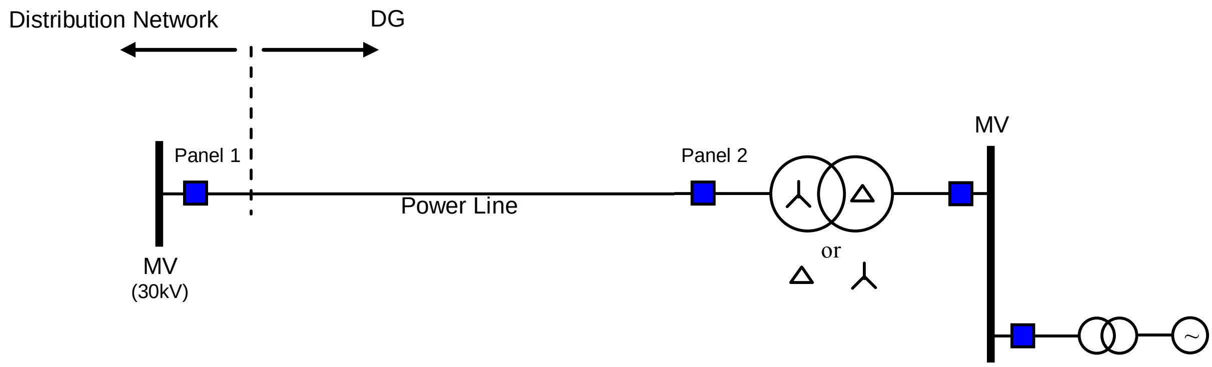

Figure D-38: Connection to a dedicated MV line in the Distribution Network (typical scheme)

NOTE: This scheme is the most used in the 30kV voltage level of the Portuguese Distribution Network.

Line Protection System:

Panel 1

- Overcurrent protection
- Directional ground-fault protection
- Zero-sequence Overcurrent protection (sensitive ground-fault protection) (dedicated to very resistive fault detection)

DG/Network Interconnection protections (associated to **Panel 2**):

- Over and Undervoltage protections (September 2007, the GDEG published the standards document which specifies that these protections on Panel 2 must be regulated to 1.15Un-1sec. and 0.85Un-1sec., respectively)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protection of the generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for Under/Over frequency protections is between 0 to 0.15sec.)
- Overcurrent protection
- Zero-sequence Overvoltage protection
- Zero-sequence Overcurrent protection (ground-fault protection)

Scheme 8 – Interconnection through a radial non dedicated MV line in the Distribution Network

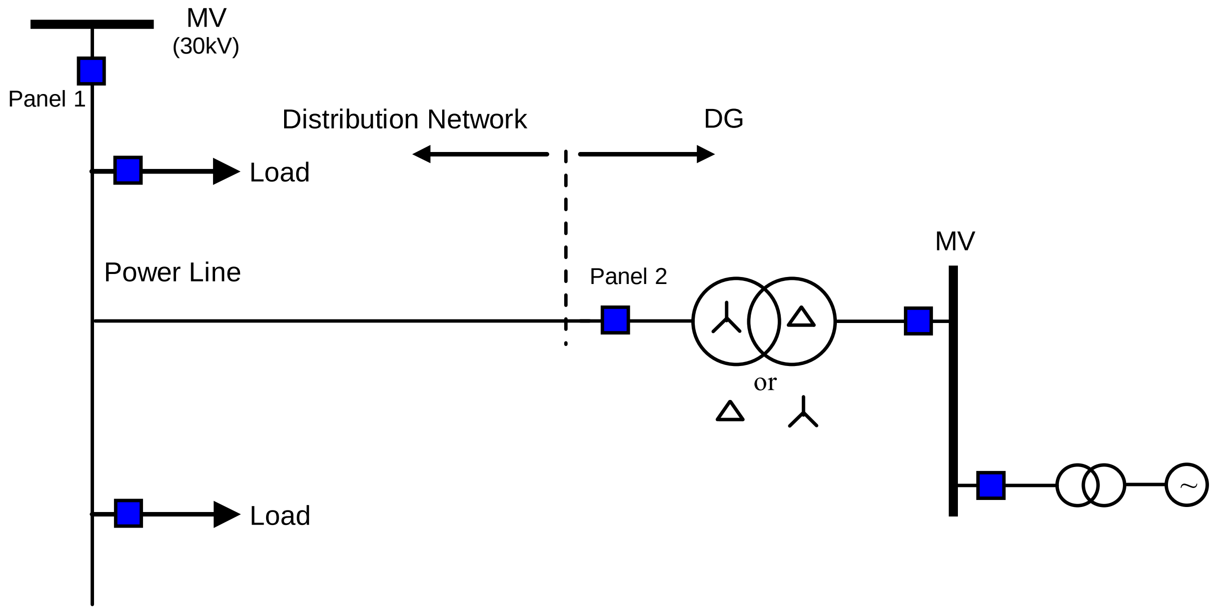

Figure D-39: Connection to a radial non dedicated MV line in the Distribution Network

<u>Line Protection System:</u>

Panel 1

- Overcurrent protection
- Directional ground-fault protection
- Zero-sequence Overcurrent protection (sensitive ground-fault protection) (dedicated to very resistive fault detection)

<u>DG/Network Interconnection protections (associated to **Panel 2**):</u>

- Over and Undervoltage protections (September 2007, the GDEG published the standards document which specifies that these protections on Panel 2 must be regulated to 1.15Un-1sec. and 0.85Un-1sec., respectively)
- Over and Under frequency protections (September 2007, the GDEG published the standards document which allocates these protections to Panel 2 and specifies that the Over and Under frequency protection of the generators must be regulated to 51.5Hz and 47.5Hz, respectively. Typically, the time delay for Under/Over frequency protections is between 0 to 0.15sec.)
- Overcurrent protection
- Zero-sequence Overvoltage protection
- Zero-sequence Overcurrent protection (ground-fault protection)

D.9 Practices with Protection of DG in Spain

D.9.1 Prevailing generation technologies

DGs are included in Spain under the so called *Special Regime*, as opposed to the *Ordinary Regime* that includes the greater conventional power plants. According to the current Spanish regulation, the Special Regime includes generators smaller than 50 MW, coming from highly efficient cogeneration, renewables, biomass and solid waste. Facilities included in the Special Regime have special conditions both technical and economical for grid connections. The incentives, together with the technological development, have pushed significantly the use of DG in Spain, which has experienced a rapid growth in the last years.

All of them are subsidized, and, in particular, renewable energy sources (RES) are subsidized in order to achieve in 2010 a goal of a 30.9 % of the whole generation and a 12.5 % of the whole amount of primary energy consumed in the country. The Ministry of Economy has set goals for the different kinds of generation for the coming years. These objectives, together with the present figures of the different sources of generation are given in Table D-19.

			2004		**Forecast for 2010**	
			MW	**GWh**	**MW**	**GWh**
Ordinary Regime		**Thermal (nuclear, CCGTs, fuel, coal)**[12]	34630	176635	47281	180604
Special Regime (DG)	**Renewables**	**Hydro >50 MW**	13521	25104	13521	25014
		10-50 MW	2897	5794	3257	6480
		< 10 MW	1749	5421	2199	6692
		Biomass	344	2193	2039	14015
		Solid wastes	189	1223	189	1223
		Wind	8155	19571	20155	45511
		Solar photovoltaic	37	56	400	609
		Thermoelectric	-	-	500	1289
		Biogas	141	825	235	1417
		CHP plants	5815	14525	9100	19959
			67478	251347	98876	302813

Table D-19. Source of energy produced in Spain with installed power and production [116]

Special mention is deserved for the high development of wind energy due to enterprising initiatives and a favourable environment. In the last three years, the installed power has been increased at a rate of 1600 MW a year. Some factors that have contributed to this are a high wind potential in the country to be exploited, regulations in favour of increasing the penetration of wind power, a mature and involved industrial sector, available technology and domestic manufacturers, technological improvements in generator behaviour, reduction of unitary costs, etc., so a growing penetration is expected until 2020. The goal of the government is to achieve an installed wind power in 2010 of 20,155 MW (recently changed from a previous plan of 13,000 MW). Regarding the technologies of wind turbines, ‘squirrel cage’ asynchronous generators (26%) and doubly fed induction generators (71.4%) are the most used in Spain. Significant growth in solar energy is not expected unless deep changes in technology and reduction of unitary costs happen.

[12] Thermal power will be increased basically with new CCGTs power plants

D.9.2 Main challenges and potential benefits

Spain, due to its peninsular characteristic, is a country which is clearly an importer of energy resources. The development in RES reduces the external dependency degree, contributing actively to the supply security. Some other benefits are:

- Savings in CO_2 emissions (it is estimated a saving of 27.3 million tons of CO_2 per year)
- Improved efficiency (losses) due to the distributed characteristic of RES, since plants are located in many cases close to the consumption points.
- Employment creation, rural development and regional cohesion.

At the same time, the great amount of power and energy from RES in Spain, especially the high rate of increase of wind energy, is a challenge for Regulators. This must be handled with special care in order to take benefit of the advantages of this kind of generation keeping the necessary manageability and network security levels.

The present legal framework offers favourable conditions to increase the penetration of RES. RD 661/2007 establishes subsidized tariffs and in the case of wind power plants, economic incentives for those that contribute to voltage control and are capable of fault ride through. However, producers have to fulfil several technical requirements, especially wind plants connected to transmission network, according to recently approved procedures.

At present, RES are facing some barriers, so measures must be undertaken in the next few years for their development and integration in the power system:

- A new regulation about connection and access requirements to the network and operating conditions of RES is necessary to be developed, since the current one [117] does not respond to the present and future needs.
- RES must be integrated as far as possible into the programming and operation of the Ordinary Regime with a greater participation in the solutions for technical restrictions and ancillary services. According to [118], installations with a power above 10 MVA are required to be associated to delegated control centres, which are supervised by a unique control dispatch (CECOEL). Moreover, they have to submit generation schedules based on the short term forecast and partially assume the deviation costs. In the case of wind power plants, a sufficiently reliable prediction system of production for correcting short term deviations and techniques for optimizing available generation reserves are required. In the future, new control technologies, such as pitch control and development of new power management tools will allow a more flexible operation of wind plants and a greater integration into the market mechanisms of the ordinary regime.
- The immediate disconnection of wind plants for faults in the network due to technical limitations of equipment, involves a risk for the network stability in high penetration scenarios. In [119] fault ride through capabilities are required for new generators as well as active and reactive power consumption is limited during the disturbance. Moreover, incentives are established to adapt existent installations. Therefore, it is important to the development of this technology to fulfil these requirements with the objective of at least 75% of wind generation being adapted to these requirements. Another issue to be taken into account is the reduction of short circuit current in the system because of the greater contribution of wind plants and their system recovery capabilities.

- 220 kV and distribution networks have to be reinforced to take up new generation and rapidly growing electricity demand.
- Promoters, on their side, want from the Administration a stable regulatory framework that gives them more guarantees when financing their projects, more agile administrative processes and incentives for investigation and development of new generations technologies (i.e. biomass).
- Regarding solar energy, some challenges and opportunities for its future development are: to approach the response to requirements established in [119], to take advantage of the control capability of the inverters for voltage control, new support capabilities for service restoration, etc. An increase of the offer and reliability of silicon cells as well as lower prices are essential for their development.

Technological improvements and innovation are necessary to achieve the goals. Diverse innovation projects are currently looking at the operation of DG networks, either in isolated operation or integrated with utility networks, power management applications, market accessibility, etc.

D.9.3 Examples of typical connection arrangements in Spain

The Spanish Transmission Network is composed of 400 kV and 220 kV. 132 kV, 66 kV, 45 kV, 30 kV, 20 kV, 13.8 kV and 11 kV networks belong to the Distribution Network.

Regarding the interconnection protection, settings for under/over frequency, under/over voltage and zero sequence voltage relay were specified by an old law [117] for different types of plants up to 10,000 kVA connected to radial distribution networks. For meshed networks, the necessary protection solutions must be studied case by case in order to get the correct co-ordination with the utility protections.

These settings were intended for a quick disconnection of the small generators in MV to prevent islanding operation, so an instantaneous trip for relays and transfer trip are specified. Such a demanding condition implies a lack of selectivity for faults that are located in adjacent lines of the distribution network, so in practice utilities are delaying the relay operation (i.e. 0.6 sec or more) for a better contribution to the system stability. Furthermore, for wind turbines with a fault ride through capability, the undervoltage relay must be delayed by more than one second [119]. Also, new settings for underfrequency relays have been specified by a recent law (RD 661/2007) for co-ordination with load-shedding protection. Typical setting values are given in Table D-20.

Regarding anti-island protection, transfer trip from the remote utility breaker is the most used system at the moment although dedicated anti-islanding relays could be an alternative solution in the future. Anti-island protection could be unnecessary when, due to the characteristics of the generator (i.e. asynchronous generator without capacitor banks for reactive compensation, photovoltaic plants with inverters assisted by the network, etc.), there is not a possibility for islanded operation. This condition must be demonstrated by the producer. Another admissable solution is delaying the reclosing time of the utility breaker in case of small plants (small power compared to the minimum load of the line) when there is the certainty the generators will disconnect, generally by their frequency relay, before the utility breaker recloses. A line voltage check for reclose blocking and synchrocheck can be installed as complementary preventive measures when necessary.

Relay function	Threshold	Time
Undervoltage	80% Un	0.6 sec (1) 1.2 sec (2)
Overvoltage	115% Un	0.2 sec
Zero sequence voltage	35% Vn	0.6 sec (1) 1.2 sec (2)
Underfrequency	48 Hz	3 sec (3)
Overfrequency	51 Hz	0.2 sec

Un: rated phase-phase voltage at connection point of the network
Vn: rated phase-neutral voltage at connection point of the network
(1) Default setting
(2) Only when fault ride through is required
(3) Co-ordination with load-shedding protection

Table D-20: Typical voltage and frequency settings in Spain (Iberdrola)

Protection schemes used in Iberdrola for the most typical connections of DG to MV and HV networks are illustrated in the following figures:

Figures D-40 and D-41: connection to a dedicated line
Figure D-42: connection to a radial non dedicated line
Figure D-43: tapped connection to a two ended line
Figure D-44: connection to a two line substation
Figure D-45: connection to a dedicated transmission substation

The following considerations must be taken into account:

- For connection to a dedicated line (Figures D-40 and D-41), since there are no other loads fed by the line, no fast reclosing or reclosing at all is needed. In 66 kV networks or below, transfer trip from the utility breaker is not necessary and line voltage check for close blocking of the utility breaker is normally installed for prevention. For line protection, directional overcurrent relays are installed at the utility end. In 132 kV networks and above (Figure D-41), the connection of the transformer is normally HV grounded star - MV delta and distance relays with a teleprotection aided scheme (PUTT or POTT) and a ground directional overcurrent relay are installed in both ends of the overhead lines instead of 59N and 27 relays because a faster fault clearance is required in this voltage level and also for better co-ordination with remote line protection. An undervoltage relay is used in this case as a back up protection. For underground cables, line differential protection is added. A redundant protection system (additional distance or line differential protection) could be required to protect the line depending on the critical clearance time, according to criteria defined in [120]. Teleprotection equipment is used also for transfer trip although anti-island protection is not necessary in this case.
- For connection to a radial non dedicated line (Figure D-42), transfer trip is generally necessary to prevent an islanded operation with a portion of the network. This scheme is more common in 66 kV networks and below.

- For a tap connection to a two-ended line (Figure D-43), the condition for the transfer trip is the opening of both utility breakers. Although this scheme is not typical for 132 kV networks and above, redundant protection system could be required as mentioned above at this voltage level.
- For a direct connection to a two line substation (Figure D-44), typical for 66 an 132 kV voltage levels, with or without utility transformers connected to the substation, a transfer trip logic must be implemented so that the interconnection breaker trips for whatever breaker state condition that implies an electrical separation from the network. Line protection schemes must fulfil the general protection criteria as mentioned above. Also, synchrocheck in the breakers of both line ends may be installed to prevent an asynchronous connection.
- Figure D-45 shows a typical example of connection of several wind farms on the transmission network. In this case, the interconnection breaker is on the low voltage side of the 400/220 kV transformer.
- Differential protection for the DG transformer is generally installed in all cases above a specific power (i.e. 5 MVA).

Examples of connection schemes:

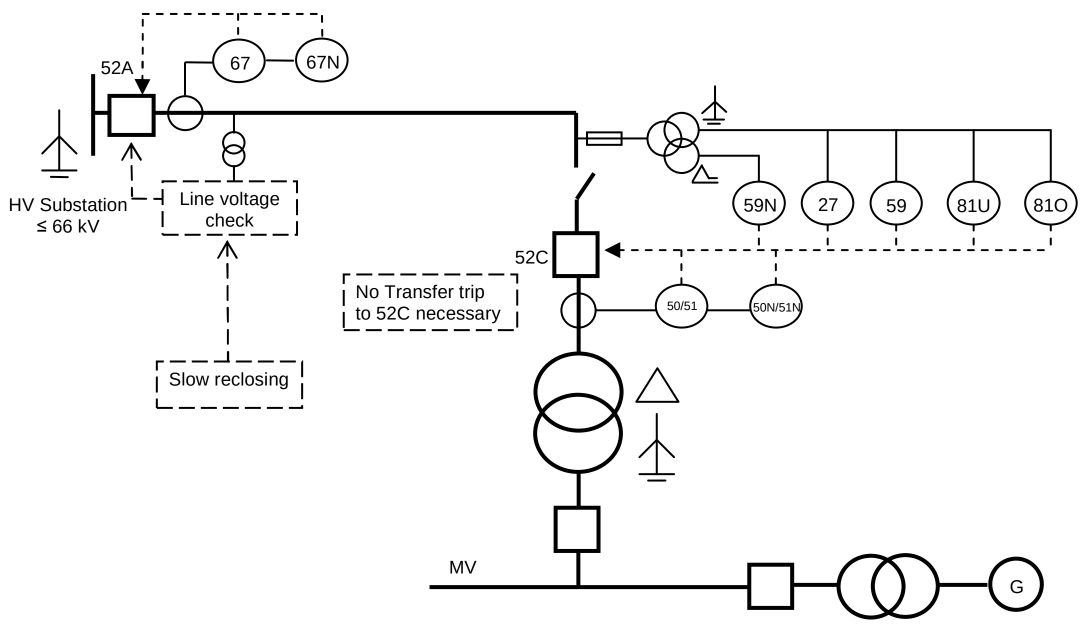

Figure D-40: Connection to a dedicated line (1)

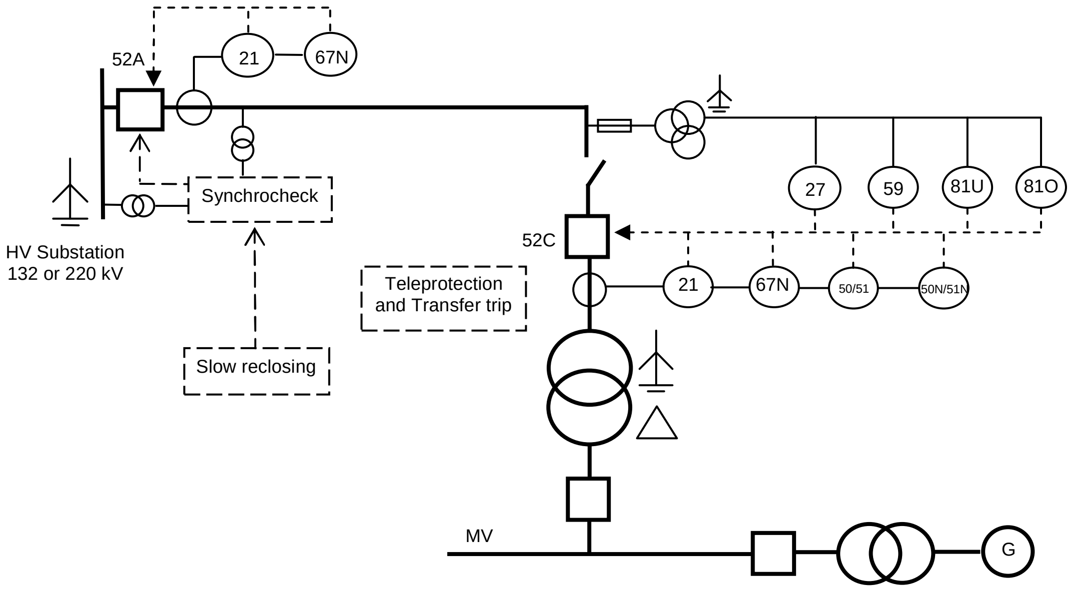

Figure D-41: Connection to a dedicated line (2)

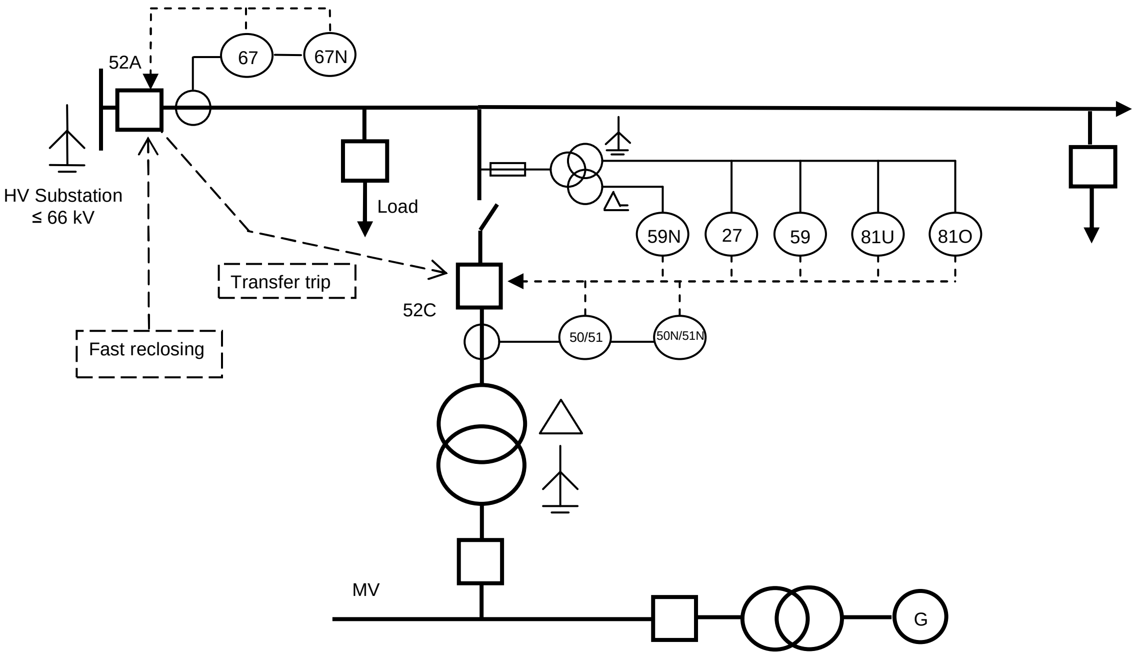

Figure D-42: Tapped connection to a radial non dedicated line

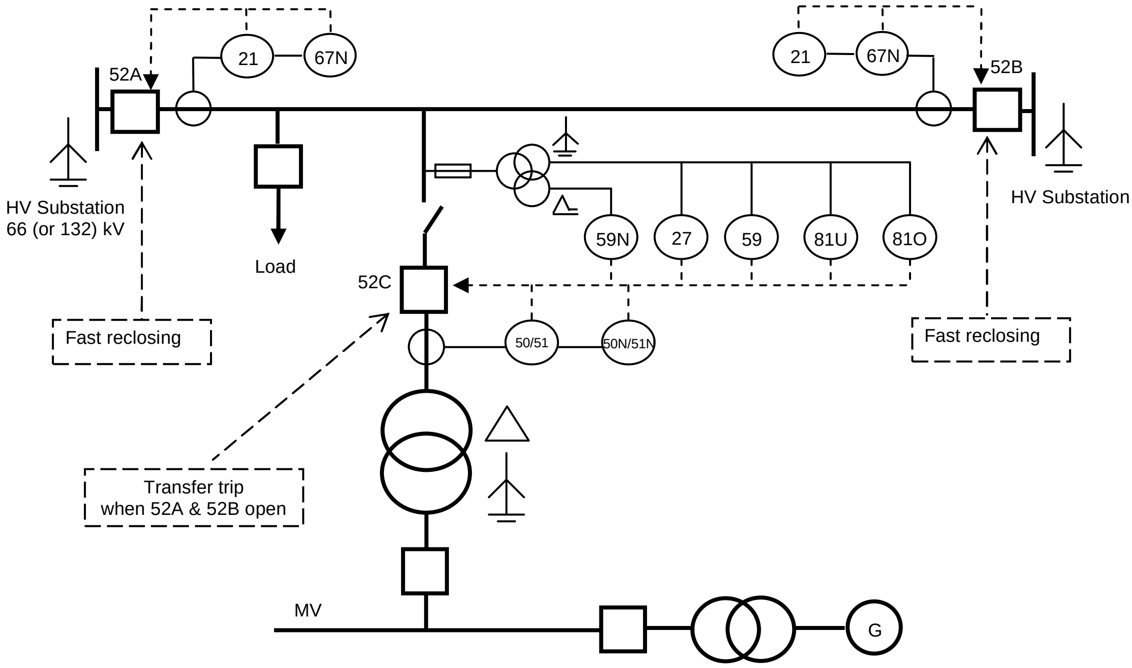

Figure D-43: Tapped connection to a two ended line

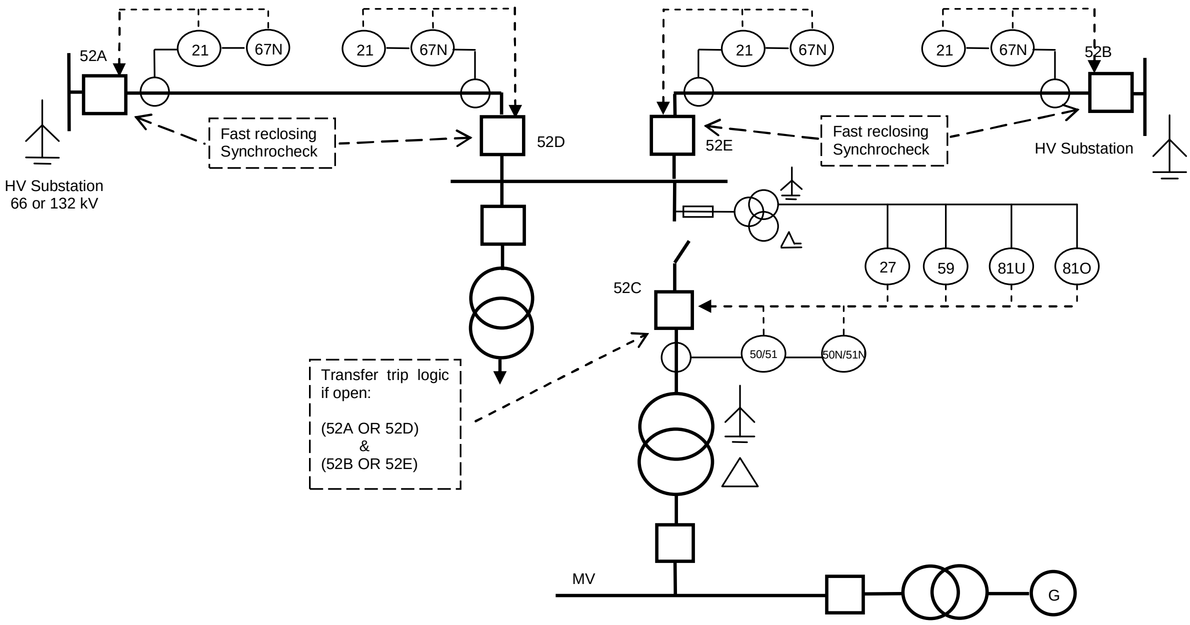

Figure D-44: Connection to a two line substation

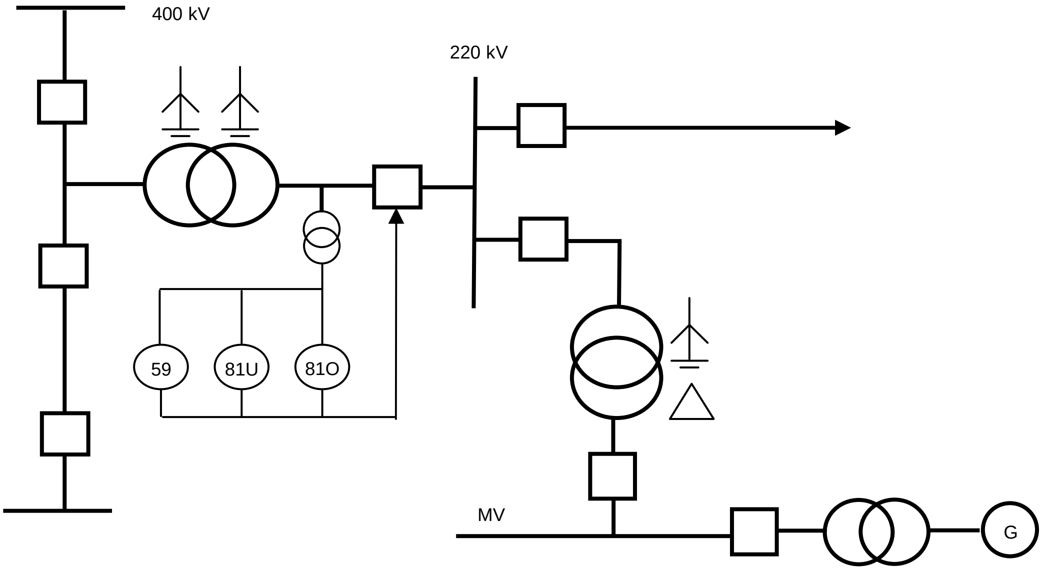

Figure D-45: Connection to a dedicated transmission substation

D.10 Practices with Protection of DG in UK

D.10.1 Prevailing generation technologies

Currently, there is around 76GW of electricity generation in UK. Total annual consumption amounts to about 350TWh and the winter peak demand is about 63GW. The relative composition of the generation mix is presented in Figure D-46. A high proportion of gas generation is a result of large number of new gas-fired power stations build in the second half of the 1990s when the economy of this type of generation was particularly attractive. Consequently, in the early 2000s the electricity prices were low due to the increased competition and excess of generation capacity.

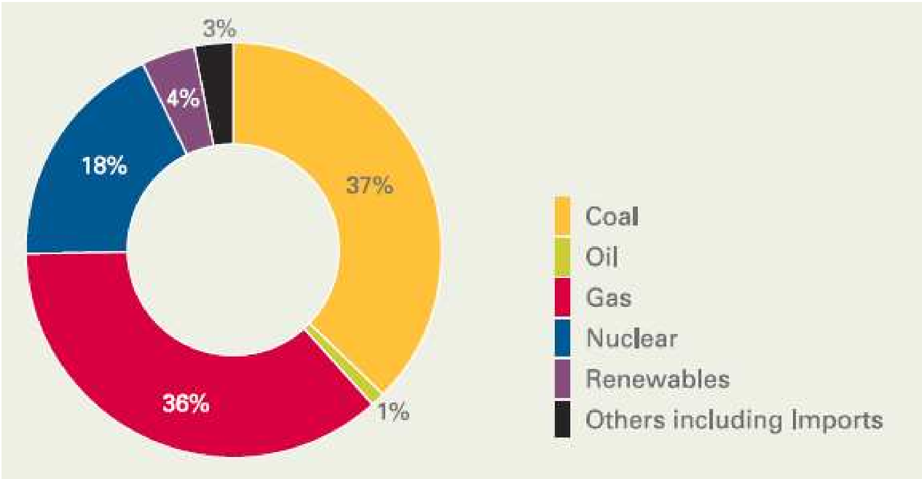

Figure D-46: Generation technology mix in UK (DTI [121])

It can be seen from Figure D-46 that the UK has a diverse electricity generation mix which helps to avoid exposure to the risks associated with single fuel or technology type and provides the system with the flexibility to accommodate the variations in demand and fossil fuel prices.

According to the most recent renewable energy statistics included in [122], renewables accounted for 5.0% of electricity generated in the UK in 2007, up from 4.5% in 2006. The overall percentage of electricity generation from renewables in recent years is presented in Table D-21.

	1990	2000	2005	2006	2007
Wind, wave, solar and biomass	0.19	1.27	3.02	3.39	3.68
Hydro	1.63	1.35	1.24	1.15	1.28
Total Renewables	**1.82**	**2.62**	**4.25**	**4.54**	**4.96**
Obligation (% of UK electricity sales)	-	1.32	4.01	4.44	4.88

Table D-21. Percentage of UK electricity generation from renewables [122]

The UK government is committed to the reduction of carbon emissions and aims to achieve 20% electricity generation from renewables by the year 2020. Currently, the total carbon emission of the UK's electricity generation sector accounts for about 47 MtC per year.

The main renewable technologies in the UK are wind, wave, biofuels, solar and hydro. The growth of the electricity generation from renewables since 1990 is presented in Figure D-47.

There is also an intention to include tidal power in the future as this could provide a significant and reliable contribution to the electricity generation mix in the UK. A major study led by the Sustainable Development Commission (SDC) is currently underway looking at issues related to harnessing tidal power. The geographical position of the UK is particularly advantageous for generating clean energy from the tides. It is estimated that this technology can meet up to 5% of the country's electricity demand.

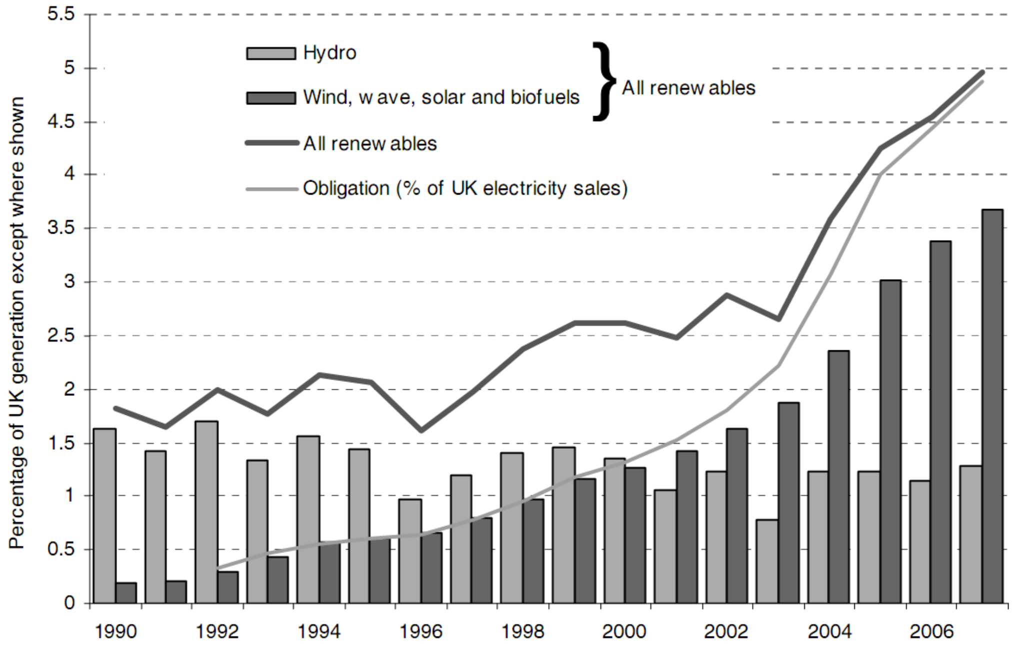

Figure D-47: Growth in electricity generation from renewable sources in UK since 1990 [123].

D.10.2 Main challenges

In the next 20 years the UK is facing a challenge of substantial investment in new generation to replace the closing coal, oil and nuclear power stations, and to meet expected increases in electricity demand. It is estimated by the DTI [121] that by 2020 about 22.5GW of existing power stations may close, which is composed of 8.5GW of coal-fired capacity (to meet the requirements of the EU Large Combustion Plant Directive by 2015), 2.5GW of oil power stations and 7GW of nuclear power stations. It is also estimated that another 10GW of new generation capacity will be needed by 2030. Due to these expected significant changes and in order to provide carbon free alternatives the UK government has put a strong emphasis on renewable energy sources (especially wind) but also considers construction of new nuclear plant in the next few decades.

With regard to renewables, there are a number of barriers slowing the rate of their deployment:

- The most competitive technologies (onshore wind and hydropower) are limited by the scarcity of suitable sites.
- It is increasingly more difficult to secure consent for renewables (especially onshore wind) which puts developers under the risk of significant delays. Currently, more than 11GW of renewables are awaiting consent under the planning system.

- Maturing technologies such as offshore wind and biomass are still more expensive than anticipated.
- There are still significant technical challenges and delays in connecting renewable generating projects to the transmission and distribution networks. This affects both onshore and offshore generation.

In the recent document [124] the Electricity Networks Strategy Group (ENSG) presented a vision for the transmission network upgrades required in order to meet the renewable energy generation target. In what will be the largest single expansion of the grid since the early 1960s, up to 1,000 km of new cables will be needed to ensure new renewables and nuclear power stations can be connected to the electricity grid. It is anticipated that investment worth up to £4.7 billion is expected to be needed to upgrade the electricity grid network by 2020. The main developments will include the installation of new subsea HVDC lines between Scotland and England, and series compensation facility in some of the existing overhead EHV lines in order to increase the transmission capacity currently limited by the narrow oscillatory stability margins. These new developments are also expected to pose some challenges for protection system. They have been implemented in other countries and some Cigré SC B5 working groups have studied the protection implication of these technologies.

D.10.3 Examples of typical connection arrangements

The following voltage levels are used in the UK power system: 400kV; 275kV; 132kV; 66kV; 33kV; 11kV; 6.6kV; and 0.4kV (LV). The use of these levels is not uniform across the country. Voltage levels (according to the UK Distribution code) are applied as follows:

- Transmission
  The major Power Stations are connected to the Transmission System (The Grid) which operates as a fully interconnected system within Scotland, England and Wales. The Grid operates at 275kV and 400kV. The 132kV network in Scotland is also classed as part of the Transmission System but this is not the case in England and Wales. The Transmission System provides a secure supply of electricity to Grid Supply Points, i.e. the Grid Exit Points, which are also the Entry Points to the Distribution System, and also to the Exit Points for Customers with large or special Demands.

- Distribution
  The Distribution System operates at nominal voltages of 66kV, 33kV and 22kV (EHV), 11kV and 6.6kV (HV) and 400 volts and 230 volts (LV). The 132kV network in England and Wales is also classed as part of the Distribution System but this is not the case in Scotland. The Distribution System provides a supply to the Exit Points to all remaining Customers for industrial, commercial and domestic purposes.

33kV Connections

DGs at 33kV are generally connected to single busbar 33kV grid supply substations which will be connected to the transmission system at 132kV or 275kV (refer to Figures D-48 and D-49). There are some exceptions where a connection is made along an existing 33kV circuit and a containerised three breaker switchboard would be installed at this point (refer to Figure D-50).

Generation feeders are protected by a current differential protection, a three phase overcurrent and ground fault backup protection and the circuits are fitted with intertripping. No autoreclosing is fitted to generation feeders and post-fault restoration is performed manually. Where the generation is synchronous, synchronising is undertaken by the generator, the utility breaker is fitted with a voltage interlock to ensure closing can only be carried out onto a dead circuit.

At the point of connection, the DNO's assets are protected by under/over voltage and under/over frequency protection.

Loss of mains is generally performed by ROCOF protection but if the connection is not too complex or there is a real risk of an island being formed with a generation/demand equilibrium, an operational intertrip will be employed.

275/132kV Connections

Larger generation sites are connected to the 275/132kV system by one or two stages of transformation to 33kV. An example is presented in Figure D-51. A substation equivalent to a grid supply substation is established and the generators connect at 33kV. Depending on the capacity of the generation, there may be more than one transformer and they will typically be 90MVA 132/33kV or 120MVA 275/33kV. The transformer protection follows standard UK practice of biased differential and restricted ground fault with mechanical protection and overcurrent backup. The protection of 132kV or 400kV feeders to the generation sites follows the standard policy.

Voltage and Frequency Protection Settings

According to the current recommendation included in the G59/1 document [125] the following settings for the frequency and voltage protection are applied:

Protection	Setting	Time delay
Under-voltage	–10% Vn	0.5 s
Over-voltage	+10% Vn	0.5 s
Under-frequency	47 Hz	0.5 s
Over-frequency	50.5 Hz	0.5 s

Table D-22: Voltage and frequency protection settings in UK

As the need to widen those settings and co-ordinate them with the Grid Code [22] and the Distribution Code [126] has been recognised, these settings are currently under review.

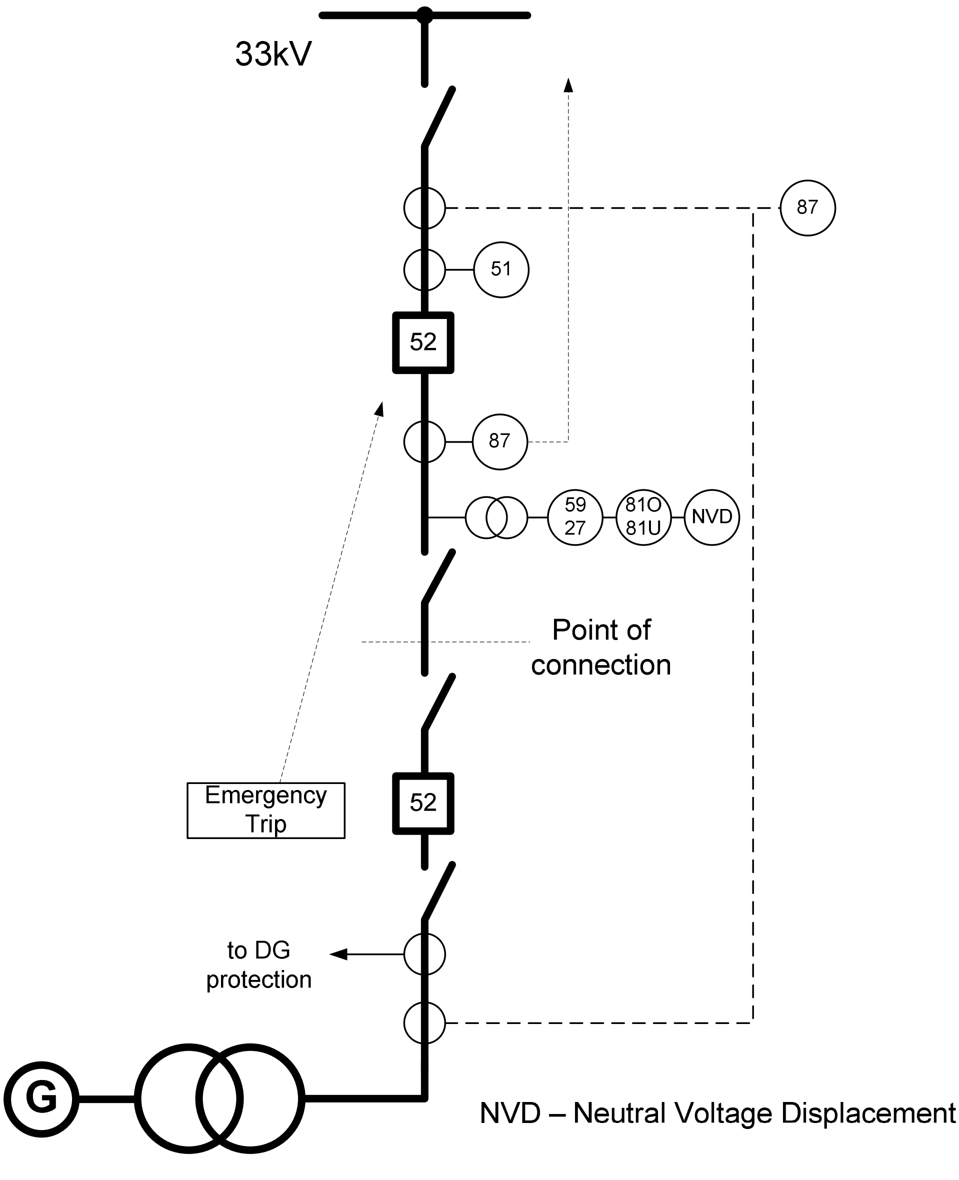

Figure D-48: DG Connection in the vicinity of a 33kV substation

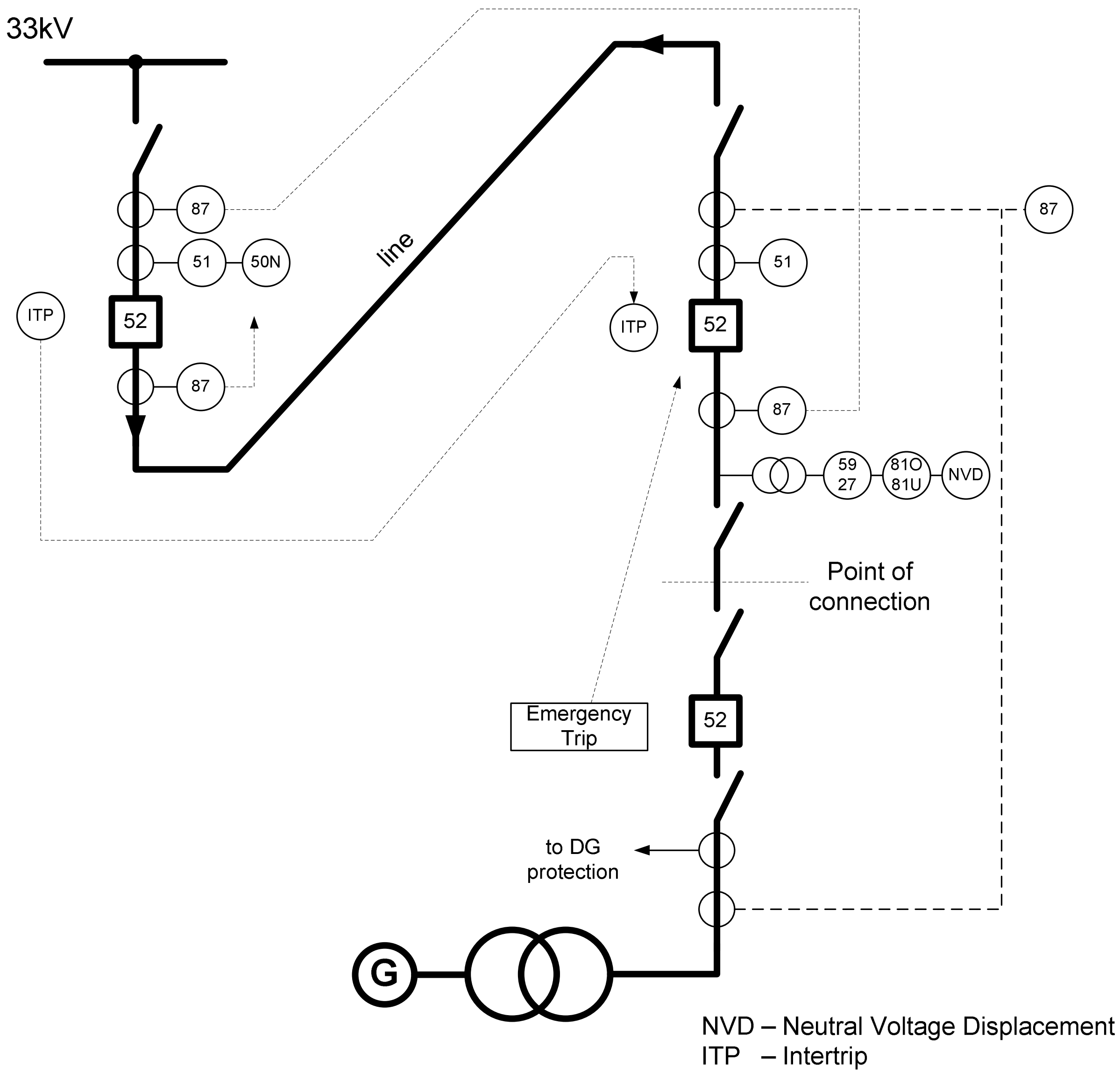

Figure D-49: DG connection through a dedicated 33kV line

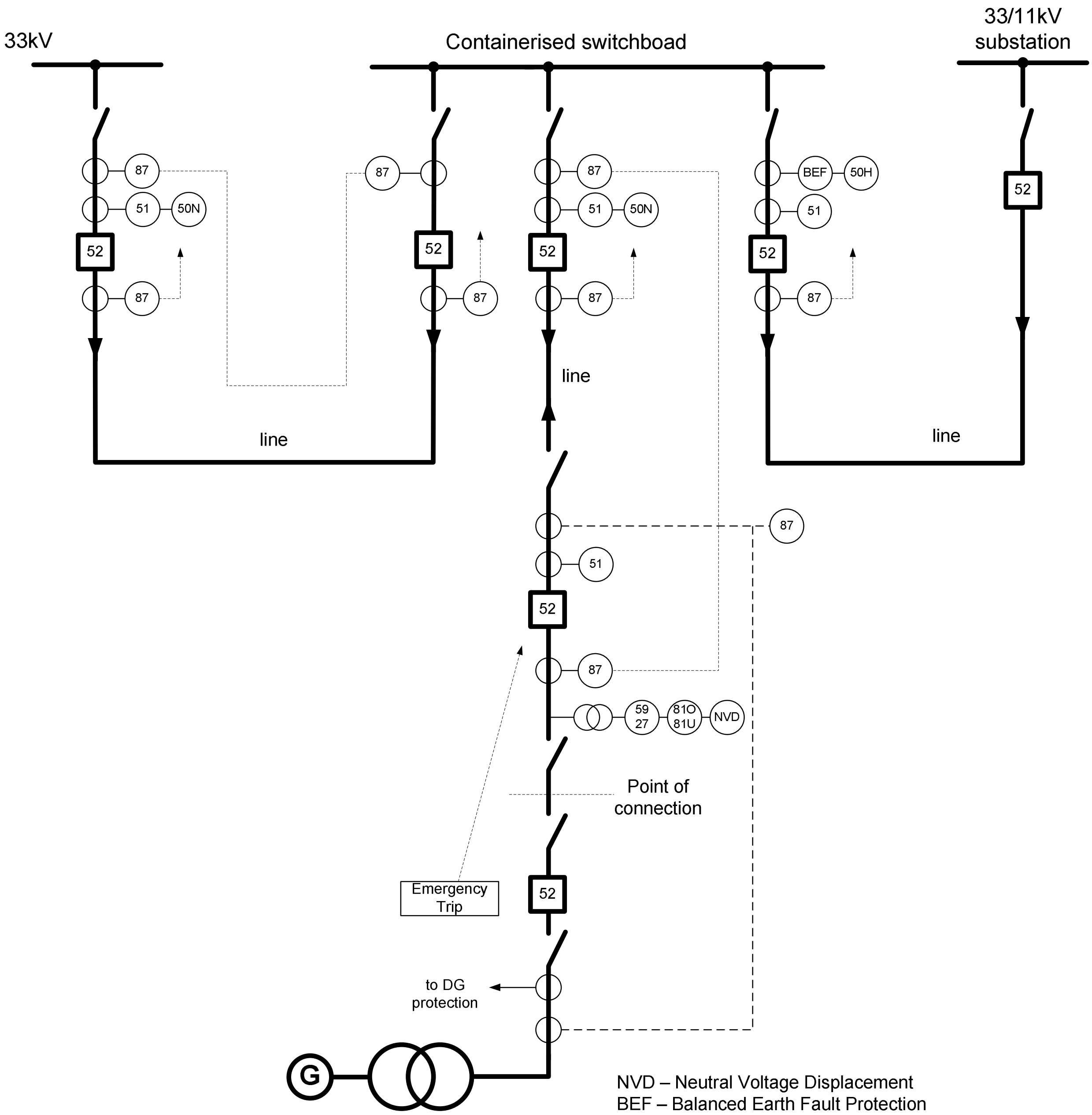

Figure D-50: Teed connection of DG to a 33kV line

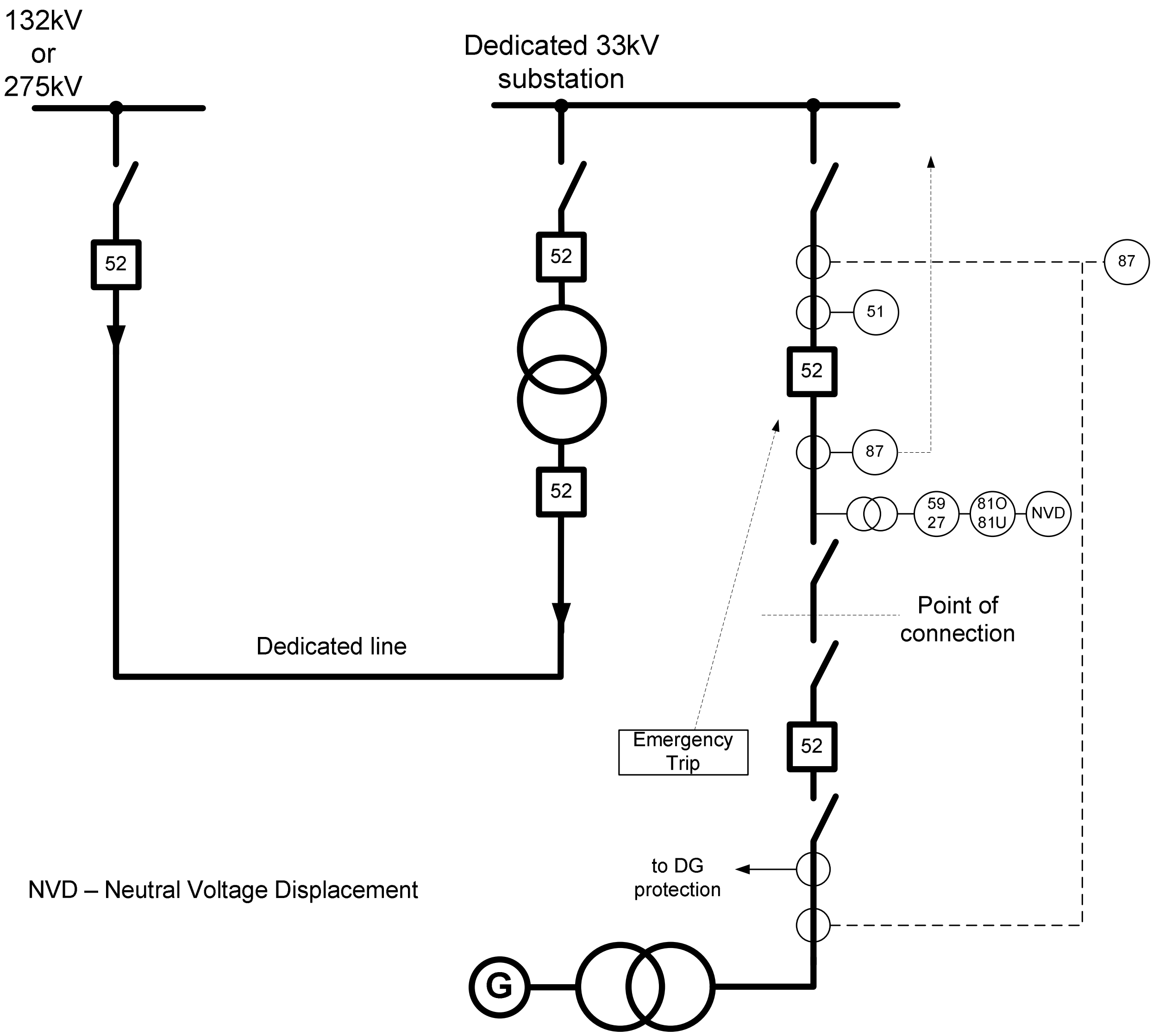

Figure D-51: DG connection to 123/275kV transmission system

D.11 Renewable Energy in China

D.11.1 Introduction

China consumes 10% of the world's total energy, 70% of its primary energy consumption was coal, which is 40% higher than the world average. The SO2 pollution caused by coal burning accounted for 70% to 80% of the total emission amount. Furthermore, the acid rain triggered by SO2 covers 1/3 of the entire area of China. The quality of the environment is continuously deteriorating, according to the World Bank; by the end of 2020 the environmental and health losses caused by air pollution will reach 13% of the total GDP value. Therefore, the development of clean energy has become the inevitable choice of China’s energy strategy.

According to the Renewables 2007 Global Status Report, China is already the leading renewable energy producer in the world in terms of installed generating capacity, with the largest hydro-electric fleet and fifth largest wind power fleet in the world. China plans to almost double the proportion of renewable energy it uses from 8% in 2006 to 15% in 2020, with concrete targets for hydro power capacity at 300 GW, bioenergy power at 30 GW, wind power at 30 GW, and solar power at 1.8 GW. The country’s renewable energy targets are close behind those of the most advanced countries such as those of the European Union which have set a renewable energy target of 20% by 2020. China ranked second for the absolute dollar amount invested in renewable energy in 2007 with approximately US$12 billion, trailing the leader Germany which invested US$14 billion. The nominal sizes of the Chinese and German economies were almost equal at US$3.3 trillion in 2007, meaning that China trails leader Germany only slightly in renewable energy investment as a percentage of GDP. New Energy Finance predicts that another US$398 billion of investment is needed to reach China’s 2020 renewable energy goals, or an average of US$33 billion per year mainly for wind, biomass, hydro and solar installations.

China is or will soon be the No.1 manufacturer of various critical low carbon technologies. China is already a leading manufacturer of solar photovoltaic technology, with 820 megawatts (MW) of production by the end of 2007, second only to Japan. The country is set to capitalize on this growing export opportunity as the world transitions to a low carbon future. In addition to its own local wind power installations which grew by about 120% in 2007, the Global Wind Energy Council announced in early 2008 that China will become the world’s leading manufacturer of wind turbines by 2009 with leading companies such as Goldwind and Sinovel expected to branch into exports. [127]

D.11.2 Renewable Energy Targets

China’s Medium- and Long-term Programme for Renewable Energy Development, which was announced on August 31, 2007, set a target to increase the share of renewable energy in total energy consumption from the current 8% to 15% by 2020. The Programme mandates that at least 3% must come from so-called ‘new renewables’, including solar, wind and biomass. To reach these goals, China’s Renewable Energy Law and other regulations mandate that the state grid purchases power provided by renewable energy projects, giving preferential prices for wind power and biomass. Together with renewable tax-break policies of 50%, this has led to strong growth in these markets. The Programme also set specific targets for 2020 such as 30GW installed capacity for wind, 30GW for biomass, 300GW for hydroelectric and 1.8GW for solar – equivalent to almost half of global solar PV production in 2007.

Rapid expansion will be required in renewable industries to meet these targets and more than double the renewable energy base to 420GW by 2020. But judging from growth trends between 2005 and 2007, the targets will be met well ahead of schedule. For example, the China Renewable Energy Industry Association has announced that China is on track to install 50GW of wind power by 2015, well above the 30GW by 2020 target. The scientific consensus suggests that global emissions need to peak no later than 2020 and then decrease by at least 50% by 2050 if we are to avoid the worst impacts of climate change. China has yet to officially make any targets past 2020, but energy planning experts have suggested that China could expect to meet 30% of energy needs from renewable energy by 2050, which would fall well short of the required amount. However, given the timeframe, there is still enough time for China to push renewable energy targets higher. Renewable energy resource constraints are certainly not the limiting factor and China boasts rich wind and solar resources that could potentially provide for the entire country's energy requirements if effective energy storage methods were used. The major short-term factors restricting the use of renewable energy in China are economic ones and, for this reason, government policy and potentially global carbon markets will need to play a strong role in managing power-related emissions.

China electricity production in 2006 Total: 2730 Terawatt hours (TWh)
1. Fossil Fuel 83.3%
2. Hydro 14.3%
3. Nuclear 2.0%
4. Wind, Biomass, Solar PV 0.4%

Table D-23. China electricity production in 2006

Estimated electric generating capacity 2020: Total: 1422GW
1. Fossil Fuel 70.3%
2. Hydro 21.2%
3. Nuclear 3.5%
4. Wind 2.8%
4. Biomass 2.1%
4. Solar PV 0.1%

Table D-24. China projected generating capacity for 2020

D.11.2.1 Wind Energy

Spurred by supportive government policies growth in China's wind energy industry has exceeded all expectations, with the market increasing by around 125% in 2007. China now has over 6GW of installed wind capacity, which is 7% of the world total and the country ranks fifth in the world after Germany, the USA, Spain and India. Although China still needs to catch up with international leaders such as Germany and Spain in terms of cutting-edge technology, the Chinese wind market is already relatively competitive, ranking alongside the likes of the UK and Australia in terms of price. There are currently a number of restrictions in the market designed to encourage the development of local manufacturers. For example, regulations were passed in 2005 to ensure that at least 70% of each wind turbine installed must be locally manufactured and import taxes have been used to discourage imports of pre-assembled turbine systems. These policies have led to the creation of over 50 local wind power technology companies in China and this group now controls over 50% of the domestic market, historically dominated by imports.

D.11.2.2 Biomass Energy

China's biomass power generation capacity is growing steadily and in 2007 the Government implemented a subsidy of 0.25 yuan (US3.2c) per kilowatt hour to help the country meet its target of 30 GW by 2020.

According to government sources, existing biomass power capacity is 2GW, and China has installed over 1,600 industrial scale biogas plants and over 18 million household biogas disgesters for cooking, heating and power. However, traditional biomass from agriculture and livestock waste remains an under-utilised resource. The majority of China's rural biowastes are discarded or burned because of difficulties in collection and transport. In China's growing cities there are currently over 50 municipal solid waste (MSW) incinerators, also known as waste-to-energy plants, producing about 1,000GWh of electricity from 3 million metric tons of garbage each year. Waste-to-energy technology is becoming more attractive as China's cities run out of landfill space and the energy content of city refuse increases due to rising proportions of plastics and paper.

D.11.3 Typical Connection Arrangements

AC voltage levels in China are: 1000kV, 750kV, 500kV, 330kV, 220kV, 110kV, 66kV, 35kV, 10kV.
Depending on the installation size, DG is connected to the main grid at 10kV, 35kV, 66kV or 110kV. For large wind power plants connection is made at 220kV or 330kV.

D.11.4 Protection & auto-reclose for DG interconnecting feeders to the main grid

When a fault occurs on the DG connecting feeder, after the fault is cleared, the circuit breaker on the main grid side will be reclosed first after a dead-line check, while the circuit breaker on the islanded grid side will be reclosed later after a synchronism check. Alternatively, an operator closes the circuit breaker manually after re-synchronizing.

D.11.4.1 Protection for transformers connected to DG

A back-up directional over current protection is used. A voltage controlled element (phase-phase under-voltage & negative sequence over-voltage) for over current protection is also used if the sensitivity is not satisfied.
The neutral point of the transformer may be grounded to avoid overvoltages which influences the distribution of zero sequence current, and thus the sensitivity of ground fault protection.
If the neutral point of the transformer is grounded, then zero sequence over voltage protection and over current protection at the neutral is applied to trip the DG.

D.11.4.2 Standby power supply auto-switch

In substations that connect to DG, if the main supply from main grid is lost as a result of a permanent fault on the in-feed line, before switching onto a standby supply from the main grid, all connections to the DG are inter-tripped to avoid asynchronous paralleling. After a successful switchover, these connections can be reconnected manually after re-synchronizing.

D.11.4.3 Inter-tripping

In the case that the capacity of the generator is too small to supply the local load in an islanded system then the DG is inter-tripped and whenever a fault occurs on the interconnecting line or transformer the DG is tripped immediately.

D.11.4.4 Islanding

Under Frequency & under Voltage protection is used to prevent islanding of the DG and keep the stability of the main grid.

D.11.4.5 Generation Rejection

Over frequency and over voltage protection is used for generation rejection for DG.

D.11.4.6 Load shedding

Under frequency load shedding and under voltage load shedding is applied in small grids mainly supplied by DG to keep the balance between generation and load when islanded.

D.11.5 Wind Farm Voltage and Frequency Operating Limits

If the voltage deviation of the connection point compared to the grid is within -10% to 10%, the wind farm should operate normally.

If the voltage deviation of the connection point compared with the grid is more than -10% to10%, the operation status of the wind farm is determined by the performance of the wind turbines. If the voltage is less than 90%Vn, the wind farm should have an undervoltage fault ride through capability as shown in Figure 2-15 (page 46).

The requirements for the operating frequency of wind turbines during frequency deviations are listed in Table D-25.

Frequency deviation range	Requirement
Less than 49Hz	Determined by the minimum operation frequency of the wind turbine
49Hz-49.5Hz	Can operate at least 10 minute every time the frequency less than 49.5Hz
49.5Hz-50.2Hz	Operating continuously
50.2Hz-51Hz	Can operate as least 2 minutes every time the frequency is higher than 50.2Hz; and no other wind turbine can start when the frequency is higher than 50.2Hz.
More than 51Hz	The wind turbine should be out of service or operate with restrictive power as per the instruction of the despatch department.

Table D-25. Wind farm operating frequency

Appendix E. Summary of Practices of DG Protection in Different Countries

<u>110 to 400 kV</u>

Country	Type of connection	Line protection	Interface protection/Settings		Anti-island protection	Reclosing co-ordination
CANADA	Radial line	Redundant equipment. Teleprotection may be required	27 59 81O 81U	Several steps of threshold/time (similar to conventional generation)	Transfer trip if islanding is possible	Transfer trip also: - If line reclosing time is less than 2 sec. - If line DG's protections are not effective - If self-excitation may occur, as when islanding a power plant with a capacitive load
	Tapped connection	21, 67-67N or 27 (ph faults) 59N/51N (undergnd faults) 50S				
DENMARK			27 59 59N 81O 81U 51 I2	<70%Un, 50 ms; <90%Un, 2-10 s >110%Un, 50 ms;>106%Un,30-60s 20%Vn, 60 s 53 Hz; 0.3 s 47 Hz; 0.3 s I>>: 50 ms 5-20%; 3-10 s	Undervoltage relay supplemented with a ROCOF relay 2,5 Hz/s; 80-100 ms	3 pole fast reclosing (0.3 s). Anti-island relay must disconnect before

FRANCE	Dedicated line 400kV	RTE's panel: 21+teleprotection, 87L, 32N, 50BF Producer's panel: 21+teleprotection, 87L, 32N, specific 27	Generator panel: 81U 81O 27 59 27 needed for 1 phase reclosing cycle	< 47 Hz > 52 Hz < 80% >110%	none	1 and 3 phase reclosing Synchrocheck at both ends
	Tapped line 225kV	RTE's panel: 21 (2 times), 32N (zero sequence power), 50BF	Generator panel: 81U 81O 27 59 27 needed for 1 phase reclosing cycle	< 47 Hz > 52 Hz < 80% >110%	none	1 and 3 phase reclosing Synchrocheck at both ends
PORTUGAL	Dedicated EHV line and Tapped connection EHV line (unusual)	Main 1 87L; 21 (blocked if 87L is operational), 67N, 50 (emergency); Main 2 21, 67N, 50 (emergency); 50S	Generator panel: 27, 59 81O 81U Interconnection point: 50, 59N	Generators: must be regulated according FRT capability; 51.5Hz (0-0.15 s) 47.5Hz (0-0.15 s) 100-200% In (0-1 s)	Not necessary;	79 - Single and Three-pole autorecloser (with live-line and dead bus or synchrocheck;
SPAIN	Dedicated line	21(teleprot.)-67N at utility and generating plant ends Redundant scheme if required	27 59 59N 81O 81U	80%Vn; 0.6/1.2 s (1) 115%Vn; 0.2 s 35%Vn; 0.6/1.2 s (1) 51 Hz; 0.2 s 48 Hz; 3 s (1) 1.2 sec if FRT is required	Transfer trip through the teleprotection	Delayed or no reclosing Synchrocheck in utility end
	Direct connection to a Substation				Transfer trip logic from local and remote breakers through the teleprotections,	Fast reclosing Synchrocheck in all ends
UNITED KINGDOM	Connection to the transmission system through a dedicated line and substation	21 – main protection 51 – backup protection	27 59 81U 81O	<90%Vn; 15 min >110%Vn; 15 min 47- 47.5 Hz; 20 s	None	Delayed 3 phase reclosing with live-line and dead bus or synchrocheck

<u>≤ 110 kV</u>

Country	Type of connection	Line protection	Interface protection/Settings		Anti-island prot.	Reclosing co-ordination
CANADA	Radial line Tapped connection	Protection for phase and ground faults (not specified) 50S (> 1MW)	27 59 81O 81U 51-51N	60-90%Un, 1 s; <60%Un, inst. 110-140%Un, 1 s; >140%Un, inst. 60.5 Hz, 0.5 s 59.5 Hz, 0.5 s	27, 81U an 81O or optionally ROCOF or VS relays if nuisance trip	Generator protection (not specified) Not reclosing Voltage supervision
CHINA		67 with voltage control	81M 81m 59 27 59N/50N	51 Hz (trip or operate with restrictive power) 49 Hz >110% Un <90% Un (less if FRT)	81m and 27 81M and 59 for generation rejection	Voltage check
DENMARK	Dedicated line Direct connection to a substation		27-1 27-2 59-1 59-2 59N 81O 81U 51 I2	<70%Un, 50 ms <90%Un, 2-10 s >110%Un, 50 ms >106%Un, 30-60 s 20%Vn, 60 s 53 Hz; 0.3 s 47 Hz; 0.3 s I>>: 50 ms 5-20%; 3-10 s	Undervoltage relay supplemented with ROCOF relay (optional) 2,5 Hz/s; 80-100 ms	3 pole fast reclosing (0.3 s). Anti-island relay must disconnect before

FRANCE	Dedicated HV line Direct connection to a substation Tapped connection	RTE's panel: 21 + backup 32N 50BF	Producer's panel: 51N if grounded 59N if ungrounded Generator panel 81+27+59	51N : 100A, 4 s 59N : V0=0.5Vn, 4 s	Performed by the interface relays of generator panel	3 phase delayed reclosing
	Radial line 20kV	eRDF's panel: 50, 51, 51N optional 27	Producer's panel: 59 59N 27 27 81U 81O	115%Un, inst. 10% Vn, 1 to 2 s 85% Un, 1 to 2 s 25% Un, instantly 49.5Hz, instantly 50.5Hz, instantly	Performed by the interface relays Transfer trip may be used if risk	3 phases delayed or fast reclosing. 27 relay is sometimes needed on distributor's panel to avoid or delay auto reclosing cycle on out of sync generators.
GERMANY	a) Connection to a MV substation through a dedicated line	21U at the substation breaker 21U at the transformer (HV side)	Utility end: 59HS 59 27 (case a) 27 (case b) 21U 32&27 Generator end: 59HS 27 (case a) 27 (case b) 27HS 81U 81O	115%Un, 0.1 s 108%Un, 1 min 80%Uc, 2.7 s 30%Uc, 0.2 s Uf=80%Un;If=20%In;Ie>=120%Ice Q>0; 85%Un; 0.5 s 120%Un; 0.1 s 80%Un; 1.5-2.4 s 80%Un; 1 s 45%Un; 0.3 s 47.5 Hz; 0.1 s 51.5 Hz; 0.1 s		
	b) Connection to MV line	Fuses, 21U or 51, 51N at the line breaker				
FINLAND	Dedicated line Direct connection to a substation		27-1 27-2 59-1 59-2 59N 81O 81U	<50%Un, 50-100 ms <90%Un, 2-10 s >110%Un, 50 ms >106%Un, 30-60 s 51 Hz; 0.2 s 47 Hz; 0.2 s	U<> and f <> are normally used for anti-islanding detection. Dedicated anti-islanding relay can be used	DG unit nust not result in failing reclosing (no method is specified)

NORWAY	Dedicated line	67,67N	27 51 59 59N 81O 81U	<50%Un; 0.2 s <85%Un; 1.5 s >115%Un; 0.2 s >105%Un; 1.5 s 51 Hz; 0.2 s 48 Hz; 0.2 s	Transfer trip is used if teleprotection exists or ROCOF (2 s.).	Delayed or no reclosing Line voltage check in utility end
	Connection to a non dedicated line	67-67N			Transfer trip logic from local and remote breakers or ROCOF (2 s.)	Fast reclosing
PORTUGAL	Dedicated line connected in Transmission Network	Main 1: 21, 67N, 50 (emergency) Main 2: 21, 67N, 50 (emergency); 50S	Generators: 27, 59 81O 81U Interconnection point: 50, 50N/59N	Generators: Must be regulated according FRT capability: 51,5Hz (0-0.15 s) 47,5Hz (0-0.15 s) 100-200% In (0-1 s)	Not necessary;	79 – Three-pole autorecloser (with dead-line supervision);
	Dedicated HV line and Connection to a dedicated HV substation	21, 50, 67N	59 27 81O 81U 50 59N 50N	1.15Vn – 1 s 0.85Vn – 1 s 51.5Hz (0-0.15 s) 47.5Hz (0-0.15s) 100-200% In (0-1 s) 10% Vn – 1 s 10% In – 0.4 s	Not necessary;	79 – Three-pole autorecloser
	Connected to a non dedicated HV line					
	Dedicated MV line	50, 67N, 50N	59 27 81O 81U 50 59N 50N	1.15Vn – 1 s 0.85Vn – 1 s 51.5Hz (0-0.15 s) 47.5Hz (0-0.15 s) 100-200% In (0-1 s) 10% Vn – 1 s 10% In – 0.4 s	Not necessary;	
	Connected to a non dedicated MV line					

SPAIN	Dedicated line	67-67N at utility end	27 59 59N 81O 81U	80%Vn; 0.6/1.2 s (1) 115%Vn; 0.2 s 35%Vn; 0.6/1.2 s (1) 51 Hz; 0.2 s 48 Hz; 3 s (1) 1.2 sec if FRT required	Not necessary, although transfer trip is used if teleprotection exists	Delayed or no reclosing Line voltage check in utility end
	Tapped connection	67-67N or 21-67N at the utility end/s			Transfer trip from utility breaker/s or any approved anti-islanding protection	Fast reclosing
	Direct connection to a Substation	21-67N			Transfer trip logic from local and remote breakers if teleprotections exists or any approved anti-islanding protection	Fast reclosing Synchrocheck in all ends
UNITED KINGDOM	Connection in the vicinity of substation	87, 51 (typical)	27 59 81U 81O NVD	90% Vn; 0.5 s 110% Vn; 0.5 s 47Hz; 0.5 s 50.5Hz; 0.5 s >30%Vn, time delayed to co-ordinate with the network ground fault protection.	Dedicated anti-islanding protection (ROCOF or VS) Transfer trip can be employed	No auto-reclose
	Connection through a dedicated line	87, 51, 50N, (typical)			Dedicated anti-islanding protection (ROCOF or VS)	
	Tapped connection					