PV in Urban Policies- Strategic and Comprehensive Approach for Long-term Expansion

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WP4 – Deliverable 4.2

UTILITIES EXPERIENCE AND PERCEPTION OF PV DISTRIBUTED GENERATION

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1 THE PV-UP-SCALE PROJECT

PV-UP-SCALE (*PV in Urban Policies – Strategic and Comprehensive Approach for Long-term Expansion*) is a European funded project under the Intelligent Energy for Europe programme related to the large-scale implementation of photovoltaics (PV) in European cities. Its' objective is to bring to the attention of the stakeholders in the urban planning process the economic drivers, bottlenecks like grid issues and the does and don'ts within the PV-urban planning process. To reach the urban decision makers workshops will be organised and a quality handbook will be written using experience gained with PV-Urban projects in the Netherlands, Germany, France, Spain and the United Kingdom. The project complements the activities that are being executed in the International Energy Agency – Photovoltaic Power Systems Programme (IEA PVPS) Implementing Agreement, in particular IEA PVPS Task 10. It takes information from Task 7 (building integrated PV), which ended in 2001 and Task 5 (grid issues), ended in 2003.

The structure of the project is summarised in the following figure.

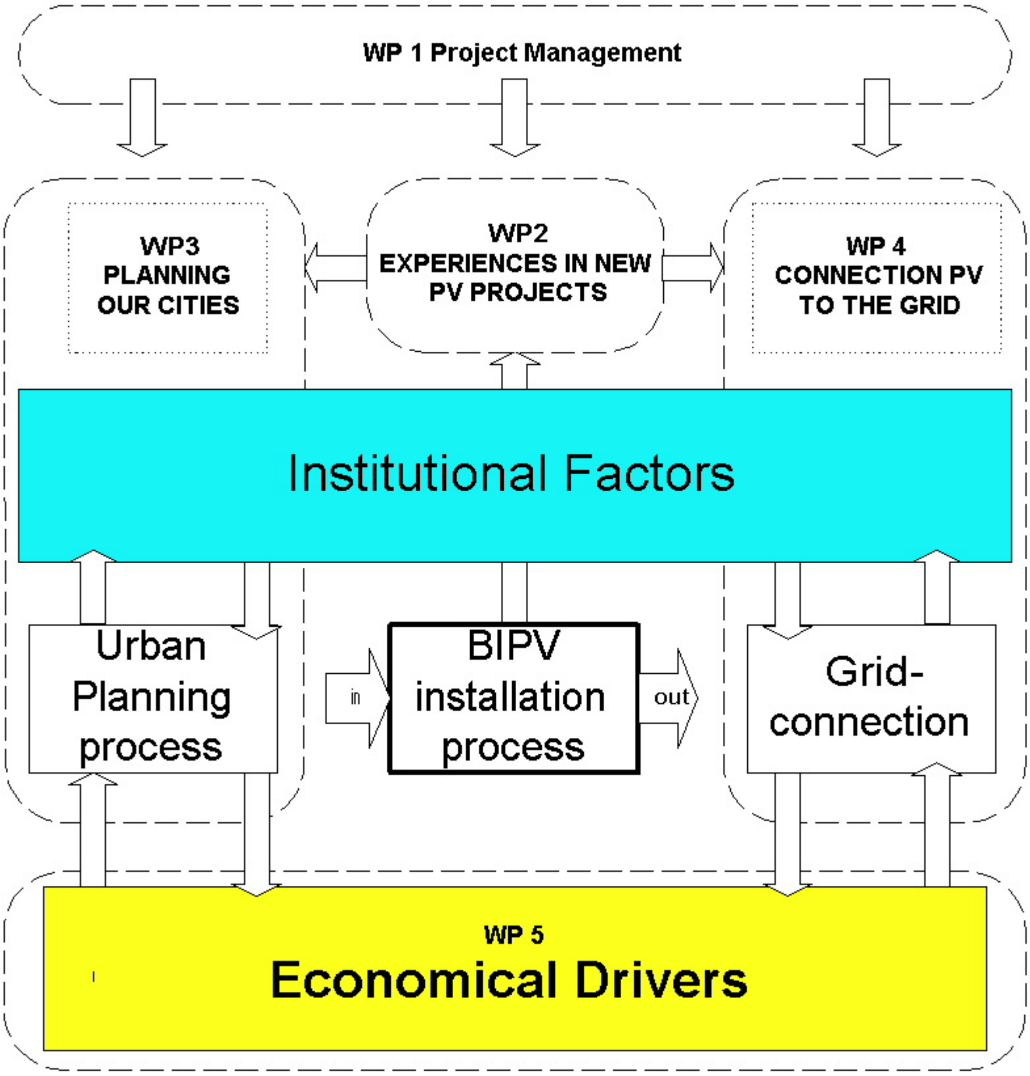

Figure 1. Structure of PV-UP-SCALE project

PV-UP-SCALE consortium brings together complementary expertise from Educational, Research and Development, Engineering, Architecture and Utility sectors:

Sectors	
Educational, Research	**ECN- Energy research Center of the Netherlands**, Research Institute, The Netherlands (Project Coordinator) **Vienna University of Technology - EEG**, Energy Economics Group, Austria **Fraunhofer Institute für Solare Energiesysteme**, Research Institute, Germany **Universidad Politecnica de Madrid – Instituto de Energía Solar**, Spain
Consultancy	**HORISUN**- Consulting, The Netherlands **HESPUL-** Consulting, France **Halcrow-** Halcrow Group Ltd, Consulting, United Kingdom **Ecofys**- Ecofys Energieberatung und Handelsgesellschaft GmbH, Consulting, Germany
Electricity	**Continuon-** Netbeheer NV, Utility, The Netherlands **MVV-** MVV Energie AG, Utility, Germany

Of the project Work Packages, Work Package 4 (WP4) is the one dealing with technical issues of grid interconnection such as mutual impacts of PV systems and Distribution networks, interconnection guidelines, network risks, and required inputs to network planning. Fortunately, some thorough collective work on PV-grid issues has been done under the framework of IEA PVPS-Task 5, R&D projects previously supported by the European Commission, national and international Standardization bodies (IEC-TC82, CENELEC-SC82). WP4 draws upon on this work to contribute to identify still existing barriers and solutions for a successful dissemination of PV systems in electricity networks of urban areas.

For more information, please visit the project web-site: www.pvupscale.org

2 EXECUTIVE SUMMARY

Over the last decades, a number of factors increasingly demand a gradual shift from the central approach for electricity power systems to more distributed generation, where Distributed Generation (DG) technologies are effectively integrated into the networks.

Over the last two decades, many PV systems have been connected to distribution networks worldwide. This has made possible to gain a deeper understanding of the mutual interaction between PV systems and the network. PV serves as a “scout” for other emerging DG technologies like micro –cogeneration. To learn about utilities experiences and views, the PV-UP-SCALE project has carried out an extensive survey amongst Electricity Distribution companies of the participating countries (Austria, France, Germany, Spain, The Netherlands and United Kingdom), which represent 98 % of the PV capacity installed in the European Union. 35 utilities have been interviewed, all of them amongst those with more experience with PV-DG.

The main topics addressed are:

- Experience with PV-DG
- Penetration limits for PV distributed generation
- Voltage level and regulation
- Harmonics from inverters
- External disconnect
- Reclosing practices
- Anomalous situations in distribution networks
- Unintentional islanding
- Electromagnetic compatibility of inverters
- Planning, operation and maintenance of the networks in relation to PV-DG
- Applicable standards / new regulations requirements
- Research and development needs perceived.

According to the focus of the project PV-Upscale, conclusions here are drawn focusing on rather small, domestic PV systems in an urban environment.

Overall, it can be concluded that the experience and perception of PV-DG by European utilities is positive. Grid connected PV plants have demonstrated compatibility with LV distribution networks even at high densities.

On the other hand, some of the potential concerns are not PV-specific, but common to most Distributed Generation technologies. Consequently, technology advances and harmonisation of technical requirements achieved in the PV-DG field will also facilitate the integration of other DG in future electricity networks and vice versa.

Main concern in nearly all countries is voltage rise from strong generation near end-of-feeder. This effect is being noticed, however, in strong grids it is not critical. It may become critical in terms of violation of power quality standards, or reduction of produced power due to voltage limitation, or costs for grid strengthening mainly in rural areas with higher impedance networks.

The Netherlands reported overvoltage due to resonance effects between grid impedance and inverter capacities. This effect seems to be related to a high inverter density and should completely be understood.

All other issues are perceived to be less important. In several countries some technical topics like harmonics, or radio high frequency noise emissions (EMC), rise diffuse concerns, without much evidence of encountered problems.

In most of the countries there is no concern that the network protections may not function properly due to the presence of PV-DG,

Interestingly, Germany with the highest installed PV capacity seems to have the fewest concerns of problems. It is assumed that this can be attributed to good experiences with that technology, strong urban grids, as well as clear responsibilities for DNOs in the relevant law.

Even with little PV capacity on the grid potential effects of large inverter capacities should be taken into account, since these inverters will operate for the next 10 … 15 years. Therefore, in Germany, due to the large PV capacity of some 3 000 MVA (2007) on the grid, PV inverters – even small ones - are nowadays required to provide "fault-ride-through" capability like central power stations.

Potential benefits from inverters like active filtering, reactive power control, phase balancing are generally acknowledged, but currently have no market value. Rules for decentral provision of these "system services" need to be developed. In future, they may become features of the "smart grid".

Technical standards for DG should be revised. Some issues seem not to be adequately covered. These include harmonics emission limits for inverters with output current above 16 A per phase, islanding, flicker, interaction of multiple inverters, voltage imbalances, inverters capacitance, coordination of standards concerning safety in low voltage grids.

Work on integration of DG should take into account that existing standards do not provide consistent rules among network operators, inverter developers, network regulators and system operators concerning an active integration of DG in grid-supporting modes of operation, nor do they provide incentives to provide the potential benefits.

In some cases specific grid operation requirements are requested for PV-DG. Utility controlled generator shedding is enforced in Germany for large DG including PV systems as means against overloading of transmission lines with the ultimate risk of a large area black-out.

Finally, some research and development needs have been identified on the following issues: islanding, harmonics emission limits, interaction of multiple inverters, penetration limits, power factor regulation, power production forecast, active integration of PV-DG into the networks.

3 INTRODUCTION

Electricity power systems worldwide have been traditionally designed following a vertically integrated scheme characterised by centralised generation, distributed consumption and limited interconnection capabilities between the different grid control areas. Over the last decades, a number of factors increasingly demands a gradual shift from the central station approach to a more distributed approach where Distributed Generation (DG) technologies are effectively integrated [1,2]:

- Liberalisation of electricity markets and new technology developments, from which the economic risk for constructing big power plants has become much higher than for small power plants.
- Security and quality of supply greatly influenced in most countries by a strong dependency on fossil fuels for electricity generation and the ageing infrastructures of transmission and distribution networks.
- Environmental issues associated to pollutants emissions resulting from the use of fossil fuels, and their influence on climate change.

DG is also thought by many to reshape the electricity network structure during the next thirty years. In this context, Photovoltaic Distributed Generation (PV-DG) is also expected to contribute to this re-structuring process, both through building integrated or mounted PV systems (BIPV) and by means of central PV plants.

Over the last two decades, many PV systems have been connected to electricity distribution networks worldwide, which have made possible to gain a deeper understanding of the conditions necessary for a sustainable market by the relevant stakeholders: utilities, PV system planners and developers, architects and building services engineers, banks and final users. In some areas erection of PV systems has been restricted by local utilities for various technical grid-related reasons —“the network is too weak” or “network capacity is at its limit” is argued in such cases. This is often difficult to challenge because of lack of technical background and/or the knowledge of characteristic network parameters. Too complex administrative procedures, in other cases, also constitute important barriers that hinder the penetration of PV technology in the electricity networks and therefore the development of a mature PV market.

To reach such a situation, it is of utmost importance that a good understanding exists between the stakeholders traditionally responsible of the electricity supply chain, and those involved in the PV systems design, promotion and operation. To this aim, the PV-UP-SCALE project has carried out an extensive survey amongst Electricity Distribution companies of the participating countries (Austria, France, Germany, Spain, The Netherlands and United Kingdom), following a common approach aiming at a technical and non-technical assessment of PV-DG.

The document content is as follows. **Section 2** justifies and describes the issues covered in the surveys. In **section 3** a general description of the regulatory framework applicable to grid-connected PV systems in the different reporting countries is provided, with the aim of facilitating the understanding of some answers provided by the interviewed companies. **Section 4** includes an overview of the national electricity distribution and PV grid-connected markets, and summarises the utilities experience with that technology. Finally, in **section 5** a comparative assessment is presented, in order to identify common perceptions as well as most relevant differences between the countries; also, some general conclusions are drawn. The Annex section of this report includes the interview template used, as well as some individual interviews conducted in the different countries and further documents concerning the discussed issues.

4 SURVEY DESCRIPTION

As it has been mentioned in the previous section, the objective of the surveys was to obtain up-to-date information of European utilities' perception and experience concerning PV Distributed Generation. The variety of the markets covered, with different promotion strategies (target programmes, financial incentives and others [3]) and different experiences recommended focusing not only on technical issues such as harmonics, voltage regulation, islanding, interaction with the networks, etc., but also on non-technical aspects of PV-DG (e.g. administrative procedures, legal obligations) that fall under the responsibility of the utility companies. Besides questions on specific topics, the interviewed companies had also the possibility to express further opinions on other relevant subjects, such as standardization, research and development needs.

The inspiring sources behind the surveys design have been the related work done under the framework of IEA PVPS-Task 5 on technical grid-related issues of interest for utilities at the end of the 1990s [4], as well as the findings of an extensive literature survey carried out within PV-UP-SCALE project [5].

The following tables summarise the topics and specific issues covered. Also, given the growing penetration of PV systems in Medium Voltage networks in several countries (centralised PV plants in Germany and Spain, for example), the questions addressed separately Low Voltage and Medium Voltage electricity distribution grids.

TECHNICAL ASSESSMENT OF PV DISTRIBUTED GENERATION
Harmonics from inverters – Typical voltage distortion values in the networks operated by the interviewed companies. – In the present scenario (with very low/low penetration of PV-DG), perception of current concern over PV-DG and harmonic emissions. – Perception of future concern over PV-DG and harmonic emissions. – Potential interest of PV plants operating as “active filters” (harmonic generation in order to reduce/suppress existing network harmonics).
Voltage regulation – In the present scenario, perception of current concern over PV-DG and voltage regulation of the networks. – Description of the voltage regulation systems/techniques used. Adaptation of such systems to bi-directional power flows, which may result from PV-DG under specific circumstances (e.g. low load, high PV generation). – Maximum overvoltage allowed to PV-DG interconnection to the networks. Are national regulations enough? Are there any further requirements applicable in the companies' networks? – Perception of future concern over the influence of PV-DG in the voltage regulation of the networks. – Potential interest of PV plants operating as “voltage regulators” (compensation of voltage drops under high loads conditions).
Anomalous situations in distribution networks

- Does PV-DG imply different or new requirements for network operation?
- Perception of concern over malfunction of the networks protections due to PV-DG.

PV systems grounding

- Perception of current concern over interferences with the networks grounding practices.
- Perception of future concern.

Unintentional islanding

- Perception of current concern over unintentional islanding by PV-DG.
- Perception of future concern.
- Are current technical requirements (standards) considered adequate and sufficient?
- Opinion on active methods for islanding detection (network impedance measurement, frequency deviation, active/reactive power deviations,…).

Electromagnetic compatibility of inverters

- Are current technical requirements (standards covering emission limits and susceptibility for electrical equipment) adequate and sufficient?
- Perception of concern about mutual disturbance of large numbers of inverters.

External disconnect

- Opinion and potential interest on automatic switches enabling remote disconnection of PV-DG at high penetration levels.

Reclosing practices

- Description of the reclosing procedures used in the companies' networks.

DC-currents and transformerless inverters

- Have adverse effects of DC-current injection been observed?
- Have transformerless inverters shown noticeable operation differences from inverters using transformers?

Penetration limits for PV Distributed generation

- Define penetration limits in relation to the network / transformer capacity.
- Are/should penetration limits be different in urban and rural grids?

Planning, operation and maintenance of the networks in relation to PV-DG

- Is PV-DG currently considered in planning? Are new tools needed?
- Potential interest for including PV-DG into load dispatching. Are new tools needed?
- Does PV-DG imply different/new requirements for network operation?
- Description of the procedure used for disabling PV-DG for maintenance work in the networks.

Table I. Issues covered in the technical assessment of PV Distributed Generation

GENERAL ASSESSMENT OF PV DISTRIBUTED GENERATION
Experience with PV-DG – General experience. – Are there PV plants where regular measurements are done? – Incidents with PV-DG over the last 10 years.
Applicable standards / new regulations requirements – Standards and guidelines used for admission of PV-DG. – Are current standards for PV-DG sufficient? – Issues at present not covered by standards, which should be included. – Incidents with PV-DG over the last 10 years.
Other issues – Research and development needs perceived. – Any other comments or remarks.

Table II. Issues covered in the general assessment of PV Distributed Generation

5 REGULATORY FRAMEWORKS APPLICABLE TO PV-DG

5.1 Austria

Since the middle of the 80-ths PV systems are subsidized in different sizes in Austria. At the beginning the Austrian utilities have been supported this technology through research and development activities.

In 1991 the Austrian Ministry for Economic Affairs launched a promotion program for small decentralized PV systems namely 200 kWp PV-rooftop program which was implemented between 1992 and 1994. Within this program about 100 small residential grid-connected systems were subsidized by means of 58 % of the investment costs by utilities and governmental authorities [6].

In the 90s the main PV activities have been implemented in Upper Austria like the first governmental bidding programme for decentralised grid-connected PV. Currently province Upper Austria offers 3000 Euro investment subsidy for each installed kWp PV capacity as well as 300 Euro for further measurements costs. 2006 statistics indicate that the customers have mostly used PV subsidies in this province [7].

Since 2002 diverse local incentives have been also implemented in province Vorarlberg and thereby Vorarlberg has become to be the province where the most PV systems have been installed. The successful privately organised shareholder programme "SONNENSCHEIN" (sun bill) campaign was also launched in Vorarlberg in 1997. Within this programme private individuals and local governments are encouraged to purchase “Sonnenscheine” (= “Sun bill”) and the price of a share was 1000 ATS (≈ 70 US$, ≈ 70 EURO). The systems are operated either by private persons or communities. The installations are supported by means of 30 % to 35 % rebates from the province of Vorarlberg. This program caused to increase of interest in PV systems [6]. After that in October 2001 the feed in tariff came into force —72 €cent/kWh for new systems and 50 €cent/kWh for old systems have been granted for 15 years— and this support stimulated the residential PV System installations in this province. Currently this province offers no supporting for PV systems.

As described above until 2003 the Austria framework for renewable energy support had been based on diverse local and regional incentives. In January 2003 the first nationwide Green Electricity Act (GEA) came into force and within this act the support in form of preferential feed-in tariffs for electricity from renewable sources together with a purchase obligation for green electricity created a very attractive environment for investment in general and PV in detail [8]. In the framework of this legislation for PV systems installed, the feed-in tariff was set to 60 Eurocent per kWh for systems up to 20 kW and 47 Eurocent for larger installations for 13 years. However this support was set for an overall capacity cap of 15 MW which fulfilled in 14 days after the GEA came into force [8]. Because of no national supporting any more in 2004 installed capacity declined 64 % compared to the year 2003.

After a period of about 3 years with no federal support for PV, Austria’s parliament has passed a revision of the Green Electricity Act in May 2006, including a once again renewed slight photovoltaic incentive. The overall aim of the Green Electricity Act (GEA) is to increase the share of electricity from Renewables to more than 78,1 % in 2010, based on the obligations from the EU directive on Renewable Electricity. The GEA governs not only the support for green electricity but also for electricity from combined heat and power generation. A new paragraph now includes support for larger hydro power plants (50-100 GWh/a) [9].

Starting from 2006 up to 2010, another 17 MEUR will be dedicated each year to cover feed- in tariffs for newly installed energy systems. While the main part is dedicated to biomass and a much smaller part for wind, 10 % is reserved for all other sources such as PV, liquid biomass, co-firing power plants and/or others. Concluding from that, for PV an annual maximum of 1,5 MEUR from the federal budget can be expected; specifically for PV support, regional parliaments are encouraged to double this federal subsidy, which makes the support system even more complex [9].

Photovoltaic feed-in tariffs for 2007 are 46 Eurocent (< 5kW), 40 Eurocent (< 10 kW) as well as 30 Eurocent (>10kW). Compared to the former regulation, the time frame for the feed-in tariff is reduced, as well as the tariffs being reduced in total (100 % of the source/size specific tariff in year 1 to 10, 75 % in year 11, 50 % in year 12). Also, a decrement factor shall be implemented to reduce the source/size specific maximum tariffs each year by about a few percentage points. It can be expected that this new regulation will lead to about 4-6 MW annually installed systems in Austria [9].

5.2 France

The very beginning of the French PV market dates from the early 80's, when the first off-grid home systems were installed in remote rural areas thanks to European "THERMIE" programs. Since then up to the early 90's, most PV had been used for supplying power to climbers' huts in Alps and Pyrénées. The very first grid-connected plant was installed in 1992 by a private initiative led by Hespul, but the French Environment and Energy Management Agency (ADEME) initiated in the same year a first FP4 EC program concerning 5 grid-connected PV systems, followed up to 1999 by a suite of 4 EC programs initiated by Hespul that brought grants to hundreds of private facilities totalling around 400 kWp, sometimes co-financed by Regional Authorities. As there was, by that time, no specific framework for the connection of small scale PV systems to the LV distribution grid, the energy was just exchanged with the grid (net-metering).

Considering the global market trends and the needs of French PV industry to develop, ADEME decided in 1999 to officially support the grid-connected market in France, through its direct involvement in the FP5 "HIP-HIP project", aimed at installing 500 kW of BIPV in each of the 6 participating member states, thus allowing partners within the project to take benefit from the experience of the most advanced countries (Germany and Netherlands). This successful project combined with past initiatives led the Ministry of Industry to release, by the end of 1999, the first legal text for the connexion to the grid of PV systems: a contract for the purchase by EDF of the energy produced by a PV system at the same price fixed by EDF to sell the energy to the customer [10].

The market really started to grow in 2002, after the official publication in March 2002 by the Industry Minister of feed-in tariffs for the energy produced by PV systems as a direct consequence of the transposition of the European Directive 96/92/CE relating to the common rules for internal electricity markets and the opening of electricity markets. The reference feed-in tariff defined by this Arrêté was 0,1525€/kWh for systems in Continental France and 0,305€/kWh for Overseas Departments [11].

In 2004, the independent administrative body in charge of regulating the French electricity and gas markets, CRE, decided that grid operators have to share with grid users rules applicable for the connection to public grids. This led EDF Réseau de Distribution (ERD), the entity in charge of distribution grids in Continental France, to publish a detailed guideline for the connection of small scale PV systems (<36 kW) to the LV distribution grid [12].

Feed-in tariffs were revised in July 2006 with the official publication by the Industry Minister of a new Arrêté which sets:

- The feed-in tariff for PV systems in Continental France at 0,30€/kWh;
- The feed-in tariff for PV systems in Overseas Department at 0,40€/kWh;
- A grant for Building Integrated PV systems (BIPV) at 0,25 €/kWh in Continental France and 0,15 €/kWh in Overseas Departments [13].

Combined with a 50 % tax credit on equipment costs (excluding labour costs for the investment of renewable energy systems installed in individual homes), the objectives of the government is to boost two specific market segments :

- Small to medium scale BIPV systems in Continental France, specifically targeted to individual home owners;
- Large scale ground-mounted or roof-top PV systems in Overseas Departments.

The effects of this incentive policy are in line with the objectives since the annual market for grid-connected PV systems was 12,4 MW, a 122 % market growth between 2005 and 2006. Overseas Departments represent approx. 2/3 of the annual market (8,4MW) and Continental France 1/3 (6MW). In Continental France, 60 % of the annual market was installed on individual homes (3,4 MW). With 11 MW of stand-alone PV systems, the total PV capacity installed in France by the end of 2006 was 41 MW [14].

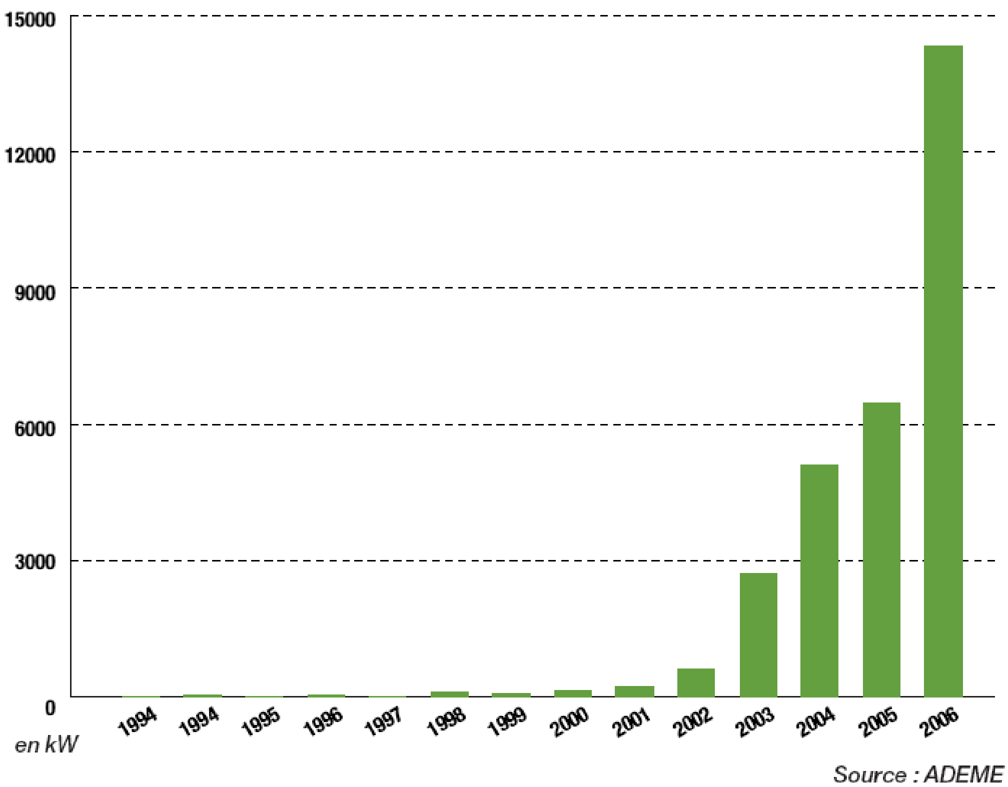

Figure 2: Annual grid-connected PV market in France

5.3 Germany

5.3.1 Legal frame

There are two most important legal documents on grid access for electrical power from RE in Germany: the EEG (Renewable Energy Act, updated in August 2004) and the new Energy Economy Act including the amendments from July 2005.

The EEG set a firm obligation for electricity companies to buy electrical power from Renewable Energy sources and to buy it fixed rates. The Energy Economy Act including lots of amendments introduced central regulation to German electricity market. The responsible authority is called “Bundesnetzagentur”, i.e. “Federal network agency”.

5.3.1.1 Federal network agency (FNA)

Business environment for electricity companies in Germany has changed significantly during the last 10 years due to liberalisation and deregulation. Currently (2007) it is changing from re-regulation from a new regulation authority, the Federal Network Agency FNA (in German: Bundesnetzagentur, BNetzA) [15].

The Federal Network Agency (German: Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, abbreviation: BNetzA) is the German regulatory office for the telecommunications, postal services, electricity, gas and train markets. In July 2005, the agency had been renamed to Bundesnetzagentur (Federal Network Agency). The regulatory office primary purpose is the regulation of former governmental market segments which have been released into public economy.

All enterprises serving at least 100 000 customers, regardless in which service branch, are subjected to regulation from FNA. That means, about 90 % of the electricity market are ruled by FNA.

5.3.1.2 Renewable energy act (EEG)

PV development in Germany during the last years has been shaped by the “EEG”, the act for feed-in from renewable energy sources. It defines that DG installation operators bear the costs of connection to the next suitable point of the grid, and that grid operators take on the necessary measures and costs for reinforcing the grid. However, they may take these costs into consideration in their charges for use of the grid.

The act guaranties a defined buy-back rate for each kWh generated. The rate is high enough to allow PV systems to be operated profitably with typically some 5 % to 7 % profit rate. Feed-in tariffs depend on mounting – attached to a building or on open land – and system size. The tariff is fixed for the next 20 full calendar years. The following table gives the 2007 rates.

Attached to buildings	up to 30 kW larger than 30 kW to 100 kW above 100 kW	49,21 Cent/kWh 46,82 Cent/kWh * 46,30 Cent/kWh *
Facade integrated:	As above plus additional	5,00 Cent/kWh
Other systems:		37,96 Cent/kWh
* For systems larger than 30/100 kW reduced values refer to the system fraction beyond the threshold. For systems installed in 2008 and later feed-in tarifs are reduced by 5 % for building mounted systems and by 6,5 % for other systems.		

Table III: Feed-in tariffs for systems commissioned in 2007

A detailed discussion of the provisions of EEG is found in [16] also attached as separate document, Annex D4_2_DE_A-1_eeg_main_features_en. The text of the act translated into English language is reproduced as annex D4_2_DE_A-2_eeg_act_text_en.

5.3.2 Technical rules and standards

Specifically for the construction of small, dispersed, grid-connected PV-systems a special section to the basic electric safety code, the VDE 0100, has been written, the "VDE 0100 Teil 712, Photovoltaikanlagen". This code section applies to the erection of PV systems and deals with protection measures, wiring, short circuit protection, grounding, overvoltage protection and selection of components for these systems. This code has also been included as part 712 into the IEC 60364 series of standards.

A second set of PV specific rules has been fixed in the specifically German standard DIN VDE 0126-1-1. These concern mainly a safety interface for islanding prevention. Technical specifications and test requirements for inverters, respectively separate interface units, are given. The standard includes specific requirements for transformerless inverters. For systems below 30 kVA generator it allows under certain conditions to replace an external isolation switch. Important requirements for the hardware are “single-fault-security” and “fail-safe” construction [17] /VDE 2007/.

This standard had been revised in 2006 and now includes impedance measurement, as well as other islanding detection methods than. Furthermore, it now uses the same cut-out criteria for inverters as for large power plants connected to the high voltage network. These criteria are listed in [18] /EON 2006/ (see also Annex D4_2_DE_A-3_EON_HV_grid-_connection_requirements_ENENARHS2006de).

A third collection of rules is issued as a general guideline by the VdEW, the Association of Electric Power Companies. This guideline, "Guidelines for the operation of private production systems parallel to the low voltage public grid", last updated 2005, does specifically address PV-systems [19] /VdEW 2001/.

Extensive information on structure and content of German standardisation has been collected in the DISPOWER project. The related report can be found in [20] /Viotto 2005/, also annexed as D4_2_DE_A-4_Standards_guidelines_DE_tech_2005_0058.

5.3.3 Market development

Due to favourable provisions in the "EEG" market for PV systems in Germany was growing quickly.

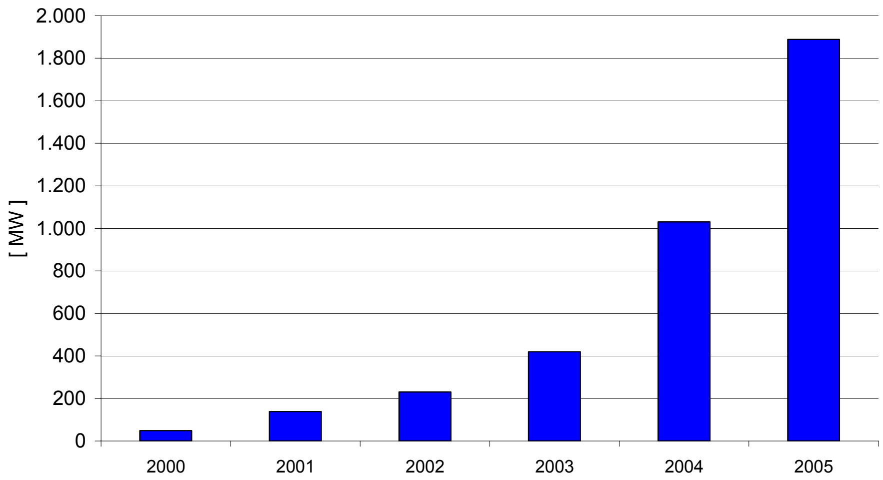

Figure 3: development of PV market in Germany (source: Photon magazine, November 2006)

This growth concentrates on the southern German states as can be seen for figure 4. Southern Germany receives a slightly higher irradiation than central and northern Germany.

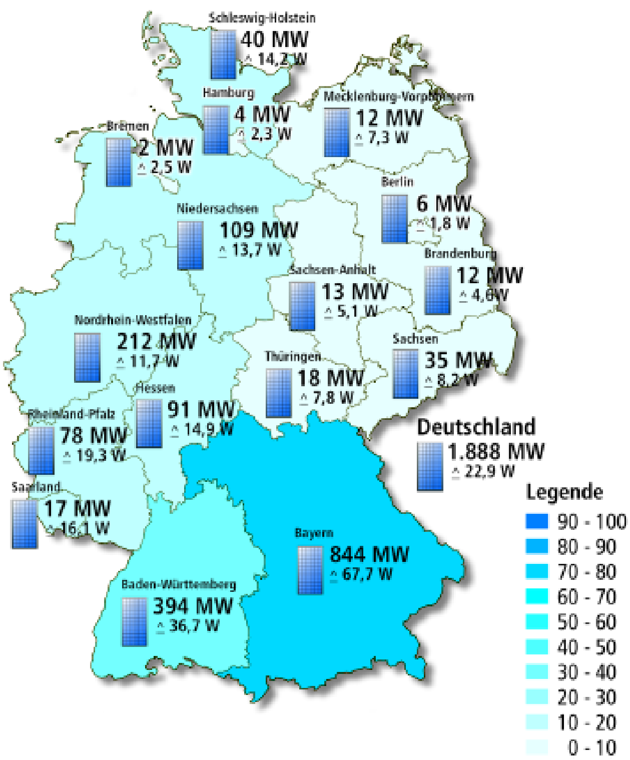

Figure 4: distribution of market shares among the German states. The second figure indicates the installed PV capacity per capita (Source: Photon magazine, November 2006).

5.4 Spain

The evolution of PV grid-connected systems in Spain over the last decade (from less than 10 MW installed in 1996 to 106 MW cumulative at the end of 2006) can be explained by the evolution of the regulatory framework applicable, which is summarised in the following paragraphs:

- PV-generated electricity, as all electricity coming from Renewable tecnologies, is included under the so-called "Special Regime" since 1980 when the Spanish government enacted the "Law on Energy conservation" (*Ley 80/1980 de Conservación de la Energía*), in order to face the challenges imposed by the second oil crisis. As a consequence, "electricity sef-generation" (Distributed Generation) and hidroelectric production from small plants were promoted, further on with the Spanish Energy Plan (*Plan Energético Nacional 1991-2000*) and later regulations (*Ley 40/1994 de Ordenación del Sistema Eléctrico)*. The few existing PV grid-connected systems were mostly in this period of centralized-type, promoted and operated by utilities.
- The first PV feed-in-tariff was established in 1994 by a "Royal Decree" on electricity generation by renewables and cogeneration (*Real Decreto 2366/1994*) [21]. Each kWh of PV-electricity was valued at 90 % the "Average Electricity Tariff"[a], or around 3-4 c€ (3-4 €/MWh).
- In 1997, the Law of the Electrical System (*Ley 54/1997 del Sector Eléctrico*) was enacted in order to make the electrical market liberalisation compatible with the objectives of guarantee of supply, quality and low environmental impacts. It promoted explicitly the "Special regime", defined as generation units powered by renewable energies and cogeneration, with power capacity up to 50 MW.

  The administrative, energy delivery and economic procedures of the "Special regime" were established in 1998 by another Royal Decree (*Real Decreto 2818/1998*) [22]. PV grid-connected systems had two options:

  a) To participate in the regular electricity market. PV feed-in-tariff varied monthly, according to the following expression:

  $$PV_{\text{feed-in-tariff}} = AEC + B \pm REC$$

  with *AEC* being the Average Expected generation Costs (base or peak electricity hours); *B* a bonus of 18 or 36 c€/kWh for PV systems with power up to 5 kW or higher[b], respectively; and *REC* a Reactive Energy related Complement (positive if power factor >0,9 and negative otherwise).

  b) To deliver their production at a fixed price: $PV_{\text{feed-in-tariff}}$ = 21,64 or 39,67 c€/kWh, for systems with power capacity up to 5 kW or bigger, respectively.

- Notwithstanding the previous favourable financial incentives, no specific administrative and technical requirements for PV grid-connected systems were available until 2000[c].

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[a] Expected average electricity generation cost, plus an increase that includes transportation, distribution, commercialisation, maintenance, supply diversification and security of supply related costs.

[b] PV systems power is defined as the name-plate nominal power of the inverter (or sum of inverters, if more than one connected to a single PV generator).

[c] Technical requirements applicable to PV were also applicable to small hydroelectric plants up to 5000 kVA and other renewable powered plants with power up to 100 kVA.

These were established by a Royal Decree (*Real Decreto 1663/2000*) for systems up to 100 kVA connected to the low voltage electricity grid [23]. PV systems over 100 kVA are still regulated by the previous requirements *(Orden de 5 de septiembre de 1985)* [24].

- In 2004, new legal and economical regulations applicable to the "Special Regime" were established by another Royal Decree (*Real Decreto 436/2004*) [25]. In relation to PV grid-connected systems, an important difference with the previous situation is worth mentioning, namely, a time framework is explicitly considered (the whole lifetime of the plant), although a cap of 150 MW was also mentioned for revision of the feed-in-tariffs[d]. Again, PV grid-connected systems had two options:

  a) PV systems up to 100 kW: to deliver their production at a regulated tariff, related to the "Average Electricity Tariff":
  - Year 1 to 25 of operation: $PV_{\text{feed-in-tariff}}$ = 5,75 x *AET*, with *AET* being the Average Electricity Tariff (7,3304 c€/kWh in 2005; 7,6588 c€ in 2006, that is, a 4,48 % increase over the previous year).
  - Year 26 on: $PV_{\text{feed-in-tariff}}$ = 4,6 x *AET*.

  b) PV systems over 100 kW:
  - b.1) To deliver their production at a price related to the "Average Electricity Tariff":
    - Year 1 to 25 of operation: $PV_{\text{feed-in-tariff}}$ = 3 x *AET*.
    - Year 26 on: $PV_{\text{feed-in-tariff}}$ = 2,4 x *AET*.
  - b.2) To participate in the regular electricity market (minimum of one year). PV feed-in-tariff varied monthly, according to the following expression:

    $PV_{\text{feed-in-tariff}} = SP + AET \times (I+B)$,

    with *SP* being the Selling Price (variable, depending on the market conditions); *I* an incentive for market participation (0,1); and *B* a bonus:
    - Year 1 to 25 of operation: *B* = 2,5.
    - Year 26 on: *B* = 2.

  Note: in practical terms, all PV grid-connected systems over 100 kVA applied to the b.1 option.

- In March 2006, a new Spanish technical standard for buildings, called the "Technical Building Code" (*Código Técnico de la Edificación*, CTE) [26], came into effect. Of special relevance for solar technologies is the objective of rational use of energy through the limitation of energy demand, by increasing the thermal and lighting systems efficiency and the use of active solar technologies (solar thermal and photovoltaic). It is fully applicable since September 2006 to new as well as certain retrofitted buildings (bigger than 1000 m^2 surface, with more than 25 % of the enclosure modified by retrofit). As far as PV technology is concerned, it shall be compulsory only in certain types of buildings, depending on their final use and minimum size:
  - Commercial, large supermarkets: 5.000 m^2 surface.
  - Commercial, multi-stores: 3.000 m^2;
  - Commercial, big stores: 10.000 m^2;
  - Showgrounds (for trade fairs): 10.000 m^2;
  - Office buildings: 4.000 m^2;
  - Hotels and guesthouses: 100 beds; and

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[d] Later on, the cap was extended to 371 MW.

– Hospitals and clinics: 100 beds.

In these buildings, the minimum PV power to be installed depends on the local climatic conditions (5 different categories are defined) and the building use, with a minimum of 6,25 kWp.

- Besides feed-in-tariffs, since the late 1990's other supporting schemes for PV Distributed Generation have been available for investors:
  – Subsidies given by European development demonstration projects (European Commission, several Framework Programmes) and regional governments programmes (from 2005 on, in all of the 17 regions comprising Spain).
  – Soft loans from the Spanish Official Credit Institute (*Instituto de Crédito Oficial*) and the Institute for Energy Diversification and Savings (*Instituto para la Diversificación y Ahorro de Energía*) [27], in effect until 2005.
  – Soft loans from banks and credit institutions.

- Finally, in June 2007, a new Royal Decree (*Real Decreto 661/2007*) has introduced new changes in the regulation of the "Special Regime" electricity production activities, with the aim of fostering the penetration of renewable and cogeneration technologies beyond the levels reached to date, and therefore contribute to a more sustainable electricity market [28]. The alternative for PV systems selling electricity at regulated tariffs are:

  a) PV systems up to 100 kW:
  – Year 1 to 25 of operation: $PV_{\text{feed-in-tariff}}$ = 44,0381 c€/kWh.
  – Year 26 on: $PV_{\text{feed-in-tariff}}$ = 35,2305 c€/kWh

  b) PV systems over 100 kW and up to 10 MW :
  – Year 1 to 25 of operation: $PV_{\text{feed-in-tariff}}$ = 41,75 c€/kWh.
  – Year 26 on: $PV_{\text{feed-in-tariff}}$ = 33,40 c€/kWh

  c) PV systems over 10 MW and up to 50 MW :
  – Year 1 to 25 of operation: $PV_{\text{feed-in-tariff}}$ = 22,9764 c€/kWh.
  – Year 26 on: $PV_{\text{feed-in-tariff}}$ = 18,3811 c€/kWh

  Annual updating of the previous feed-in-tariffs will be according to the CPI (Consumer Price Index) – 0,25 % up to 2012, and CPI – 0,5 % from 2013 on. Besides the feed-in-tariffs, the PV systems will receive a REC (reactive energy complement), depending on the quality of the electricity generated (power factor).

  Also, the option exists to participate in the regular electricity market.

Concerning the evolution of PV-DG in Spain, it was not until 2001 when a substantial number of systems could profit from the feed-in-tariffs (see Table IV), once specific technical requirements were available. Also, the average size of the PV systems has changed, from 5 kW being the dominant size up to 2002, up to 100 kW at present, clearly influenced by the financial incentives applicable (feed-in-tariffs levels). It is expected that with the new feed-in-tariffs issued in 2007, the size of many PV systems will continue to grow into the MW size. Figure 5 shows the cumulative installed PV power since 1998, when the first feed-in-tariffs came into effect.

Year	number of systems	Net Capacity * (MW)	Electricity generation (GWh)
1998	5	1	1
1999	7	1	1
2000	33	1	1
2001	183	3	2
2002	777	7	5
2003	1548	11	9
2004	3180	21	18
2005	5221	44	41
2006	8374	106	112,2

Source: Spanish National Electricity Commission
*: Net capacity is the cumulated max capacity of inverters at the end of the year, which is about 10 %-20 % of the PV modules peak power

Table IV. Evolution of grid connected PV systems under the "Special Regime" [29]

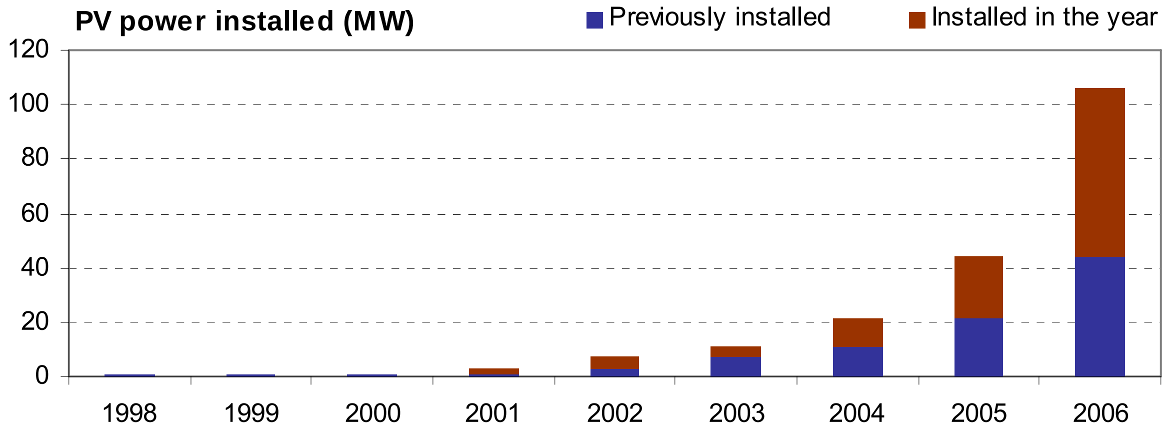

Figure 5. Cumulative installation levels of PV-DG in Spain ("Special Regime")

5.5 The Netherlands

Until 2000, research and development of PV in The Netherlands was carried out in the framework of a dedicated national PV R&D program operated by SenterNovem (Novem) on behalf of the Ministry of Economic Affairs. In addition, many PV projects were (co)financed through general programs aimed at fundamental research, technological and ecological innovation, and industrial development. Finally, a variety of projects were part of the European research programs. PV demonstration and implementation projects were part of the "learning program", also operated by SenterNovem. The total of PV activities fell under the umbrella of the so-called "PV Covenant", which set targets for market development (in terms of MWp installed PV capacity and turn-key system price levels) and removal of existing barriers. The Covenant was voluntarily signed by almost all players in the PV field: national and local governments, energy companies, project developers and building companies, manufacturing companies, R&D institutes, consultants, an others. The Covenant 1997-2000 was completed successfully and a total of 10 MWp grid-connected PV systems were in operation at the end of 2000. [30, 31]

History of PV-projects in the Netherlands (1983-2000):

1983: First large European autonomous 50 kWp PV-project "Willem Barentz", Terschelling.

1988: First off-grid solar house in Castricum 2,5 KWp with a 10 kWh storage capacity.

1991: 10 Houses with a grid connected PV-system in Heerhugowaard.

1994: 66 houses in the district Nieuw Sloten in Amsterdam (250 kWp).

1996-2000: project Nieuwland: 1,3 MWp in Amersfoort.

2000: Floriade 2.3 MWp Exhibition roof, Haarlemmermeer.

In 2001 the national government changed its policy concerning Renewable Energies. Since the main contribution to the 10 % target was expected to come from wind energy and biomass, it was decided that all dedicated (R&D, demonstration and market development) programs on other Renewables, such as thermal solar energy and PV, would be ended immediately. In line with this, the target of 1500 MWp PV in 2020 was also abandoned. The PV R&D program was replaced by the “Renewables in The Netherlands” program (DEN), in which all major Renewables would have to compete in terms of their contribution to the 10 % target and in terms of their innovation quality [30]. The DEN program was followed by the EOS (energy research subsidy) program which still has the competition element. The program has five focus areas:

- Energy-efficiency in the industrial and agricultural sectors;
- Biomass;
- New Gas/ Clean fossil;
- Built environment;
- Generation and grids.

The subsidies in the program can be applied in the technology development traject "idea to market introduction" and is mentioned for technical research institutes and companies.

In last decade several PV incentives were initiated and ended (see the following paragraphs). Nowadays solar power does not have direct financial support on a national level. The continuously strong changing Dutch governmental policy has resulted in unstable market climate. The market demand in the last decade is only influenced by the changing policy. In 2003 the Dutch government finished the successful EPR regulation which ended the demand and leaded to a real buyers strike (see figure 6) [32,33,34]. Other regulations like corporate tax benefits (except the EIA regulation) also disappeared in the last years. On a provincial and municipality level local financial support initiatives via the BANS regulation are organized yearly for consumers. The amount of support depends per municipality and province. The future for PV is still cloudy. The government is debating about reinstalling the MEP regulation, a type of a feed-in tariff.

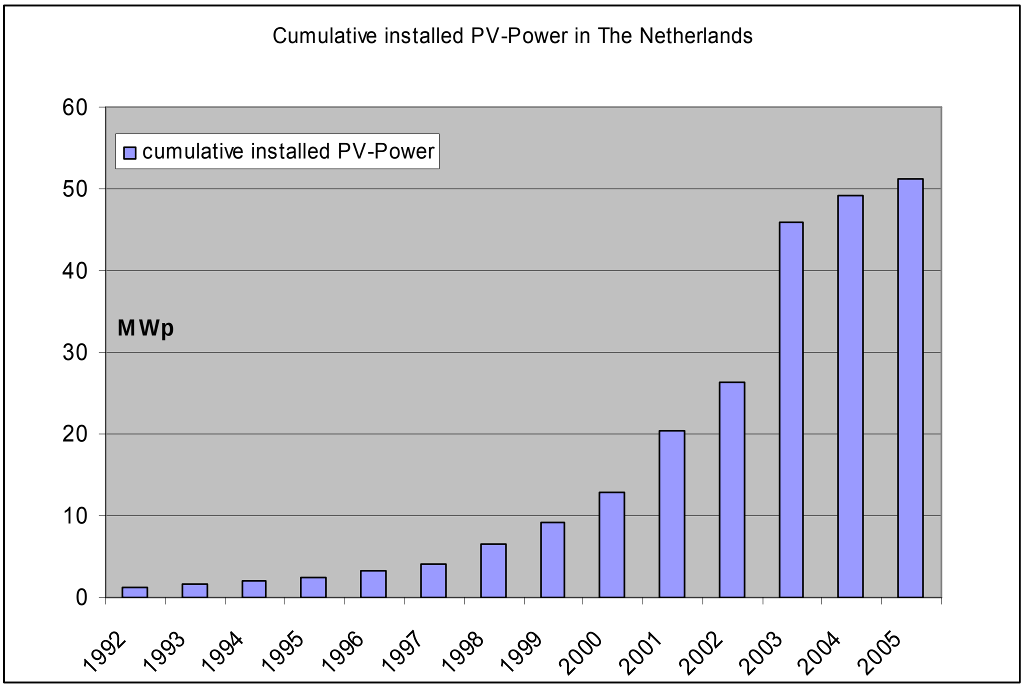

Figure 6: Cumulative levels of PV installations in the Netherlands [3][4]

2001-2003: EPR regulation: Energy Contribution Regulation

The EPR regulation was initiated to stimulate the purchase of energy efficient apparatus and renewable energy technologies for house owners. In the period 2001- 2003 house owners were able to get subsidies of € 3,50 to 4,25 per Wp. The amount of systems in the Netherlands grew rapid with the EPR regulation. The Dutch government ended the EPR regulation in 2003 due to the success of the incentive.

2001-2007: VAMIL-regulation: Arbitrarily Deductible Environmental Investments

The VAMIL regulation offers companies a liquidity and interest advantage. They can extend the payment for income tax or corporation tax by variable depreciation of environmental investments. When companies depreciate faster the fiscal profit decreases and finaly pay lesser tax. The VAMIL regulation can be combined with the MIA regulation (see below). However, PV is not a part of the VAMIL regulation in 2007.

2001-2007: MIA-regulation: Environmental Investment Deduction

The MIA regulation is a company tax regulation. Companies can deduct 15 %, 30 % or 40 % environmental investment costs from their fiscal profit. The MIA regulation can be combined with the VAMIL regulation. However, PV is not a part of the MIA regulation in 2007.

2003-2006: MEP regulation: Environmental Quality Electricity Production

The MEP regulation substituted the scheme that producers of green electricity were exempted for energy tax (REB). The REB was substituted due to the fact that tax money was leaking to foreign countries because foreign green electricity producers could not be excluded based on EU policy.

Via the MEP regulation producers could get a maximum of 0,07 €ct/kWh over a period of 10 years. The Ministry of Economical Affairs finally stopped with the regulation due to its success in 2006.

2002- 2007: EIA regulation: Energy Investment Deduction

The EIA regulation is a company tax regulation. Companies are allowed to deduct 44 % of the investment in renewable technologies from their fiscal profit. This regulation is still valid for PV.

2004-2007: BANS regulation: Directorate Agreement New Style

In order to stimulate measures favorable for energy reduction and implementation of renewable energy the central government supports municipalities and provinces through the BANS framework agreement (*BestuursAkkoord Nieuwe Stijl*). By the end of 2004 about 200 municipalities had indicated their intent to actively participate in the program. Since the actual activities are expected in 2005, the effect of BANS was rather limited in 2004. However, during 2004 a number of municipalities began to actively encourage building corporations and private citizens to invest in PV installations on their roofs. Examples are the municipalities of Eindhoven and Leiden offering investment subsidies of 1 to 1,50 € per watt.

5.6 United Kingdom

The market for PV in the UK is still relatively small compared to some other countries, but is growing at a fast rate. It is estimated that by the end of 2005 around 10,9 MWp of PV was installed in total in the UK. The cumulative installation of PV has grown substantially over the last years with 33 % growth in 2005 as shown in the following figure.

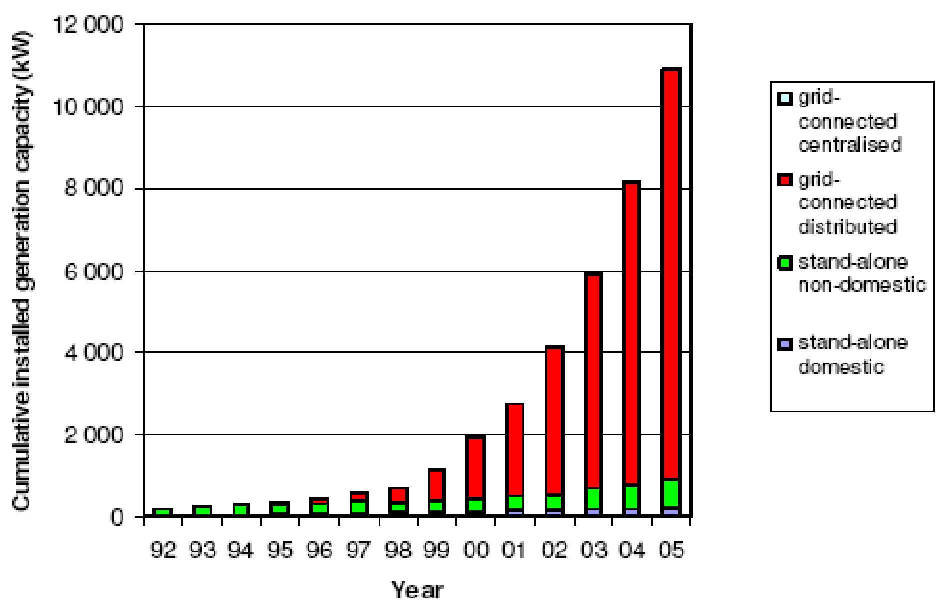

Figure 7: Cumulative levels of PV installations in the United Kingdom [35]

Looking to the future, the Renewables Innovation Review estimated that PV could contribute 6-8 % of overall UK electricity supply by 2050 and lead to a 3 million tonnes of carbon (MtC) reduction in carbon emissions.

In addition Renewable Energy is an integral part of the Government's longer-term aim of reducing CO2 emissions by 60 % by 2050. The Government has set a target of 10 % of electricity supply from renewable energy by 2010. In 2005, 4,2 % of the UK's electricity supply came from sources of renewable energy.

The following milestones in the regulatory framework have facilitated the installation of grid connected systems in the UK both from the technical and regulatory point of view:

- PV-generated electricity (of all system sizes) initially covered by technical Engineering Recommendation G59/1 published 1991.
- Introduction of simplified Guidance in Engineering Recommendation G83/1 in September 2003 to cover smaller generators (following collaborative work between PV Generators and Electricity industry).
- First round of grants 'Major PV Demonstration Programme' released in 2002:
  - Stream 1 initially with grants of 50 % for domestic systems up to 5kWp size.
  - Stream 2 initially with grants of 50 % or 60 % for commercial/ public buildings up to 100kWp.
  - Caps introduced later in the scheme to limit the maximum grant per kWp depending on the building integration technology used.
- The Low Carbon Buildings Programme (LCBP) took over from this scheme in 2006 based on a similar system of grants, but covering other Renewable technologies as well as PV.
- P81 'profiling' introduced in 2003 to provide simplified payment for small domestic generators, size increased in 2004 to cover systems up to 30kW..
- ROCs (Renewable Obligation Certificates) extended to small distributed generators by allowing outputs to be accumulated and claimed for over a year, 2006.
- Planning Guidance Note PPS22 introduced encouraging planning consent for PV, 2004.
- Planning consultation document currently underway 2007, to examine if PV can be included as a 'Permitted Development'.

6 UTILITIES EXPERIENCE AND PERCEPTION OF DISTRIBUTED PV

6.1 Austria

In Austria the generation sector is mainly publicly owned. Due to a constitutional act the main Austrian electricity companies are owned by federal, provincial or municipal governments. The main generator is Verbund AG, followed by the nine provincial utilities: EVN, Wien Strom, STEWEAG-STEG, EAG OÖ, KELAG, TIWAG, VKW AG, BEWAG and Linz AG. These few companies generate almost 95 % of all electricity injected into the public grid. Large distribution networks belong to these provincial utilities which are legally unbundled [36].

The Austrian electricity market was fully liberalised on 1 October 2001 and within the federal territory of Austria the electricity market is divided into three control areas. Within the control areas market participants (power generators, traders and consumers) are pooled in balance groups, which are organized on market principles [37].

Austrian control area managers (transmission system operators) are *VERBUND-Austrian Power Grid AG* (APG), TIWAG-Netz AG and *VKW- Netz AG* and they are responsible for power-frequency control. The control area of *VERBUND-Austrian Power Grid,* which constitutes a control block itself and accounts for approx. 90 % of the Austrian electricity market, and western control areas of Tyrol and Vorarlberg, which are assigned to the control block of Germany [37]. The figure below shows the control areas and three responsible enterprises (transmission system operators). Organisational separately from their other functions the control area managers (APG, TIWAG-Netz AG and VKW-Netz AG) set up also the eco balance group managers[e].

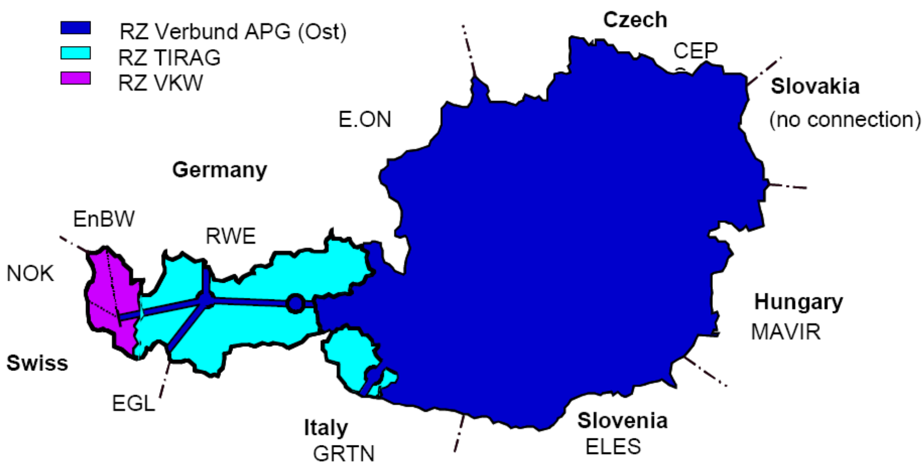

Figure 8: Control areas of the electricity market in Austria [38]

The main activities of interviewed utility "VKW-Netz AG" are:

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[e] In German: Öko –BGV (Ökobilanzgruppenverantwortliche)

- Control area manager in Vorarlberg,
- Transmission and distribution utility, and
- Eco Balance group manager in control area Vorarlberg.

In this respect VKW-Netz AG is the most relevant company concerning PV–DG in Austrian distribution networks. Its distribution networks received in 2006 about 58 % of the PV electricity fed in these balance groups. The table below shows the allocation of grid connected PV systems to balance group managers. This table doesn't provide the complete picture of grid connected PV systems as there are also PV system operators which offer their generation on the free market in Austria. However for these systems there is no statistical obligation as their amount is under about 1 MWp [39].

Province	***number of systems***	***Net Capacity * (MW)***	***Electricity generation 2005 (GWh)***	***Eco Balance Group Managers***
Burgenland	34	0,203	0,150	Verbund
Carinthia	156	2,189	2,147	Verbund
Lower Austria	164	0,666	0,295	Verbund
Upper Austria	319	1,256	0,598	Verbund
Salzburg	144	1,312	1,275	Verbund
Styria	196	1,003	0,705	Verbund
Tyrol	40	0,312	0,182	TIRAG
Vorarlberg	**885**	**8,266**	**7,424**	**VKW**
Vienna	37	0,151	0,146	Verbund
TOTAL	**1.975**	**15,358**	**12,922**	

Source: E-Control, Stand March 2006 [40] [41]
*: Net capacity indicates the max capacity of inverters which is about 10 %-20 % under the peak power capacity of PV modules

Table V. Grid connected PV systems that are contractual relationship with eco balance group managers

6.1.1 Technical assessment of PV Distributed Generation:

Harmonics from inverters

- According to the company VKW-Netz AG harmonics is considered as a current problem. They experienced a disturbance of electricity meters in a community where 260 kW PV connected to the low voltage grid because of harmonics induced by inverters.
- The company considers harmonics a current concern in the future with large penetration of PV-DG.
- PV plants operation as "active filters" are of potential interest for this company in urban areas as well as in rural areas.

Voltage regulation

- Currently the company has perceived often problems regarding voltage regulation. That's why this is a present concern.

- According to company the voltage regulation systems -which they use- adequate for bidirectional power flows.
- The allowed maximum over voltage by Austrian regulations (PV-DG 5 % of nominal voltage: 2 % in MV, 3 % in LV) is considered not sufficient by this company. Because it is a challenge to put 5 % into the voltage range of +/-10 %.
- A VEÖ measurement campaign showed smaller voltage differences in real networks as demanded in the regulatory framework “TOR D2” ([42,43])
- Voltage regulation could be a concern in the future in urban as well as in rural areas.
- PV plants operating as “ voltage regulators” are of potential interest.

Anomalous situations in distribution networks

- PV–DG imply different /new requirements for network operation but it has not been specified by this company.
- Regarding malfunction of networks protections due too PV-DG there is a concern in LV but this issue is in MV level little known.

PV systems grounding

No concern (present and future) regarding this aspect.

Unintentional islanding

No known area for this company. No comment has been given.

Electromagnetic compatibility of inverters

- There is a lack of knowledge regarding standards of electromagnetic compatibility.
- There is some concern about mutual disturbance of large numbers of inverters.

External disconnect

According to this company automatic switches would be necessary for each PV-DG but in this regards a question appears; who should pay for changing present integrated switches (relay) into automatic switches.

Reclosing

Description of protocols is momentary being worked out by this company.

DC currents and transformerless inverters

No comment has been given.

Penetration limits for PV-DG

- Penetration limit: 1/3 of the transport capacity of the line /transformer capacity.
- For this company higher penetration limits should be in urban areas while smaller penetration limit should be in rural areas.

Planning, operation and maintenance of distribution grids in relation to PV-DG

- PV-DG currently considered in planning in LV as well as MV level significantly.
- The company has found that the fundamental software for calculation of load flow is sufficient.
- There is no interest for including PV-DG into load dispatching in LV level. For MV level no comment has been given.
- Specific requirements are needed for network operation due to PV-DG.
- Maintenance (PV disabling): no specific requirements/measures are needed.

6.1.2 General assessment of PV Distributed Generation:

Experience with PV-DG

The experiences which were given by this company can be classified as follows:

- At times with few load (weekend) PV-DG can be noticeable,
- Often PV-DG in rural areas cause cable connections with disproportionately (big) dimensions at the end of supply network, not justified by the existing loads.

Applicable standards / new regulation requirements

- Current standards applicable to PV-DG are considered insufficient.
- Issues at present not covered by standards are flicker and harmonics, which also should be included.

Other Issues

Other research and development needs have not been identified.

6.2 France

In France, electricity distribution grids are owned by municipalities. The law of nationalization of the electricity and gas signed in 1946 which officially created *Electricité de France* (EDF) gave the choice to municipalities either to operate their own local distribution grid or to choose EDF as the operator of their grid.

Among the 36 000 French municipalities, approx. 95 % decided in 1946 to let EDF operate their electricity distribution which is now still done by an entity of EDF, EDF Réseau de Distribution (EDF-ERD). But 2 500 municipalities decided to keep the control of their local electricity grid and created local distribution companies called Entreprises Locales de Distribution (ELD). Today, there are approximately 170 small to medium size ELD in France (see Figure).

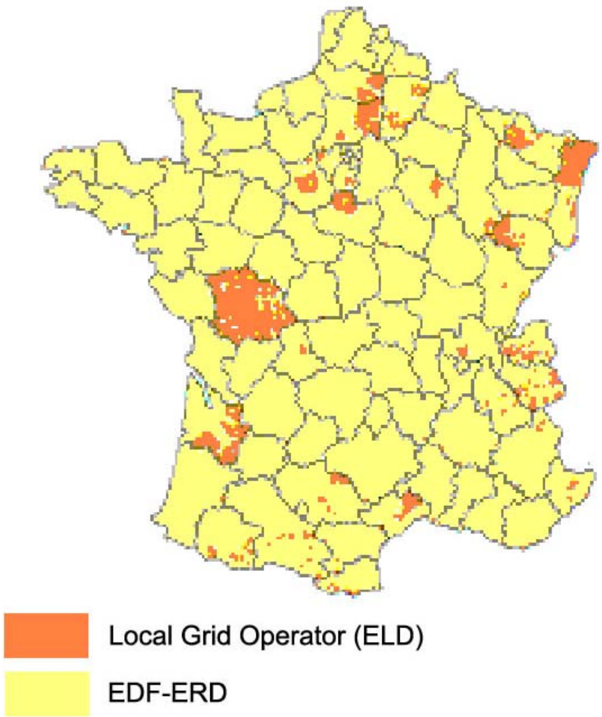

Figure 9: Location of distribution electricity grids operated either by EDF-ERD of by an ELD [44]

In addition to EDF-ERD which is a key actor in the distribution grid sector since it operates 95 % of distribution grids, the questionnaire was translated into French and sent to the 4 largest ELD of France: Électricité de Strasbourg, Sorégies, Usine d'Électricité de Metz and Gaz et Électricité de Grenoble (see below).

Company	*French Network Operators*	*Network characteristics*
	EDF Réseau Distribution **ERD** www.edfdistribution.fr	586.000 km MV lines 654.000 km LV lines
	Électricité de Strasbourg **ES** www.electricite-strasbourg.fr	700 km HV lines 4.340 km MV lines 8.400 km LV lines
	Sorégies **www.soregies.fr**	12.000 km of MV and LV lines
	Usine d'Électricité de Metz **UEM** www.uem-metz.fr	4.000 km MV and LV lines
	Gaz et Électricité de Grenoble **GEG** www.geg.fr	486 km MV lines 562 km LV lines

Table VI. List of grid operators contacted for an interview

All grid operators contacted for an interview claimed to have to little experience with PV to answer the technical questionnaire, except EDF Recherche et Développement (EDF R&D) that, on behalf of EDF-ERD and EDF-SEI, the entity in charge of Overseas Departments and therefore non-interconnected distribution grids, accepted to give its experience and perception of PV.

At the end of 2006, EDF-ERD claimed to have approx. 1 500 PV systems connected to its grid for a total cumulative power of 5 MW. EDF-ERD also mentions that the number of PV producers that connection requests to the grid is growing very fast with approx. 250 new requests each month [45].

6.2.1 Technical assessment of PV Distributed Generation:

Harmonics from inverters

- Harmonics are not considered as the most urgent present issue by grid operators.
- High even DC current harmonics (H6 and H8) measured during a monitoring campaign on a 6 inverter PV system with 2 transformerless inverters. The origin of the high H6 and H8 current harmonics still need to be determined.
- PV plants operating as "active filters" (harmonics generation to reduce/suppress existing network harmonics) are of potential interest.

Voltage regulation

- Although the total power installed in France is low, a problem of voltage rise/drop was already identified on a weak LV grid.
- Grid operators expert other similar problems to occur on weak LV grids in the future.
- PV plants operating as "voltage regulators" (compensation of voltage drops under high loads conditions) are of potential interest, especially on weak LV grids.
- No problem identified on MV grids since the voltage regulation is automatic and does not depend on the origin of the voltage rise/drop.

Anomalous situation in distribution networks

- Grid disturbances that impacted the continental European transmission grid on 4 November 2006[f] show that DG is not adapted to support the grid in case of anomalous situations, although it would be of great benefits from distribution grids if PV-DG could participate in the grid stability to prevent a major blackout.
- Present legal framework and new framework under preparation at European level are supposed to deal with this issue.

PV systems grounding

- No concern regarding this aspect.

Unintentional islanding

- At present, voltage and frequency controls are considered enough by grid operators to prevent islanding conditions. Grid operators allow PV users to disconnect the impedance measurement of the inverter to reduce disturbances generated by PV-DG.
- Distribution grids operator would like to receive information about islanding in order to take appropriate measures to avoid islanding operations without creating additional disturbances on the grid.

Electromagnetic compatibility of inverters

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[f] A severe disturbance that was originated in Northern Germany and produced power imbalances in different countries (amongst others, Germany, France and Spain), causing an interruption of supply for more than 15 million European households.

- There is some concern on the EMC of multiple inverters under simultaneous operation.

External disconnect

- Remote connection/disconnection of PV-DG by means of automatic switches (telecontrol) is considered of great interest, especially for big PV plants connected to the MV non-interconnected network.

Reclosing

- ---

DC currents and transformerless inverters

- Grid operators do not have any requirements at present regarding that issue. Information on that subject would be welcome.
- Small DC current value measured during a monitoring campaign on a 6 inverter PV system with 2 transformerless inverters. The origin of the measured DC current still needs to be determined.

Penetration limits for PV-DG

- There is no legal penetration limits for PV-DG. The penetration limits of PV, at the transformer level, are technical and depend on the grid characteristics and are therefore different for rural grids and urban grids :
  - Power installed limited by nominal power of distribution transformer.
  - Power installed limited by voltage rise.
- For non-interconnected network, grid operators would be interested to have some information about the theoretical penetration limit of PV-DG.

Planning, operation and maintenance of distribution grids in relation to PV-DG

- Planning:
  - For each PV-DG to be connected to LV or MV network, a technical study is done to check the compliance with voltage rise current regulations.
  - There is a need to improve existing tools.
- Concerning the potential interest for including PV-DG into load dispatching:
  - For non-interconnected networks, grid operators are interested to have more information about power forecasts in order to take PV-DG into account for power consumption forecasts.

6.2.2 General assessment of PV Distributed Generation:

Experience with PV-DG

- No specific concern in France Mainland at present.
- In Overseas Departments, the grid operator is concerned about the very quick market

development due to the incentive feed-in tariff (0,4 Euro/kWh) and the good solar irradiation. The grid operator would like to be sure to take appropriate measures in order to manage properly its network without preventing the PV market.

Applicable standards / new regulation requirements

- Current standards applicable to PV-DG are considered sufficient but a harmonization at European level seems necessary, especially concerning appropriate measures to avoid islanding operations without creating additional disturbances on the grid.

Research and Development needs

- Appropriate measures to avoid islanding operations without creating additional disturbances on the grid.
- Theoretical penetration limit of PV-DG in non-interconnected network.
- Power forecasts in order to take PV-DG into account for power consumption forecasts.
- EDF R&D is involved in a consortium that submitted a proposal to work on the appropriate characteristics and settings of the disconnection device of PV-DG in order to support the grid in case of anomalous situation so as to avoid the situation that occurred in Europe on 4 November 2006.

6.3 Germany

6.3.1 Electricity companies

The electricity business in Germany is characterised by an oligopolic generation structure. Four big companies own about 80 % of the power generation capacity. However, there is a total of some 800 electricity companies in Germany. Most of them are regional or local network operators (DNO) including small municipal utilities and municipal utilities of large cities. Many of them operate some generation capacity as well.

6.3.2 Technical assessment of PV Distributed Generation

This section of the report draws on three different sources.

- Interviews with utility personal
- informal discussions with utility personal
- governmental evaluation of effects of the German EEG

As shown in fig. 4 the majority of PV systems is erected in southern Germany. Therefore, utilities from southern Germany had been interviewed with regard to their experiences with PV and other distributed generation. Selected utilities cover a broad range of sizes from serving a village with 500 inhabitants to a city of 300 000 inhabitants. Utility sizes are grouped in size classes according to a VdEW classification as given in section 4.5.1 of the main annex. A list of the interviewed utilities is found in section 4.5.2 of the main annex.

The interviews were conducted openly taking the questionnaire as a guide. Results are summarised in the following list.

Harmonics from inverters

- Harmonics are generally not a concern. Modern inverters obey to IEC 61000-3-2 or VDEW interconnection guidelines. Also no concern for future. “Computers and TV sets are much worse.”
- Some big inverters already can operate as “active filters”. However, currently nobody can draw a financial benefit from this service, so there is only theoretical interest. Especially cancelling 5th harmonic had been suggested.

Voltage regulation

- Voltage regulation is not done on LV network. Voltage rise from DG is within accepted limits in urban networks even under high PV density. At rural feeders sometimes grid reinforcement had to be done.
- PV plants operating as “voltage regulators” are of potential interest on long rural overhead feeders to avoid grid strengthening. Currently not employed yet.

Anomalous situation in distribution networks

- No anomalous situation on the network caused by PV had been mentioned.
- New inverters/safety grid interfaces have to show “fault-ride-through” capabilities

- On MV and HV level reduced short circuit currents may cause slower fault clearing at high penetration with inverters

PV systems grounding

- No concern (present and future)

Unintentional islanding

- is not an issue. For small inverters the safety grid interface (former ENS) is established. Systems >= 30 kWp need accessible disconnect switch

Electromagnetic compatibility of inverters

- Not regarded as a problem for modern, type tested inverters.

External disconnect

- Generally required for systems larger than30 kVA nominal inverter power. Thus mandatory for MV systems.

Reclosing

- Not a problem for utilities. Not a problem in urban areas, due to cabling system without reclosing. No information on damaged inverters was available.

DC currents and transformerless inverters

- DC currents from inverters are not an issue. Never had any effect been noticed. (Only from trams.)
- Transformerless inverters are well accepted and constitute no difference for the grid compared to other inverters.

Penetration limits for PV-DG

- There is no specific penetration limit set for PV, but the voltage rise at nominal power must stay below 2 % for any DG. So the tolerable penetration level depends on local network impedance. This corresponds to typically 30 - 40 % of rated transformer power. If demand from potential owners exceeds this level, DNO has to strengthen the network by law.
- At urban grids up to 5,5 kVA inverter power per house is in operation without troubles.

Planning, operation and maintenance of distribution grids in relation to PV-DG

- Phase imbalance due to many one-phase inverters connected to the same phase has been noticed without harm. Should be avoided by coordinated planning of installations.
- No consideration for small domestic PV systems. These can be accommodated by conventionally planned LV networks. Plants on MV level need network analysis before realisation.
- Load dispatching: some DNO use irradiance forecast to estimate PV production for day-ahead electricity purchase.

- For maintenance no specific measures are needed.

6.3.3 General assessment of PV Distributed Generation:

Experience with PV-DG

- Probably all utilities in Germany have experience with PV. Generally, experience from a technical point is good for new systems. There are few technical problems.

Applicable standards / new regulation requirements

- Current standards and VDEW Guideline for private generation are considered sufficient. Requirements to improve phase balance and harmonics compensation could be added.

Research and Development needs

- No such needs were mentioned, however, generally “smart grids” and “distributed generation” should be further developed.

6.3.4 Evaluation of EEG

Due to the fast growing wind energy capacity in northern Germany some transmission network operators face occasional near-overload situations for their network components. This affects especially transmission lines from northern to southern Germany during strong wind regime. On the long run the lines concerned need to be reinforced.

To avoid overloading the network and subsequent instability in the mean time power generation has to be controlled. This approach is discussed for general application.

EEG includes the obligation to regularly analyse its effects and discuss improvements. The last evaluation took place in 2006 and a draft report was published in July 2007 [46] /BMU 2007/.

This report gives suggestions for future changes:

“*For better integration of renewable Energies, especially from fluctuating sources PV and wind, into the transmission and distribution network the network operator should have the option to temporarily reduce power output from these sources, if grid stability is at risk.*

This option affects profitability of the RE system and has therefore be used as limitedly as possible. Furthermore, it should be connected to an obligation to employ all other options of technical network optimization, including strengthening of the network.”

Governing aim is to maximize electricity production from Renewable Energy and Cogeneration plants – as long as transmission system stability is insured.

Operators of RE and Cogen systems, however, should be obliged to implement the technical means for remote control of their systems´ output by the responsible network operator.

Operation of the generation management should be transparent and a compensation scheme should be introduced, which compensates for financial losses of RE system operators, which are heavily subjected to generation management.

System below a certain threshold capacity (for example 30 kWp PV) should be excluded from the generation management."

A discussion paper [47] */VDEW 2006/* by the Association of electricity companies (VDEW) and by the Association of Network Operators (VDN) suggests to employ a variable power reduction scheme using several reduction levels: 0 %, 30 %, 60 %, and 100 % with respect to nominal system power:

"*The network operator does not directly control the generation system, but sends suitable control signals. Reduction of generation power falls within the responsibility of the generation system owner. Power reduction should affect all systems to the same degree. A relation to the date of commissioning – "last in / first out"- is not intended.*

Otherwise the administrative burden for network operators would rise and erection of new systems would be discouraged."

6.4 Spain

In the context of European deregulation, the Spanish electricity market has undergone a process of reform with the objective of increasing efficiency and competition. Starting in 1998, since January the market is in principle completely liberalised, although its effective implementation is taking place progressively. Regarding the Distribution market (defined by nominal voltages up to 66 kV[g]), there are five main Distribution Network Operators regions, as shown in Figure and **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Company	*Spanish DNOs*	*Network characteristics* [g]
IBERDROLA	**Iberdrola Distribucion Eléctrica** www.iberdrola.es	18.200 km HV lines 200.000 km MV,LV lines Population served: 16,5 million
endesa	**Endesa Distribucion** www.endesa.es	298.550 km transmission & distribution lines Population served: 20 million
UNION FENOSA	**Unión Fenosa Distribucion** www.uef.es	Population served: 3,5 million
Enel Viesgo LA ENERGÍA QUE TE ESCUCHA	**Enel Viesgo Distribucion** www.enelviesgo.es	29.500 km distribution lines Population served: 670.000
hc energía	**Hidrocantábrico Distribucion Eléctrica** www.h-c.es	8.202 km HV, MV lines 11.089 km LV lines

Table VII. List of Distribution Network Operators in Spain

[g] Distribution voltages: Low Voltage (LV), < 1 kV; Medium Voltage, (MV) 13-15-20 kV; High Voltage (HV), 30-45-66 kV

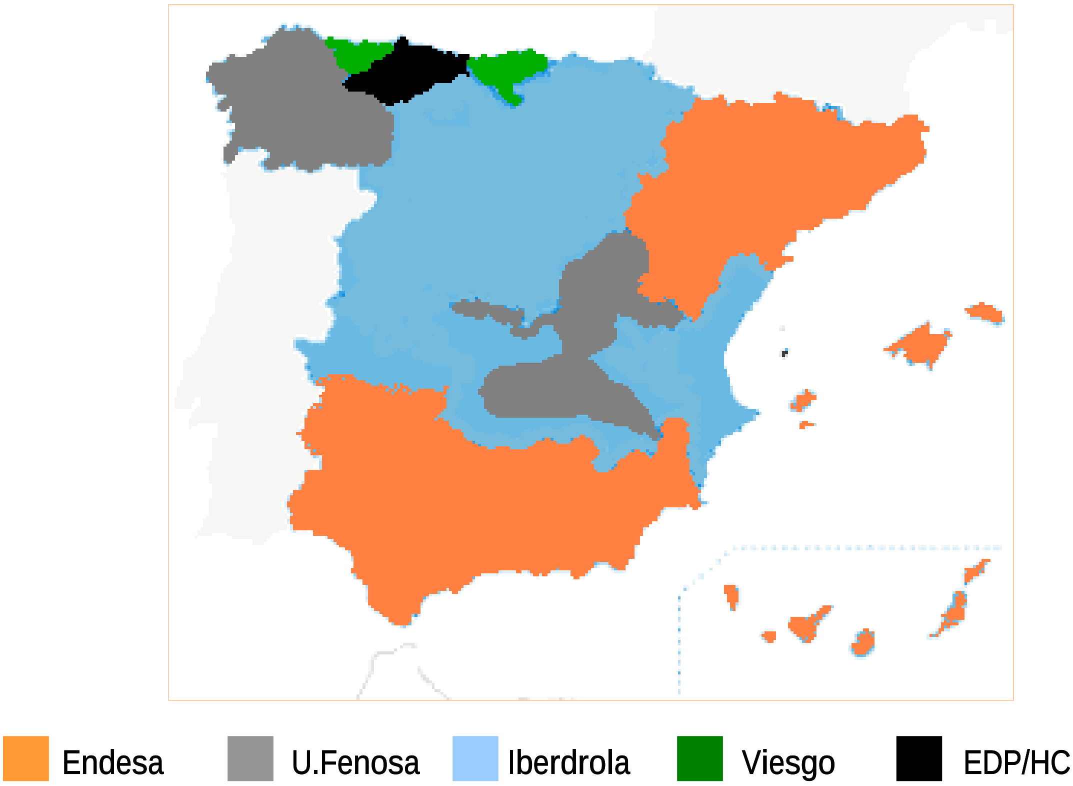

Figure 10: Electricity distribution networks control areas in Spain

Concerning PV-DG, the three distribution companies interviewed, Iberdrola Distribución Eléctrica, Unión Fenosa Distribución and Endesa Distribución Eléctrica are the most relevant; in particular, in 2006 their distribution networks received 97 % of the electricity fed by PV plants under the "Special Regime" (112,2 GWh, with the following breakdown: Iberdrola D.E. 67 %; Endesa D. 24 %; 7 % Unión Fenosa D. 6 %; see Figure: 11) [48].

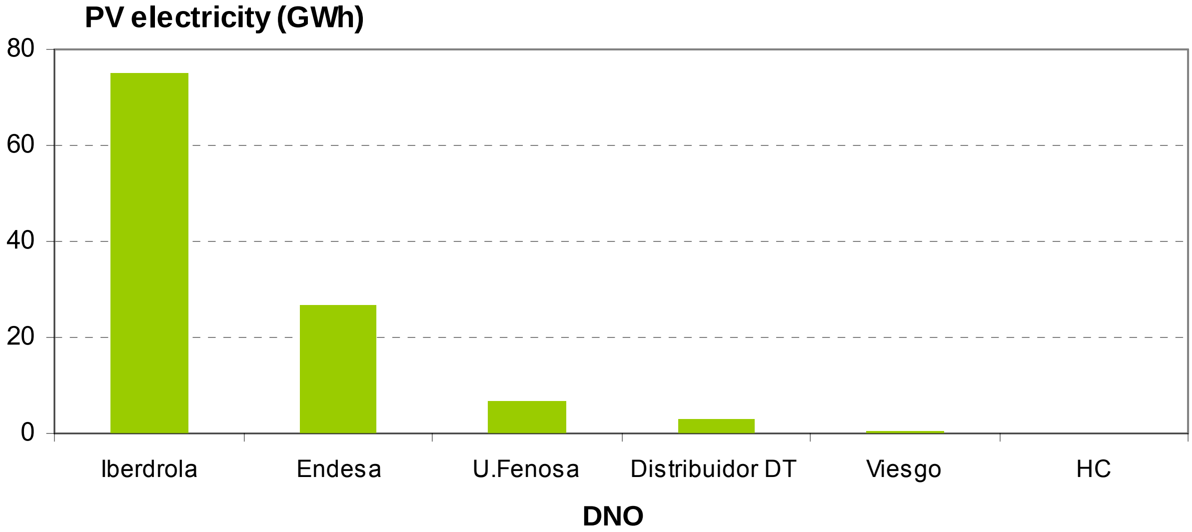

Figure: 11. Electricity fed into Spanish DNO's networks by the end of 2006 [48]

6.4.1 Technical assessment of PV Distributed Generation:

Harmonics from inverters

- Harmonics are not considered a current concern, with the exception of big PV plants (MW size) connected to Medium Voltage (MV) distribution networks. One distribution company has found evidence of harmonics induced by the operation of multiple inverters in a PV plant.
- Harmonics could be a concern in the future with big PV plants, as well as with small single-phase PV plants that have higher possibilities to create unbalances in the networks.
- PV plants operating as “active filters” (harmonics generation to reduce/suppress existing network harmonics) are of potential interest for 67 % (2/3) of the distribution companies interviewed, especially in urban areas (where current harmonics are usually higher) and with three-phase PV plants.

Voltage regulation

- Voltage regulation related to big PV plants is not a current concern for 67 % of the companies interviewed.
- Voltage regulation techniques presently used are adapted for bidirectional power flows at MV levels in 67 % of the cases. In the remaining case adaptation is possible and indeed foreseen for the new networks and extensions of existing networks.
- Regarding maximum overvoltages allowed to PV-DG by Spanish regulations (±5 % of nominal voltage), they are considered sufficient by 67 % of the companies. In one company a stricter limit is required for PV plants connected to MV grids.
- Voltage regulation could be a concern in the future, in case of high penetration of PV-DG in distribution networks, with big PV plants connected at MV levels.
- PV plants operating as “voltage regulators” (compensation of voltage drops under high loads conditions) are of potential interest, provided that this functionality is telecontrolled, it does not lead to unintentional islanding conditions and is compatible with existing voltage regulation techniques (e.g. precision levels of regulating devices).

Anomalous situation in distribution networks

- No specific —different from today’s— requirements are needed for networks operation, arising from PV-DG.
- For 67 % of the interviewed companies there is no concern that the network protections may not function properly due to the presence of PV-DG. There is some concern, however, about the lack of control of operation of decentralised multiple PV plants.

PV systems grounding

- No concern (present or future) regarding this aspect.

Unintentional islanding

- Unintentional islanding is no current concern by 67 % of the interviewed companies. In the remaining case there is some concern that PV plants may be able to maintain the voltage, and therefore operate under islanding conditions. Islanding is considered a potential future concern by 67 % of the companies.
- Regarding current requirements to avoid islanding (Spanish regulation: passive method based on voltage and frequency monitoring) it is considered sufficient. It is also generally considered that more research is needed on this aspect.

Electromagnetic compatibility of inverters

- Current standards (related to emission limits and susceptibility, generally applied for electrical equipment) are considered sufficient by 67 % of the interviewed companies.
- There is some concern on the EMC of multiple inverters under simultaneous operation.

External disconnect

- The remote disconnection (telecontrol) of PV-DG by means of automatic switches is considered of interest, especially for big PV plants at high penetration levels.

Reclosing

- Current regulations for PV plants reconnection after the network is restored (3 minutes after recovery of normal voltage and frequency values) are compatible with reclosing practices used by all the interviewed companies. One company has found evidence of some commercial inverters not complying with existing regulations.

DC currents and transformerless inverters

- Spanish regulation for PV-DG connected to LV networks requires galvanic separation between the DC and AC circuits of the PV plant, which is usually provided by inverters with insulation transformers.
- The use of transformerless inverters has been allowed in some cases (big PV plants), provided galvanic separation with the network was guaranteed by the corresponding Transformation centre. No adverse effects have been observed.

Penetration limits for PV-DG

- For PV plants connected to LV networks, 67 % of the companies interviewed consider current regulations appropriate [50 % of the transport capacity of the line / transformer capacity], although the interpretation should be clarified since it may lead to confusion. One distribution company is of the opinion that the limit should take into account the local loads at the PV plant location.
- 67 % of the companies would be in favour of establishing different penetration limits for rural and urban networks (higher limits in urban areas due to the existence of stronger grids). For one company, different requirements should exist for PV-DG in rural and urban networks, although based in parameters such as voltage stability, rather than absolute penetration limits.

Planning, operation and maintenance of distribution grids in relation to PV-DG

- Planning:
  - For PV-DG to be connected to LV networks, simulations or experimental verification is done of compliance with voltage rise current regulations by all companies interviewed.
  - For PV-DG to be connected to MV networks, simulations are carried out to verify the compliance with voltage rise regulations. One company also performs load flow analysis.
  - New tools for including PV-DG in future network planning are considered necessary by 33 % of the companies interviewed.
- No specific requirements are needed for networks operation, due to PV-DG.
- Maintenance (PV disabling): no specific requirements/measures are needed.
- Concerning the potential interest for including PV-DG into load dispatching:
  - For one company, no interest exists given the current differentiation between generation, distribution and commercialisation businesses.
  - For another company, it would be interesting in the framework of Demand Side Management programmes continuously supported by the corresponding regulating bodies.

6.4.2 General assessment of PV Distributed Generation:

Experience with PV-DG

- General experience from a technical point is good, with no major problems or incidents over the last 10 years.
- However, the interviewed companies are concerned about the present boom of big PV plants in Spain (generally called “Solar gardens”), with special emphasis on the following aspects:
  - Complex administrative procedures, the main burden of which falls on the PV plants promoters and distribution companies. In this sense also, lack of “filters” to distinguish between mature and immature or speculative projects.
  - Lack of proper regulations: legislation is considered incomplete and fragmented; also, the Regional Governments do sometimes set different requirements for the construction and commissioning of PV plants.
  - The connection permits requested exceed by far the technical capability of existing networks. This means that should all the connection requests be accepted, many rural distribution networks would turn into “exporting” ones. Too permisive conditions for connecting PV plants to the networks are in this sense a matter of concern, due to the fact that the distribution systems have no tools for generation dispatching. Problems with PV-DG may result in damages for customers, or expensive solutions to avoid such problems (costs for PV-DG owners and utilities).

Applicable standards / new regulation requirements

- Current standards applicable to PV-DG are considered insufficient. Amongst the issues considered important not presently covered, it is worth mentioning: harmonics, flicker, islanding, maximum penetration limits, maximum allowed voltage unbalances, interconnection and interaction of multiple inverters.

Research and Development needs

- Islanding, harmonics, flicker, Power factor regulation, interaction of multiple inverters.

6.5 The Netherlands

The Netherlands has 10 Distribution Network Operators regions (see Figure 2).

- Delta Netwerkbedrijf B.V.
- ENECO Netbeheer BV
- Essent Netwerk BV
- InfraMosane NV
- Centraal Overijssel BV
- NRE Netwerk BV
- Continuon beheer
- Rendo Netbeheer BV
- Westland Energie Infrastructuur BV

The largest DNO's are Continuon, Essent, Eneno (E Netbeheer) and Delta Energy. Continuon, Essent and Eneco were interviewed, their experience and perception is reflected in the following paragraphs.

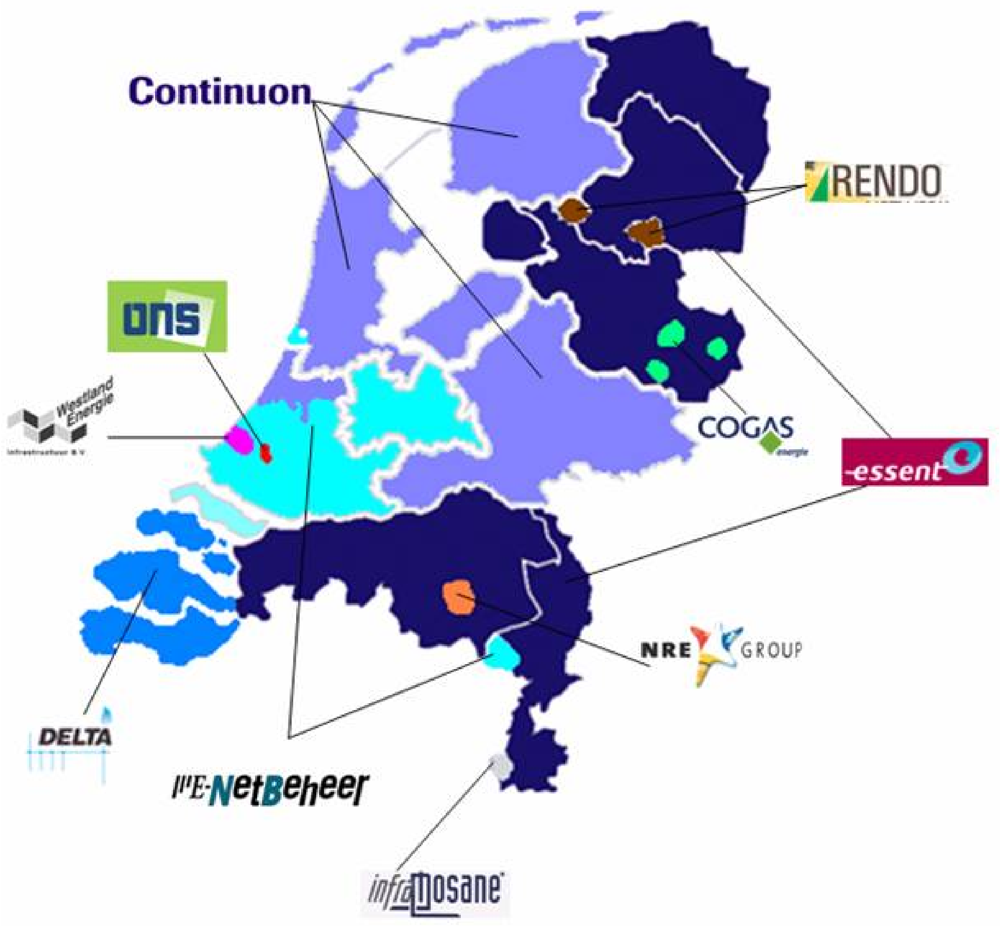

Figure 12: Distribution Network Operators areas in The Netherlands [49]

6.5.1 Technical assessment of PV Distributed Generation:

Harmonics from inverters

- On the low voltage grid some special cases (resonance) occurred due to the capacitor of the inverters. In combination with background harmonic voltages there were resonance problems at a few sites with PV-systems. On the MV-grid no problems occurred.
- Harmonics could be a concern in the future on the LV and MV grid. There has to be found a limit to the capacitor for PV-inverters and in general for low voltage devices.
- For the LV grid there is no interest for PV plants operating as “active filters”. In principle the current should be limited at the source so filtering should not be needed. Perhaps in special cases it could be advisable (high power inverters). On MV it could be interesting because the power of the inverters shall be higher and a more concentrated approach is possible.

Voltage regulation

- Nowadays, there is no problem for the LV and MV grid regarding voltage regulation. In some cases the upper limit in the voltage was reached but by changing the set point of the tap changer of the MV/LV transformer the voltage level could be improved.
- The DNO grid does not use voltage regulation systems for the LV. They manually change the tap changer of the MV/LV transformer and for the MV grid a regulator on HV/MV transformer. These systems are adequate for bidirectional power flows for the LV grid and for the MV grid to some extent. For implementation of a lot of dispersed generators additional regulation principles will be needed.
- The maximum over voltage of the grid is 6 %. New developed inverters need to comply to ± 10 %. The distribution company did not set additional requirements. The power quality standard EN 50160 is sufficient. For the MV grid no additional requirements are needed. This will not cause any problems in the future for the LV and MV grid. The voltage level can be easily controlled and calculation of this power quality phenomenon can be done easily
- There is no interest of operating PV plants as voltage regulators.

Anomalous situation in distribution networks

- Additional or different PV-DG requirements are not needed for the LV grid. It could be needed for the MV grid if the quantity of PV increases. This also applies for the possible concern of malfunction of network protections.

PV systems grounding

- No problems are present or foreseen with respect to interferences with the networks grounding practices.

Unintentional islanding

- No problems are present or foreseen with respect to over unintentional islanding by PV-DG.
- The current technical requirements (standards) are considered adequate and sufficient. Only a voltage and frequency window is required and is proven to be sufficient for the LV-

grid and MV-grid.

- Active methods for islanding detection are not necessary.

Electromagnetic compatibility of inverters

- The current technical requirements (standards related with emission limits and susceptibility for electrical equipment) are considered to be inadequate and insufficient. There are no harmonic emission limits in combination with harmonic distortion and no limiting of inverters capacitance.
- With respect to mutual disturbance of large numbers of inverters concerns are presently about harmonic distortion due to capacitance low resonance frequencies. This applies for the LV and MV-grid.

External disconnect

- It occurs that the interest on automatic switches enabling remote disconnect of PV-DG at high penetration levels is not present. In the Netherland this will be solved with the implementation of the "smart meter".

Reclosing

- In Dutch grid code requirements are implemented regarding disconnection. In the final draft prEN50438 "Requirements for the connection of micro-generators in parallel with public low-voltage distribution", times for reclosing are presented.

DC currents and transformerless inverters

- So far (adverse) effects of DC-current injection have not been observed.
- With respect to the difference between transformerless inverters and inverters with a transformer inrush currents were noticed from inverters with transformer leading to disconnection of B-type circuit breaker.

Penetration limits for PV-DG

- The penetration limits in relation to the network / transformer capacity for the LV -grid is 75 % and for the MV-grid 50 %.
- The penetration limits for rural grids could be a little lower.

Planning, operation and maintenance of distribution grids in relation to PV-DG

- In the LV grid PV-DG is currently considered in the planning. In the LV design is made with 500W dispersed generation for each connection point (not for all grid operators).
- New tools are not necessary for the LV and MV grid. Several software packages exist for grid calculation where dispersed generation can be implemented in the grid and the grid calculations.
- A large penetration of PV implies different/new requirements for network operation. A quantity was not given.
- Standard safety procedures are used in case of disabling PV-DG for network maintenance work in the networks.

6.5.2 General assessment of PV Distributed Generation:

Experience with PV-DG

- The general experience with PV is positive. On the LV-grid harmonic problems occurred in special cases. This was also a problem with external generator in the situation of an outage of the normal supply. The generator disconnected from the grid probably due to inverse current.
- In several cases measurements have been made. A national PQ program is performed where PV-sites are compared with the average PQ-levels.
- In the last ten years only harmonic problems occurred with PV.

Applicable standards / new regulations requirements

- It is recommended to change values in the Dutch grid codes applicable to PV. Changes in IEC 61000-3-2 "EMC limits for harmonic current emissions" are also advisable.
- The following issues are not covered by a standard:
    - Maximum value of the inverters capacitor.
    - Maximum harmonic current limits in environments with harmonic voltage distortion (interaction between harmonic voltages and currents).
- Coordination of standards concerning safety in low voltage, connection of micro generators, IEC standards about limits for harmonic currents.

Research and Development needs

- Application of PV-systems in combination with generators used to deliver electrical energy in emergency cases.
- Development of inverters with low harmonic currents and limited capacity.

6.6 United Kingdom

The following map and table show how the 15 Distribution Network Operators (DNO) regions are served by 8 Distribution companies. Several DNO areas are typically operated by the same company.

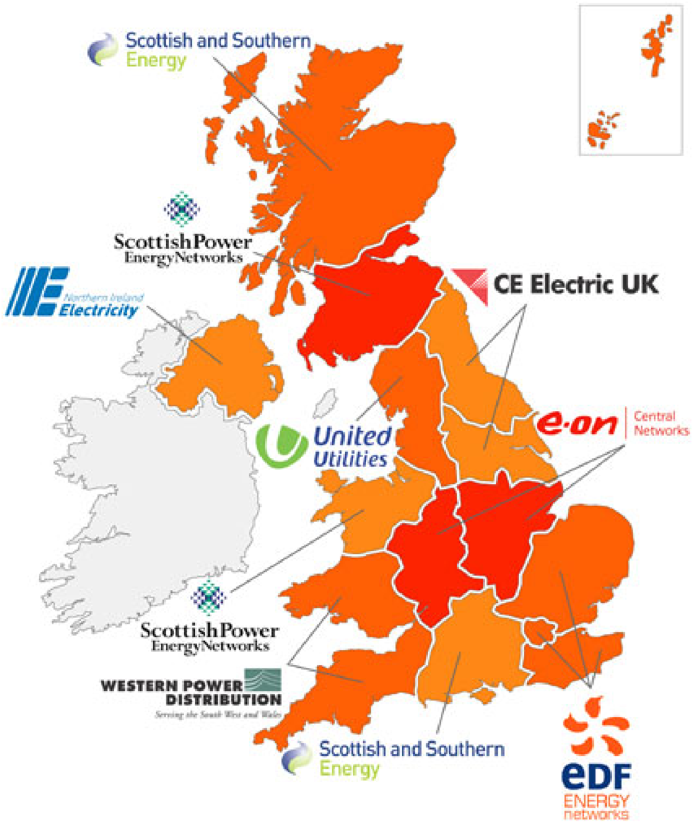

Figure 13: Distribution Network Operators areas in the United Kingdom

Company	***UK Network Operators***	***Area Served***
CE Electric UK	**CE Electric UK** CE Electric UK, through its subsidiaries Northern Electric Distribution and Yorkshire Electricity Distribution, delivers electricity to 3.6 million customers throughout the North East of England, Yorkshire and north Lincolnshire. It is owned by MidAmerican Energy Holdings Company. ***www.ce-electricuk.com***	North East Yorkshire

	Central Networks Central Networks is the new name for Midlands Electricity and East Midlands Electricity. The company brings power to 4.8 million customers across the East and West Midlands through 133,000km of underground and overhead cables and via almost 97,000 substations. Central Networks covers an area from the Peak District in the north to parts of Bristol in the south, and from the Welsh Borders to the Lincolnshire Coast. ***www.central-networks.co.uk***	West Midlands East Midlands
	EDF Energy EDF Energy is one of the largest energy companies in the UK. Over a quarter of the UK population, in London, the South East and East of England benefit from EDF Energy's distribution of electricity. EDF are also a major generator and supply electricity and gas to over 5 million customers through their regional brands: London Energy, SWEB Energy and Seeboard Energy. ***www.edfenergy.co.uk***	Eastern London South East
	Northern Ireland Electricity Northern Ireland Electricity (NIE), a major subsidiary of the Viridian Group PLC, is responsible for the regulated procurement, transmission, distribution and supply of electricity to 742,000 homes and businesses in Northern Ireland. ***www.nie.co.uk***	Northern Ireland
	Scottish and Southern Energy Scottish and Southern Energy (SSE) owns one transmission network and two distribution networks totalling 123,000 km of overhead lines and underground cables. This covers one third of the UK landmass and delivers electricity to 3.3 million customers. In addition to its networks business, SSE supplies gas and electricity to over five million customers, operates the fifth largest generation portfolio in the UK and is involved in energy trading, gas storage, contracting, retailing and telecoms. ***www.scottish-southern.co.uk***	North Scotland Central Southern England

ScottishPower EnergyNetworks	ScottishPower Scottish Power plc is an international energy business listed on both the New York and London Stock Exchanges. Through its operating subsidiaries, the company serves in excess of 5 million homes and businesses in the western US and across the UK. It provides electricity generation, transmission, distribution and supply services in both countries. The company's US activities extend to coal mining and gas storage, including a gas facility in western Canada. In Great Britain, ScottishPower also stores and supplies gas. ***www.scottishpower.com***	South of Scotland
United Utilities	United Utilities From keeping the lights shining and taps flowing, to helping businesses communicate and manage their customers; United Utilities provides essential services to millions of people around the world. ***www.unitedutilities.com***	North West
WESTERN POWER DISTRIBUTION Serving the South West and Wales	Western Power Distribution Western Power Distribution operates and maintains the electricity distribution network in South West England and South and West Wales. It delivers electricity to 2.5 million customers over a 26,000 sq kms service area. ***www.westernpower.co.uk***	South Wales South West

Table VIII. Distribution Network Operator companies in the United Kingdom

The following figure shows how Distributed Generation connections in the UK are distributed between the various DNO areas [50]. It includes all types of Distributed Generation technologies, and it can be seen that the levels for the year shown remain fairly constant between the DNO regions.

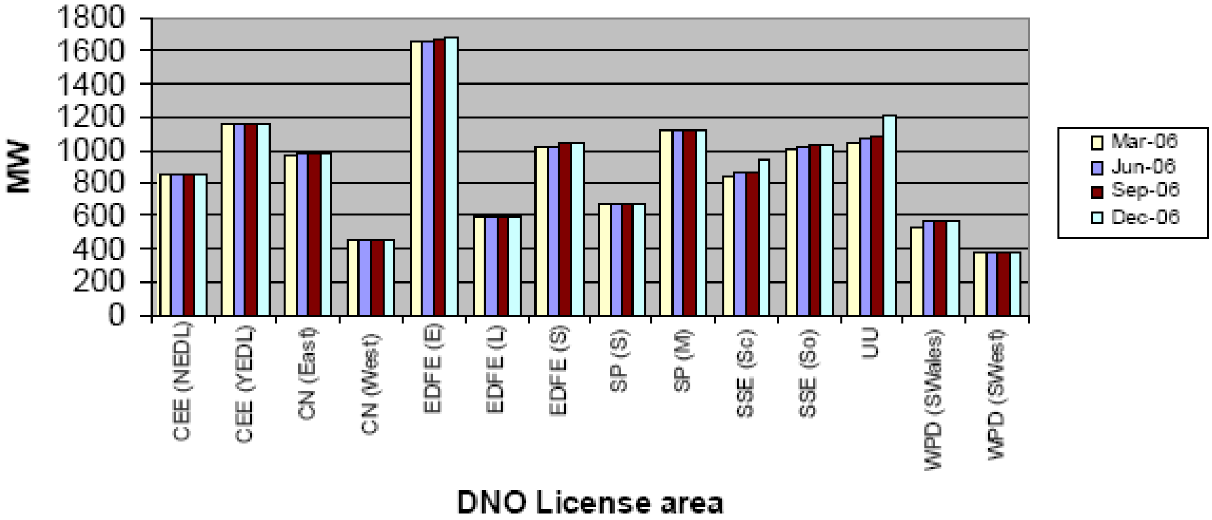

Figure 14: Distributed Generation connections in the different DNO areas in the United Kingdom

Examining this in terms of the split of installed capacity from the various technologies, it can be seen that PV, shown arrowed in Figure 15, makes up only a very small proportion of the connections made by a DNO. This should be kept in mind as the context for the DNO perspective as shown on the interview included in this report.

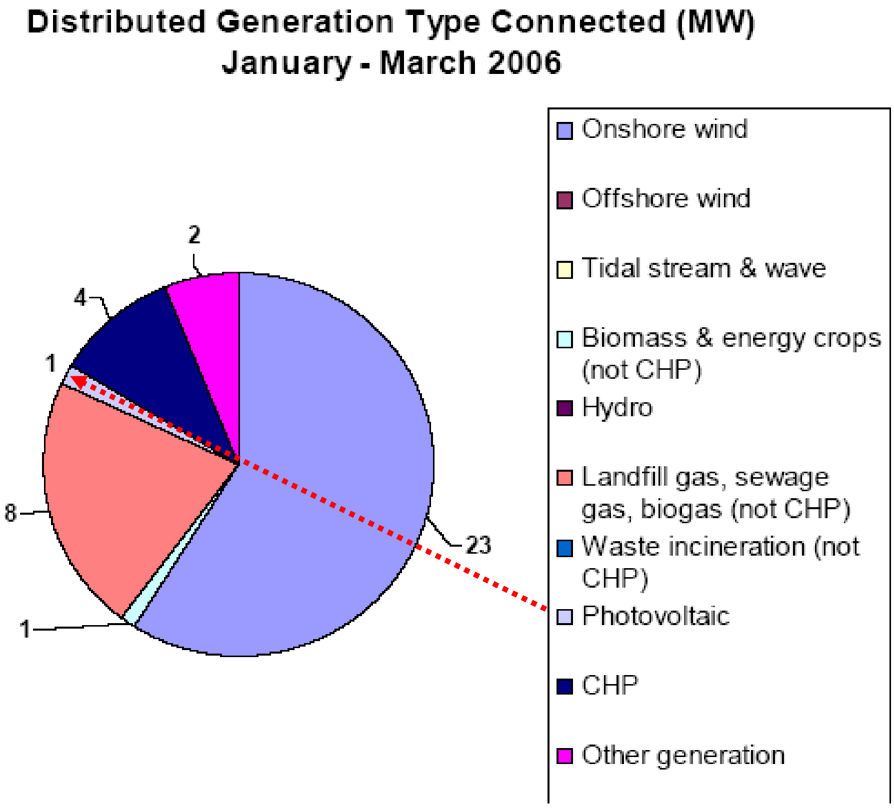

Figure 15: DG technologies connected in the United Kingdom in the first quarter of 2006

6.6.1 Technical assessment of PV Distributed Generation:

Harmonics from inverters

- Harmonics are not considered a current concern for G83/1 type tested inverters installed in relatively small numbers as at present. Some of the larger (non-PV) plants have generated significant harmonics making it hard for the cumulative effect on the network to stay within the limits of G5/4.
- Harmonics could be a concern in the future mainly for bigger systems (mainly non-PV) where inverters are not yet type tested.
- PV plants operating as “active filters” (harmonics generation to reduce/suppress existing network harmonics) are of potential interest to cancel the high levels of the 3^{rd} and 5^{th} harmonics currently on the network.

Voltage regulation

- Voltage regulation is seen as the biggest challenge to be addressed to enable an increasing density of PV DG on the network, especially overvoltages caused by generators at the end of long rural feeders.
- Old voltage regulators fitted in the network do have problems with bi-directional flows, but the new devices being fitted now are OK for two way flow.
- PV plants operating as “voltage regulators” (compensation of voltage drops under high loads conditions) are of potential interest. Experience to date is that in one instance (non-PV) the pf set-up in the generator was inadvertently reset during maintenance, and the voltage was thus made worse, without the DNO having knowledge or control of this.

Anomalous situation in distribution networks

- Currently there are few anomalous situations on the network caused by PV.
- However for the future, active networks are being investigated but not specifically for PV.
- There is also a concern that if the number or specification of generators connected to the network changes from when the network calculations were carried out, the design assumptions may no longer be valid. Also the DNOs do not have direct control of the generators which might be required for active control.

PV systems grounding

- No concern for small PV inverters regarding this aspect if using fully Class 2 systems on the DC side. However, if earthing is required there are differences between how PME and non-PME systems are treated.
- Also the requirement for Neutral Voltage Displacement (NVD) on larger (normally non-PV) systems is being debated for the revision to G59/2.

Unintentional islanding

- The current arrangements to prevent islanding under G83/1 are found to be adequate so far.

- On larger systems (usually non-PV) the settings for the G59/1 relay are under debate to try and reduce nuisance tripping (perhaps a two stage protection).
- One DNO thought that G83/1 settings should be brought back to the statutory limits so as not to ‘encourage’ operation of the network outside these ranges. At present they are set wider to avoid nuisance tripping.

Electromagnetic compatibility of inverters

- Not regarded as a problem for current G83/1 inverters.
- However, there is little operating experience for ‘multiple systems’.
- There is some concern over non type-tested systems under G59/1 where the harmonics have been found to be large for one biomass plant.

External disconnect

- The current requirement under G83/1 is for the switch to be located in an accessible position within the Customer’s installation.
- There is some interest in the potential for ‘central switching’ as part of an active network. At present some inter-tripping is specified by some DNOs.

Reclosing

- This has not been found to be a problem for G83/1 inverters where a delay is specified before retrying to connect, and it is required that the inverter will not to be damaged by connecting out of phase.

DC currents and transformerless inverters

- Although transformerless inverters are not ruled out under G83/1, there are none currently on the type testing register, possibly because it is hard for them to meet the requirement for DC injection limits, and the recommendation to include galvanic isolation between the DC and AC systems to simplify the earthing arrangements.

Penetration limits for PV-DG

- There is no specific penetration limit set for PV, but for ‘multiple systems’ the DNO has to be notified in advance so that they can carry out a network study if required.
- Some work has indicated that 30 % of houses with a 1kWp system might be about the limit for a typical network.

Planning, operation and maintenance of distribution grids in relation to PV-DG

- Planning - LV modeling programmes are now being modified to take account of generation, although present levels of PV are too small to be a significant factor in longer term planning.
- Operation – The current situation works for the present levels of PV. As part of the wider mix of distributed generation, active networks and load dispatch etc may be considered - see Distribution Working Group (www.ensg.gov.uk) above.
- Maintenance – the current situation of G83/1 protection, and the assumption by the

DNO that the network is live for maintenance is seen as adequate at present.

6.6.2 General assessment of PV Distributed Generation:

Experience with PV-DG

- General experience from a technical point is good based on the G83/1 requirements, with no major problems or incidents over the last 10 years.
- However, the overall connection rate is still relatively small compared with other forms of distributed generation, so experience of multiple systems etc is still quite limited. There are also few fully instrumented test areas to gain data from.

Applicable standards / new regulation requirements

- The current 'Engineering Recommendations' of G83/1 and G59/1 are considered adequate at present. Draft upgrades for G59/1 to G59/2 are currently being discussed.

Research and Development needs

- The Electricity Networks Strategy Group (ENSG) - Distribution Working Group (www.ensg.gov.uk), has a programme of work investigating longer term needs in research and development in both technical and regulatory fields. The topics are listed in the proforma above.
- Also there are now some centers of excellence combining University and industry research e.g. The new Centre for Distributed Generation and Sustainable Electrical Energy, University of Strathclyde and UMIST http://www.sedg.ac.uk/
- Research topics can be put forward for part funding by the DTI under the DTI Technology Programme: Emerging Energy Technologies: Low Carbon Energy Technologies www.dti.gov.uk/innovation/technologystrategy/technologyprogramme/.

7 ANALYSIS OF RESULTS

The report covers the utilities experience and perception of Photovoltaic Distributed Generation in 6 European countries (Austria, France, Germany, Spain, The Netherlands and United Kingdom), which represent 98 % of the PV power installed in the European Union [51] [h].

Overall, 35 electricity distribution companies have been interviewed, all of them have collected experience with PV-DG. In the following paragraphs a comparative assessment is presented, in order to identify common perceptions as well as most relevant differences between the countries.

Finally, some conclusions are drawn on the perception and experience of European utilities with PV-DG, with the aim of contributing to a higher penetration of PV technology in electricity distribution networks.

7.1 Technical assessment of PV Distributed Generation

Harmonics from inverters

- Harmonics emission by inverters is considered a current concern in 4 of the 6 countries, with only a few experimental evidences reported.
- Harmonics are also considered a potential future concern, at high PV penetration levels.
- However, in Germany with the largest PV capacity, harmonics are no concern.
- PV plants operating as “active filters” (harmonics generation to reduce/suppress existing network harmonics) are of potential interest for most of the companies interviewed, especially in urban areas (where current harmonics are usually higher) and with three-phase PV plants. 3rd and 5th order harmonics from conventional loads could be reduced.

Voltage regulation

- Voltage regulation related to PV-DG is a present no big concern in urban areas. Only for weak grids with high PV penetration several companies interviewed are concerned.
- The voltage regulation systems used in the networks are relatively common, with manual tap-changers in MV/LV transformers, and automatic tap-changers and voltage regulators in MV distribution grids. In this respect, the voltage regulation techniques used are mostly adapted (totally or to some extent) for bidirectional power flows.
- Regarding maximum overvoltages allowed to a specific PV plant by the different regulations, the limits are typically within the range 5-6 %. Except for two country (Austria and Germany), these limits are generally considered enough, for the time being.
- Generally, voltage tolerances at consumers are defined in EN 50 160 to ±10 %.
- In most countries except Germany and The Netherlands, however, voltage regulation is deemed to be a future concern at high penetration levels of PV-DG in distribution networks, especially in rural or weak grids.

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[h] Cumulative PV power installed by 2006 in the European Union: 3,31 GWp. Of these, 91,5 % in Germany, 3,1 % in Spain, 1,4 % in The Netherlands, 0,8 % in Austria and 0,4 % in France and United Kingdom.

- PV plants operating as “voltage regulators” (compensation of voltage drops under high loads conditions) are of potential interest for most of the companies interviewed.

Anomalous situation in distribution networks

- In 4 of the 6 countries considered no specific (different from today’s) requirements are needed for networks operation, due to PV-DG. In one country (France), it is mentioned that PV-DG could provide great benefits to distribution grids if it could participate in the grid stability to prevent a major blackout. A recent experience of grid disturbances that originated in the continental European transmission grid (4 November 2006) has shown that DG is not adapted to support the grid in case of anomalous situations.
- For most interviewed companies there is no concern that the network protections may not function properly due to the presence of PV-DG. For some utilities in Austria, Spain and the UK, there is a certain concern about the lack of direct control of DG in general, which might be required for active control of the networks under anomalous situations.

PV systems grounding

- No concern (present or future) regarding this aspect. DG technologies (and therefore PV) should always comply with the regulations in force.

Unintentional islanding

- At present, there is no concern that PV-DG may operate under unintended islanding conditions.
- Regarding the future, only in Spain and the United Kingdom unintentional islanding of PV-DG is a matter of concern, especially for high penetration levels.
- Current technical requirements to avoid unintentional islanding are considered sufficient
- Concerning the use of active methods for avoiding unintentional islanding such as impedance measurement, they are favored in Austria and Germany and considered not suitable elsewhere.

Electromagnetic compatibility of inverters

- Current standards (related to emission limits and susceptibility, and generally applied for electrical equipment) are considered adequate by most utilities from Germany, Spain and United Kingdom. In The Netherlands, however, they are considered inappropriate; in the remaining cases no opinion was given. However, it should be mentioned that most people interviewed had no own expertise and trust equipment standards
- There is a some concern in several countries on the EMC of multiple inverters under simultaneous operation.

External disconnect

- The remote disconnection (telecontrol) of PV-DG by means of automatic switches is considered of interest by all companies except those from The Netherlands, especially for big PV plants at high penetration levels. Germany employs automatic, not remotely controlled, disconnection under irregular network conditions. Systems larger than 30 kVA need a manual operated, utility operated switch. For large systems remote control of output power in stages to protect the HV transmission system during faults is demanded by the association of electricity companies (VDEW). Control signal switching could be part of active electricity networks management systems in the future.

Reclosing

- Reclosing practices used by the interviewed companies that provided information about this aspect (Spain, The Netherlands, United Kingdom and Germany) are fully consistent with regulations applicable for PV-DG regarding automatic reconnection after a network outage.

DC currents and transformerless inverters

- Transformerless inverters are not allowed to operate by existing regulations in some of the countries analyzed (Spain and United Kingdom)[i]. In the most experienced countries were these inverters are accepted (Germany and The Netherlands), no adverse effects have been experienced.

Penetration limits for PV-DG

- Only utilities from three countries (Austria, Spain and The Netherlands provided fixed power limits for PV-DG penetration, in relation to the network/transformer capacity: For LV grids limits vary between 33 % and 75 %, whereas for MV grids the limits are at 50 %. In the remaining countries the limit is established on a case-by-case basis.
- Most companies interviewed suggest that PV-DG penetration limits should be higher in urban networks than in rural ones, due to the higher strength of the first ones.

Planning, operation and maintenance of distribution grids in relation to PV-DG

- Planning:
  - Except in Germany and the United Kingdom, PV-DG is generally considered in networks planning, mainly to verify the compliance with voltage rise regulations.
  - New tools for including PV-DG in future network planning are in general not considered necessary. Adaptation or improvement of existing tools (modeling software) to take into account PV-DG is considered necessary by utilities from France, Spain and United Kingdom.
  - Except for the Austrian utility, no specific (different from today's) requirements are considered necessary today for networks operation due to PV-DG. New requirements could be needed in future scenarios with high PV-DG penetration levels or in the context of "active networks" management.
- Concerning the networks maintenance in relation to PV-DG disabling, standard safety procedures are used by the interviewed companies. Specific requirements/measures are not needed.
- Regarding the inclusion of PV-DG into load dispatching, only 2 utilities from France and Spain see this as a potentially interesting functionality. In this sense the current separation of generation, distribution and commercialisation businesses and the fact that Demand Side Management is still not widely supported are mentioned as two limiting factors for including PV-DG into load dispatching.

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[i] Spain: PV-DG connected to LV networks needs to comply with galvanic separation between the DC and AC circuits of the PV plant, which is usually provided by inverters with insulation transformers. United Kingdom: no transformerless inverters have G83/1 approval at present.

7.2 General assessment of PV Distributed Generation

Experience with PV-DG

- General experience from a technical point is good. There are no major incidents over the last 10 years. In urban environments PV is doing fine and does need no technical attention from a utility´s point of view. Amongst the minor technical problems experienced so far, harmonics emissions of multiple inverters in Austria and The Netherlands are to be mentioned.
- In some countries with favorable feed-in-tariffs for PV-DG such as Spain and, more recently, France, there is some concern about the very quick PV market development (especially of PV plants) and the following aspects:
  - Spain: complex administrative procedures for big PV plants, lack of national harmonisation concerning regulations applicable, and technical limitations of existing networks (especially rural grids where many of the so-called "Solar gardens"[j] are being implemented) to accommodate all the connection requests received over the last year, which may require expensive solutions (costs for PV-DG investors and utilities).
  - France: proper management of the networks with large PV systems in regions with the best market development prospects (Overseas Departments).
  - Germany: prices for modules do not reflect production cost, but are high due to a producers market.

Applicable standards / new regulation requirements

- Except for Germany and the United Kingdom, current standards applicable to PV-DG are generally considered to need improvement. Amongst the issues not adequately covered, the following are to be mentioned: harmonics emission limits for inverters with output current over 16 A per phase, islanding, flicker, penetration limits, interaction of multiple inverters, voltage imbalances, inverter capacitance, coordination of standards concerning safety in low voltage. Most of these concerns seem to stem from a lack of positive experience and operating extended grids with large rural sections.

Research and Development needs

- The following needs were identified: islanding, harmonics emission limits, interaction of multiple inverters, penetration limits, power factor regulation, power forecasts, active integration of PV-DG in the networks, flicker.

[j] "Solar garden" is a generic tem used in Spain for centralized PV plants usually installed in rural areas, which are owned by several . private investors.

8 CONCLUSIONS

According to the focus of the project PV-Upscale, conclusions here are drawn with a focus on rather small, domestic PV systems in an urban environment.

Overall, it can be concluded that the experience and perception of PV-DG by European utilities is positive. Grid connected PV plants have demonstrated compatibility with LV distribution networks even at high densities.

On another hand, some of the potential concerns are not PV-specific, but common to most Distributed Generation technologies. Consequently, technology advances and harmonisation of technical requirements achieved in the DG field will also facilitate the integration of PV-DG in future electricity networks.

Main concern in nearly all countries is voltage rise from end-of-feeder generation. This effect is noticed, however in strong grids it is not critical. It may become critical in terms of violation of power quality standards, or loss of power due to voltage limitation, or costs for grid strengthening mainly in rural areas with higher impedance networks.

The Netherlands reported overvoltage due to resonance effects between grid impedance and inverter capacities. This effect seems to be related to a high inverter density and should completely be understood.

All other issues are perceived to be less important. In several countries some technical topics like harmonics, or radio high frequency noise emissions, rise diffuse concerns, without much evidence of encountered problems.

In most of the countries there is no concern that the network protections may not function properly due to the presence of PV-DG,

Interestingly, it can be noticed that Germany with the highest installed PV capacity seems to have the fewest concerns for problems. It is assumed that this can be attributed to good experiences with that technology, strong urban grids, as well as clear responsibilities for DNOs in the relevant law.

Even with little PV capacity on the grid potential effects of large inverter capacities should be taken into account, since these inverters will operate for the next 10 … 15 years. Therefore, in Germany, due to the large PV capacity of some 3 GVA (2007) on the grid, PV inverters – even small ones - are nowadays required to provide “fault-ride-through” capability like central power stations.

Potential benefits from inverters like active filtering, reactive power control, phase balancing are generally acknowledged, but currently have no market value. In future, they may become features of the “smart grid”. Rules for decentral provision of these “system services” need to be developed.

Technical standards for DG should be revised. Some issues seem not to be adequately covered. These include harmonics emission limits for inverters with output current above 16 A per phase, islanding, flicker, interaction of multiple inverters, voltage imbalances, inverters capacitance, coordination of standards concerning safety in low voltage grids.

Work on integration of DG should take into account that existing standards do not provide consistent rules among network operators, inverter developers, network regulators and system operators concerning an active integration of DG in grid-supporting modes of operation, nor do they provide incentives to provide the potential benefits.

In some cases specific grid operation requirements are requested for to PV-DG. Utility controlled generator shedding is enforced in Germany for large DG, especially wind parks, but including large PV systems as means against overloading of transmission lines wit the ultimate risk of a large area black-out.

Finally, Research and Development needs have been identified on the following issues: islanding, harmonics emission limits, interaction of multiple inverters, penetration limits, power factor regulation, power forecasts, active integration of PV-DG in the networks.

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