IDE4L is a project co-funded by the European Commission

Project no: 608860
Project acronym: IDE4L
Project title: IDEAL GRID FOR ALL

Deliverable 2.1:
Specification of Active Distribution Network Concept

Due date of deliverable: 29.02.2014
Actual submission date: 25.04.2014

Start date of project: 01.09.2013 Duration: 36 months

Organisation name of lead contractor for this deliverable: Tampere University of Technology, Finland

Revision [1.4]

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

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Description</th>
<th>Revised</th>
<th>Approved</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>23/01/2014</td>
<td>Copy of Wiki-page</td>
<td>Sami Repo (TUT)</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td>27/01/2014</td>
<td>Updated chapter 5</td>
<td>Ignasi Cairo (IREC)</td>
<td></td>
</tr>
<tr>
<td>0.3</td>
<td>30/01/2014</td>
<td>Concept slides from kick-off meeting</td>
<td>Sami Repo (TUT)</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>16/02/2014</td>
<td>Draft Chapter 4</td>
<td>Lukas Verheggen (RWTH)</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>19/02/2014</td>
<td>Distribution network scenarios</td>
<td>Davide Della Giustina, Alessio Dedé (A2A)</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>20/02/2014</td>
<td>Section 3.6 Stakeholder views</td>
<td>Davide Della Giustina, Alessio Dedé (A2A)</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>21/02/2014</td>
<td>Additions and modifications</td>
<td>MHG (UFD)</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>21/02/2014</td>
<td>Updated Chapter 1</td>
<td>Ignasi Cairo (IREC)</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>23/02/2014</td>
<td>Updated Chapters 2, 3 and 4.5</td>
<td>Sami Repo (TUT)</td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>02/03/2014</td>
<td>Whole document updated after review</td>
<td>Sami Repo (TUT), Miquel Cruz (IREC), Zaid Al-Jassim (DE), Julio Usaola Garcia (UC3M), Francisco Ramos (TELVENT)</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>04/04/2014</td>
<td>Updated Chapters 2 and 3</td>
<td>Sami Repo (TUT), Stefano Zanini (A2A)</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>13/04/2014</td>
<td>Whole document updated after review</td>
<td>Sami Repo (TUT), Eva Alvarez Gonzalez (UFD), Julio Usaola Garcia (UC3M), Davide Della Giustina (A2A), Lukas Verheggen (RWTH), Ferdinanda Ponci (RWTH), Miquel Cruz (IREC)</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>16/04/2014</td>
<td>Summary and language corrections</td>
<td>Sami Repo (TUT), Stefano Zanini (A2A), Ignasi Cairo (IREC)</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>25/04/2014</td>
<td>Few final corrections</td>
<td>Sami Repo (TUT)</td>
<td>Davide Della Giustina (A2A), Zaid Al-Jassim (DE), Ferdinanda Ponci (RWTH), Sami Repo (TUT)</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

1. INTRODUCTION .................................................................................................................................... 6
   Scope of the Work ............................................................................................................................... 8

2. DRIVERS OF ACTIVE DISTRIBUTION NETWORK .....................................................................................11
   2.1. Trends .........................................................................................................................................11
   Megatrends in the Energy Sector ........................................................................................................11
   EU Energy System Drivers ...................................................................................................................12
   Decentralization of the Electricity System ...........................................................................................13
   2.2. Electricity Network and Technology Trends ......................................................................................14
   Sustainability and Security of Supply ....................................................................................................14
   Technical Requirements ......................................................................................................................15
   2.3 Examples of Trends ...........................................................................................................................16

3. VISION OF ACTIVE DISTRIBUTION NETWORK .......................................................................................18
   3.1. Active Distribution Network ........................................................................................................18
   3.2 Power Distribution Infrastructure ......................................................................................................20
   Primary Technology ............................................................................................................................20
   Monitoring, Protection and Control Devices ........................................................................................21
   Communication...................................................................................................................................22
   3.3 Active Resources and Aggregator Concept ........................................................................................22
   3.4 Active Network Management ......................................................................................................25
   Overview of ANM concept ...................................................................................................................25
   Overview of the IDE4L Automation Concept ......................................................................................25
   Asset Management .............................................................................................................................27
   Disturbance Management ...................................................................................................................29
   Advanced Protection ...........................................................................................................................30
   Congestion Management ....................................................................................................................31
   3.5 DSO Interaction with TSO and Electricity Market ...............................................................................33

4. NETWORK PLANNING/DESIGN INCLUDING ACTIVE NETWORK FUNCTIONALITIES ............................35
   4.1. Vision for Active Distribution Network Planning...........................................................................35
   4.2. Target network planning .............................................................................................................37
   4.3. Expansion Planning ......................................................................................................................38
   4.4. Operational Planning ...................................................................................................................39
   4.5 Planning Principles for Active Network ..............................................................................................41
   Worst Case Planning Rule......................................................................................................................41
IDE4L Deliverable 2.1

Stochastic Analysis ..........................................................................................................................41
Flexibility of a Customer ...................................................................................................................41

5. NETWORK OPERATION WITH ACTIVE NETWORK FUNCTIONALITIES .................................................43

5.1. Vision for Active Distribution Network Operation ........................................................................43
Vision about how Networks are Operated .......................................................................................43
Actors Involved in the Active Network ..........................................................................................44

5.2 Future Trends in the Regulatory Framework: the Aggregator Concept ..........................................47
European Regulatory Framework and Aggregator Concept Description ...........................................47
Technical Framework ......................................................................................................................48

5.3. Functionalities of Active Distribution Networks: State of the Art ..................................................52
FENIX Project ..................................................................................................................................53
INTEGRAL Project ............................................................................................................................54
ADDRESS Project ...........................................................................................................................55
SEESGEN-ICT Project .....................................................................................................................56
REserviceS Project .............................................................................................................................57

6. REFERENCES ......................................................................................................................................59

Annexes ...............................................................................................................................................63
Annex 1 - Acronyms .............................................................................................................................63
Annex 2 - Trends in the Energy Sector ...............................................................................................64
Trends in Denmark ..............................................................................................................................64
Trends in Finland .................................................................................................................................69
Trends in Germany .............................................................................................................................73
Trends in Italy ......................................................................................................................................76
Trends in Spain ...................................................................................................................................79
Annex 3 - Examples of DER Penetration and Changes in Regulation ..................................................82
PV Penetration ....................................................................................................................................82
Electric Vehicle Penetration ..............................................................................................................87
Demand Response Penetration .........................................................................................................87
Service Continuity ...............................................................................................................................88
Power Quality .....................................................................................................................................89
DERs ancillary services ......................................................................................................................89
EXECUTIVE SUMMARY

The IDE4L project goals span three axes:

1. Prove heuristically that active distribution networks not only are up to manage but can exploit new distributed generation to the end of substantially improving the energy network reliability, continuity and serviceability;
2. Design and develop a next generation distribution network automation architecture that can encapsulate ancillary services from DER providers and technical and commercial aggregators;
3. Design, develop, prototype and field-test an array of solutions for the monitoring and control of the distribution network with incorporated DERs.

This deliverable covers the IDE4L concept of active distribution network and its management (Active Network management) – ANM).

In deliverable D2.1 the basic tenet of IDE4L, the vision of active network distribution network, the corresponding active network management and user and functional requirements to active distribution network /ANM and design points of the architecture and use case design come together and are morphed in a concept of active distribution network – that constitutes the kernel of the deliverable.

In the IDE4L project the concept, vision, drivers and architectural foundation and the roadmap go hand in hand, cross-feed along the duration of the project by e.g. updating requirements as lab and field test corroborate the vision and allow improved calibration of the architecture design and use cases.

The IDE4L vision hinges on the belief that active distribution network presupposes a new distribution network planning scheme whereby elements of DERs and DG become an integral part of the planning process; conversely the new planning scheme spearheads new network management tools.

Planning with DERs and managing a DER/DG form a continuum that give birth and feed the architecture and managing tools of an active network management that drives the hosting capacity to asset invested capital to unprecedented levels, improved efficiency, reliability and continuity of service.

Chapter 2 through 4 are devoted to cover the above; in chapter 5, the new network operation concept is expanded to include the role of technical and commercial aggregators.

The framework designed in D2.1 and updated in the roadmap as project IDE4L moves along is the host of new sophisticated functionalities – designed in work package 4 through 6 and field tested in 7 – including more accurate real-time sensing and monitoring, new state estimation algorithms (exploiting DERs and DG), asset and disturbance management and active protection, FLISR, micro-grid management and congestion management sophisticated tools.
1. INTRODUCTION

Current distribution networks (technology, network planning, operation, regulation, business) are undergoing technological advances that reshape the operation of the actual grid and enable profound transformations in the electricity system.

Technological advances are being incorporated, and already applied in Distributed Generation (DG) in many European Union countries, as well as newly emerging broad range of DERs including local storage, electric vehicles and demand response, which are driving potential changes in the planning and operation of power systems to offer a more efficient and also cleaner electricity system. Introduction of new technology also triggers potential challenges to the regulation of power systems and market design.

The transformation of today’s energy grids to new, smart, secure, flexible infrastructures that can underpin a low greenhouse gas emission ecosystem is a complex task and hinges on a broad array of changes. The transformation will take hold through gradual steps and will accompany us in the years to come, since for the modern society the continuity of electricity supply is non-negotiable.

One key ingredient of this broad-ranging transformation is the ability to exploit the increasingly available and ubiquitous supply of DERs like DG, Demand Response (DR) and Distributed Energy Storage Systems (DESS). To make that happen we have to introduce new enabling technologies and techniques in energy grid planning and operation, simply put moving from today’s energy grid management to Active Network or Active Network Management.

Not only is active distribution network contingent on technology; to yield benefits active distribution presupposes a deep understanding of the power distribution grid. Knowledge is indispensable to create a bridge from the old model to the to-be model. In essence we need to perform a high level description of the changes that the electrical distribution grid will undergo in order to seamlessly incorporate and actively manage higher demand, new energy resources, operation, automation, security and management accordingly.

Active network management allows the planning and operationalization of new power distribution grids with:

- more dynamic and complex structures,
- pervasive integration of DG,
- new energy source with dual load-generator behaviour,
- DESS, new equipment and services, such as Intelligent Electronic Devices (IEDs) and Smart Meters,
- demand side management and the information exchange between customers and market players.

The topology of the distribution network will progressively transition from predominantly radial to a more meshed topology which encompasses bi-directional power flows coming from the DGs and DESS. Traditional top-down power flows from centralized generation sources connected to the transmission and distribution power grid to consumers are challenged by the spreading of power electronics, local distributed generation and local means of electricity trade. Moreover, existing decades-old distribution infrastructure may require significant renewals soon in many systems. In order to allow for further market penetration of advanced local generation and consumption technologies and an efficient operation of distribution grids, the renewal and expansion of existing networks should go hand in hand with the mod-
ernization of distribution systems. Information and Communication Technologies (ICTs) will facilitate such operation, working hand in hand with new grid operating functionalities. In this sense, telecommunication and power network operators should provide comprehensive and optimal integrated solutions.

The role of electricity Distribution Network Operator (DNO) will change in the coming years. Today most distribution networks are a passive part of electricity infrastructure where they are delivering power from transmission grid to customers. The infrastructure of existing distribution networks has been designed to manage all probable loading conditions. The management of a future distribution network including DG, new load types like Electric Vehicles (EVs) and heat pumps, DR and DESS is becoming more challenging but also more versatile and therefore novel “tools and systems” are urgently needed. Active network management of future distribution network is not limited to the design of passive network but it may also enhance the network management by utilizing the advanced distribution automation system and services from aggregator and DERs. In order to highlight the radical change in the management of electricity distribution networks, the distribution company is called Distribution System Operator (DSO) when referred to future grid.

Distribution network management will be based on distribution network automation and active resources like DG, DR and DESS. Part of the complexity also stems from the fact that controllability of active resources may be provided by aggregators by offering flexibility services to reschedule electricity usage and production. The Aggregator is a new actor in the distribution grids and comes in two flavours:

- Technical aggregators
- Commercial aggregators

Technical aggregators are almost brand new, while some commercial aggregators already operate in the electricity market and ancillary service markets of Transmission System Operators (TSOs) [1].

Today all automation systems like SCADA (Supervisory Control and Data Acquisition), Distribution Management System (DMS), monitoring solutions for secondary substations and Automatic Meter Reading (AMR) are “up to the job” solutions to perform their specific tasks. However, they have very limited interoperability features and cannot manage the complexity of future distribution networks.

Advanced Distribution Management System (ADMS) provides the most comprehensive network management solution with monitoring, analysis, control, optimization, planning and training tools that all function on a common representation of the entire electric distribution network by merging DMS, outage management (OMS), and supervisory control and data acquisition (SCADA) systems into one. Similarly AMR is evolving towards Advanced Metering Infrastructure (AMI) where smart meters are increasingly used for network management.

Active distribution network will offer significant opportunities for the integration of DERs into the distribution network. The ability to flexibly and efficiently manage the new complexity revolves around functionalities that do not exist in today’s networks or only exist and operate in fractions of the network. A comprehensive combination of wide-spread field communication (Communication faster, more reliable, available everywhere, ...), real-time monitoring solutions and integrated automation systems altogether underpin the new ADMS which encompass functionalities such as:
More precise and real-time sensing and monitoring of the infrastructure, power lines and distribution transformers to keep infrastructure away from critical operation conditions, and facilitating the penetration of DG, EV, heat pump and DR scenarios.

The state estimation with newly defined parameters received from the IEDs would be used to estimate non-measured and missing quantities and to detect changes in the system like blown fuses (i.e. detect changes in topology).

The future distribution network monitoring system is not limited to the monitoring of network status. New sensors to monitor and sense network faults, condition of components and new parameters may also be utilized in distribution network monitoring. Aerial photographs and videos from a helicopter may be used to detect probable fault locations, to detect needs for trimming vegetation, to inspect visually the condition of components and to measure safety margins to nearby buildings.

Automatic Fault Location, Isolation and Supply Restoration (FLISR) will locate and isolate the fault and restore the service in the not-faulty areas to assure the continuity and quality of service.

The operation of micro-grids with islanding mode, grid supporting mode and grid connected mode will support the integration of the DERs into the power grid, minimizing the impact in terms of Power Quality (PQ) disturbances and enhancing network reliability.

Advanced protection systems will be introduced for distribution networks due to challenges caused by DG and requirements to improve continuity of service.

The congestion management of the whole distribution network is enabled by direct and indirect control of active devices (active and reactive power control of DERs) and by coordinating control systems within distribution, retail and end user / prosumer domains.

Aggregated DERs connected to distribution network would provide different services like reserves, regulating/balancing power, voltage support, etc. to support transmission system. Grid connection requirements for generating units like fault-ride-through requirement will be considered for DG units as well.

Real-time and automated information exchange between all parties of a power system including electricity market interactions and technical interactions between TSO and DSO. DSO would provide real-time information to the TSO for security assessment. Static and dynamic distribution system model order reduction would allow the TSO to see inside a distribution network and utilize these models for grid analysis.

Such challenges have already been recognized by the European Electric Grids Initiative (EEGI) in its road map for research and development 2010-18 where the need for increasing the coordination between TSOs and DSOs is being specified. [2]

Scope of the Work
This deliverable has two objectives:
1. Portray a vision of the new distribution management concept.
2. Identify and gather the needs and requirements of the new system to effectively integrate several solutions.

The main scope is to define the initial concept of the active distribution network. The concept of active distribution network and the roadmap to achieve this will be updated at the end of the project based on development and demonstration experiences. Therefore the main aim of the initial concept is to introduce the ideas of the project for further discussion internally and externally. For example the control
architecture for the congestion management scheme is a subject for discussion and the approach mentioned here might change.

The starting point for this work is to study the drivers for the active distribution networks, matching the European Union targets for 20-20-20 horizon and realized technical and economic trends in the energy sector. Several real use cases are being considered to compare real implementations. Also transmission network and electricity market entities are considered in their relation with distribution networks.

Several active distribution network studies have already been performed and evaluated through the deployment of different demo sites presented by several FP6-FP7 European projects during the past years. A list of these is presented in this document. Within the IDE4L project, several scenarios are also presented and will be evaluated that will demonstrate the feasibility of the solutions being developed and complemented with several previous experiences.

The main objectives of the IDE4L project are to:

- Demonstrate that active distribution network complies with the new sustainable energy generation and efficient use of electricity
- Develop a next generation distribution network automation system including the utilization of ancillary services of DER and aggregator
- Develop applications to monitor and control the whole network and DERs

Conceptual development of active distribution network, automation architecture and active network management is the basis for the whole project. The aim is to create a single concept for DSOs to start the implementation of active distribution network today based on existing technology, solutions and future requirements. There are already many mature technologies available in the market that solve specific issues and they ought not to be entirely replaced by new ones, but rather integrated and enhanced with new advanced functionalities. The whole concept will be demonstrated during the project. Secondly the project will define, develop and demonstrate the entire system of distribution network automation, IT systems and applications for active network management. An active distribution network utilizes DERs for network management including both real time operation and long-term network planning viewpoints.

Although the concept is defined as general as possible, the main scope of the IDE4L project is a subset of concept when specific applications are considered. In order to understand how these applications are interconnected, a well-defined concept is however needed. Specific applications of interest to IDE4L are:

- Planning tools to design active distribution network and to evaluate costs and benefits of developed concepts and technical solutions.
- Automation architecture to manage fast changing conditions and integrate large numbers of DG and DR. The distribution network automation system and an aggregator will be integrated to merge information from small scale DERs, to validate the performance of the distribution network, and to provide flexibility services for distribution network management.
- Embedded algorithms to enhance network reliability in active networks with a growing presence of DER to detect, locate and isolate faults, minimizing the fail probability, the outage time and the affected area, and to improve integration of micro-grids into the power grid minimizing the impact in terms of quality of service.
- Distribution state estimation algorithm utilizing near real-time measurement data from Medium Voltage (MV) and Low Voltage (LV) networks.
• Congestion management of MV and LV networks to handle extreme network conditions.
• Optimal management algorithms to optimize the integration of DER corresponding to dynamic pricing, load balancing and aggregators, and to define tools for DER participation in ancillary services provision for active/reactive power.
• Day ahead and intraday planning of active network operation (congestion management and micro-grid energy management) with short-term forecasts of load and production.
• Supervision of transmission and distribution networks coupling by exploiting Phasor Measurement Unit (PMU) data from both levels and to develop methods for interfacing TSOs and DSOs via key dynamic information exchange.

This work is organized as follows:

Section two introduces the main drivers and actors for the active distribution network, with a description of trends, the elements of the distribution network scenarios, presenting some already ongoing changes (smart metering, electric vehicles, renewable resources, transmission and distribution advanced grid automation).

Section three introduces the vision for the active distribution network, including a description of the infrastructure, the figure of the aggregator and the management operation with technical aspects.

In section four, the network planning and design is addressed with a vision of the new tools for planning purposes. Also the new type of implemented network operation is being described, including again actors involved, functionalities and responsibilities, with a relation on different projects.

Section five includes a description of the network operation. The importance of ICT technologies applying more up-to-date advanced systems. All the systems and agents participating are being described and introduced from the physical layer up to the application / operational layer. Operation is linked with new functionalities that are introduced in this section.
2. DRIVERS OF ACTIVE DISTRIBUTION NETWORK

2.1. Trends

Megatrends in the Energy Sector
Global economy has impacts on the energy sector via the financial market, fuel prices and location of energy intensive industry (in general electricity demand). The globalization of economy will also lead to a liberalized energy market and integration of energy markets. This trend is very clear in Europe, but electricity market liberalization and integration have very different schedules in member states. In Figure 2.1, the opening of electricity retail markets is shown by country, with the highest adhesion to open markets in the early 2000s. The aims of electricity market liberalization and integration are to enhance the efficiency of electricity generation and markets, and to attract investments to new and substitutive electricity production capacity.

Figure 2.1 Liberalized retail markets in Europe.

Urbanization and growing population and wealth increases energy usage. Globally natural resources, including fuels like oil, coal, gas and nuclear fuel for electricity production are becoming scarce, and, therefore, the fuel prices are increasing and the security of fuel supply might be endangered in the long run. The flows of energy sources will be diverged, which will have impacts on Europe due to its dependency on imported fuels. Nowadays the ecological footprint of the globe is estimated to be one point five times higher than the Earth’s production of renewable resources. [3] In the future, this trend will become
stronger and therefore the global competition of natural resources becomes tighter. Globally, electrical energy demand is growing rapidly which requires new investments to electricity production and delivery.

Economic decline in developed countries, due to decreasing population, industry restructuring and decreasing balance between people working and not working, increases the pressure to decrease the budget of the public sector. In the energy sector, the trend of decline means the necessity for renewal investments or maintenance of existing infrastructure instead of totally new investments (brown field investments). Electric transmission networks have also had difficulties finding right-of-ways for transmission lines in urban environment. Similar challenges might become reality also for distribution networks.

Environmental concern (global warming and nuclear disaster) has created major energy policy changes in Europe towards a more environmentally friendly and sustainable energy system. Diminishing natural resources, growing environmental matters and growing fuel costs increase the share of electrical energy consumption compared to other energy forms. When electrical energy replaces other energy forms, the total energy demand decreases, because the electricity system including the whole chain from production to end use is more efficient than other energy systems. Also CO₂ emissions will decrease if increased electricity demand is covered with Renewable Energy Sources (RES) or nuclear power. Recently the emergence of shale gas has decreased global fuel prices, endangering also renewable energy targets in some countries because cheap fossil fuels are replacing biomass based fuels in Combined Heat and Power (CHP) plants.

Global warming will also impact the energy system indirectly. In Northern Europe storms, floods and landslides are forecasted to become more common due to changes in the climate. The impacts of storms, floods and landslides are more severe for network infrastructures than expected benefits of decreasing load demand. In Southern Europe increasing temperature will further increase load demand, but the drying climate will provide less hydro power than previously.

Digitalization may seem to be a technological trend, but ultimately it will change the way business is done. Digitalization will change customer behaviour and the services they require. It provides a great opportunity to innovate new ways for energy system management in addition to utilize ICT technology to make the whole energy system more efficient.

**EU Energy System Drivers**

The EU climate change package [4] includes the so-called 20-20-20 targets which include a 20 % reduction of greenhouse gas emission, a 20 % improvement in energy efficiency, and a 20 % share of RES in the EU energy mix by year 2020. From the electricity networks viewpoint, the integration of RES and related solutions to maintain a high quality of supply are the most important questions at the moment.

European Technology Platform [5] has indicated requirements for electricity networks to fulfil above political targets. These requirements for future network are the flexibility of the system to meet customers’ needs and to respond to challenges ahead, to provide accessibility for all customers especially for RES, to ensure and improve system security and quality of supply, and to provide an economically competitive system. The main drivers for smart grid (including active distribution network) are listed in Figure 2.2. The environment driver is the main focus in EU targets today. The security of supply driver includes factors on multiple scales. It includes political aspects like the role of imported fuels during conflicts, regulation, and responsibilities of energy system participants. It also includes technical details like power system balance.
management with large-scale intermittent or inflexible production, reliability and quality of electricity networks, and mechanisms to guarantee the availability of production capacity in the system. The third driver is EU’s target to create an internal market for electricity. Internal market requires first of all liberalized and harmonized markets in each member country and secondly integration of markets e.g. by creating price coupling regions between power exchanges in Europe [6]. Internal market also includes all kinds of support schemes, like feed-in tariff or green certificates for RES and investment support for energy efficiency actions, to meet environmental targets and to promote new technology to be competitive in the future. The final aim of the internal market is to ensure long-term competitive energy prices in Europe.

Decentralization of the Electricity System

The evolvement of electricity systems started more than a century ago from isolated networks owned by cities and industries. At first, electricity systems were fully decentralized. These isolated systems were connected to enhance system operational efficiency and share e.g. reserves etc. Technological development in high voltage engineering and power plants lead towards centralized electricity and management systems where most generation units were connected to a transmission network and the systems were managed from a control centre. Nowadays national transmission networks are tightly interconnected in central Europe and several interconnections to neighbouring synchronous areas exists. However the growth of centralization has already stopped, but the existing centralized production, transmission system and electricity market will maintain their importance in the future. The trend of decentralization is very visible in terms of small-scale power production like solar power. A similar change is expected to happen also in consumption in terms of demand response and energy storage. However it is expected that centralized and decentralized systems will overlap and create a hierarchical system. The decentralization of electricity systems will affect the distribution network by introducing decentralized concepts like active distribution network and applications like energy management in micro-grid utilized for distribution network management.

Figure 2.3 represents the domains of an electricity system and their connections from physical and communication viewpoints. The domain of distributed energy resources is added to the existing centralized system consisting of markets, bulk generation, transmission, distribution and customer. The application
area of micro-grid, consisting of DERs, distribution and customer and realizing local management tasks, is also presented in the figure. Pan European energy exchange will realize the large-scale energy balance management between regions in Europe.

Figure 2.3. Electricity system domains and their connections (electricity = dashed line and communication = solid line). [7]

2.2. Electricity Network and Technology Trends

Sustainability and Security of Supply
The aim to reduce greenhouse gas emissions requires radical changes in energy production and consumption. Integration of renewable energy sources (RESs) into electrical system has penetrated during recent decade very rapidly and this trend will continue during the coming decades. The main reason for the growth of RES in Europe has been the different kinds of support schemes for RES to reduce CO2 emissions, to secure energy systems, and to foster the development of technology. The overall target is to have competitive RES technologies on the market which is mainly dependent on the development of technology and the production costs of conventional power production. The forecasts of the market diffusion of RES technologies like the one represented in Figure 2.4 clearly indicate the global growth of RES. [8]
On the electricity consumption side, energy efficiency is the main driver for the development of technology. Some examples of energy efficiency actions which have an impact on the electricity system are e.g. energy saving lamps, heat pumps and EVs. Also zero energy buildings or energy-smart buildings and districts, and integration of RESs in buildings and districts will also remarkably improve energy efficiency.

Second important challenge for a modern society is the continuity of electricity supply. Electrical networks are part of the critical infrastructure of a society that has a major impact on supply reliability for which the reliability of electrical networks is critical. The aging distribution network infrastructure is expected to threaten this reliability, but it also provides an opportunity to rebuild distribution networks for modern requirements. Realizing clean and reliable energy in the future requires a new kind of infrastructure to maximize the contribution and benefit from distributed energy resources (DERs) like DG, DR and energy storage.

Large scale penetration of renewable DG in MV and also recently in LV networks and new type of loads like heat pumps and in future EVs challenge the operation of existing networks by increasing peak load demand and variation in load demand. Already today there are situations where wind power curtailment is needed to ensure stable and secure operation of electricity network. Penetration of photo-voltaic (PV) has brought the same problem to LV networks. Self-generation and heat pumps (if replacing electric heating) will decrease the income of the network company, if existing tariff structures are applied.

Technical Requirements
The "business as usual" policy of current distribution grids is not efficient in covering the growth of the dispersed energy generation. Distribution networks are over-dimensioned today due to quality of supply obligations and missing possibility to control DERs. Therefore the over-dimensioning is the only possibility to maintain quality of supply constraints.

The future intelligent grid will achieve a common goal shared by several electrical grid components thus achieving flexibility and efficiency of the distribution network operation. They will be equipped with advanced and reliable ICT technologies, which will be able to integrate the actions of all users connected to
it, both generators and loads in order to efficiently deliver sustainable, economic and secure electricity supplies.

To provide controllability in distribution networks, the integration of advanced ICT systems is required; the grid will be able to integrate several new control schemes or algorithms for the grid management and collect information from the different actors present in the management system. A change in the regulatory framework is also needed in order to have the possibility to control some parts of the network (e.g. DG). Centralized management is becoming more critical since the huge amount of information from high-level functionalities makes the network more difficult to operate. This weakness could be solved by distributing the management system locally and by smartly using advanced ICT.

2.3 Examples of Trends

RESs for electricity generation are growing very fast in Europe. Figure 2.5 indicates the trend of RES excluding hydro power. Appendices 2 and 3 represent examples of RES penetration in a few countries and distribution network service areas. Most of RESs are connected to distribution (MV and LV networks) and sub-transmission (high voltage network) networks, only the largest wind and solar farms are connected to transmission network (extra high voltage network). Although wind and solar power get the most of the attention in public discussion, other RESs like biomass, biogas and biowaste have also remarkable shares especially in CHP. Hydro power is important RES for Europe at the moment, but in practice the amount of hydro power is not growing.

![Figure 2.5. Statistics of new RES electricity generation (excluding hydro power) in EU-27 member countries. [9]](image)

Globally, electricity consumption continues growing. In Europe the growth of electricity consumption has stopped, and in some countries or sectors of energy use the growth has become negative. Local distribution networks have very different conditions while some realize very rapid growth of consumption in the form of cooling devices or heat pumps, and other distribution networks in areas of decreasing population or declining economy experience decreasing load demand. Energy efficiency actions have also a diminutive impact on electricity consumption, but these slowly realizing actions are difficult to differentiate from other changes of consumption. One of the benefits of smart metering is the possibility to increase end
customer awareness about electricity consumption. Figure 2.6 is an example of a customer portal providing information about hourly measurements, comparison to other similar customers and advice on how to reduce electricity consumption.

![Figure 2.6. Example of customer portal information.](image)

The penetration of EVs is not yet visible in electricity consumption. In some countries like in Norway, government subsidies have promoted the sale of EVs very rapidly. EVs have been the most sold car during several months. However the penetration of EVs has been slower than the most optimistic forecasts have expected. An essential requirement for the popularity of EVs is the public charging infrastructure in addition to home charging, although the average daily driving distance is short enough for existing EVs. The public charging infrastructure is being developed in many European cities.

Demand response is a major interest of many parties at the operation of electricity market and transmission and distribution networks. In addition to a new interest of DR, in few countries retail and distribution network companies have utilized hourly tariffs based on day-head market price (only for retail), time-of-use tariffs (e.g. day/night time or seasonal tariffs), direct load control (e.g. disconnection of heating loads for a short period in emergency conditions) and smart meter based control of heating loads in order to minimize energy costs.

The DSO is the actor in the electricity supply chain in charge of planning, maintaining and operating the distribution grid in order to guarantee that nominal working conditions are respected. Nominal working conditions are set by national authorities and are compliant with the general guidelines set by the European Union in terms of energy efficiency and reliability of critical infrastructures. Distribution networks have a major impact on service continuity and PQ experienced by customers. To ensure a good reliability level, authorities often set some remuneration or penalization mechanism related to the continuity of services measured by indexes such as SAIFI (System Average Interruption Frequency Index), SAIDI (System Average Interruption Duration Index) or maximum outage duration.
3. VISION OF ACTIVE DISTRIBUTION NETWORK

Electricity distribution network is a delivery infrastructure that connects the customers of this network to the transmission network and therefore enables participation of customers into the electricity market to buy or sell electrical energy and to provide flexible DERs to Aggregators.

The customer of a network company may be a consumer or a prosumer of electricity.

In addition to energy, DER producers provide ancillary and flexibility services, predominantly via Technical Aggregator. These services are required in order to maintain secure and safe operation of the whole power system. Aggregators integrate small-scale DERs together to optimize their operation in the electricity market (Commercial Aggregator), and to provide services to TSOs and DSOs (Technical Aggregator).

Network companies enable participation to market, but their primary role is to maintain and to operate the infrastructure for power delivery. They have natural monopolies to deliver electricity in their service areas and therefore network business is strongly regulated by governments (e.g. by energy regulator). The power delivery infrastructure is also a key component of the critical infrastructures of modern society – as life in post-industrialised countries has become very dependent on the reliability and quality of power supply.

The trend toward increasing the share of RES in the electricity system and to improving energy efficiency (e.g. by replacing traditional technologies with electric vehicles and heat pumps) have put strains on the local distribution network, thus emphasizing concerns over the security and the reliability of the whole power system.

Active distribution network (ADN) is the only true answer to these issues. The basic aims of active distribution network are to enhance the reliability and PQ of distribution network and to increase the hosting capacity for RES in the existing distribution network. Active distribution network will make infrastructure/methods/processes available to enable flexible DERs participation to the market.

ADN will make use of the flexibility services offered by Aggregators and DERs for Active Network Management (ANM). ADN is underlined by an enhanced ICT infrastructure to cost-effectively enable an entirely new breed of functionalities for network planning and operation.

It is extremely important to understand distribution network processes in a holistic way instead of concentrating on single functionalities. The aim of developing a vision for the active distribution network is to present the overview of possibilities of a future distribution network. Methods and technologies presented in the following sections are not expected to be implemented by all distribution network companies because they have different requirements and needs.

3.1. Active Distribution Network

Electricity distribution networks have so far been designed and operated as passive networks according to a design point that requires them to handle all probable loading conditions. This results into sub-optimizing the network efficiency by over-planning the network capacity which is being fully utilized only a small percentage of time. With that design point, the only way to increase the number of serviced users is adding network infrastructure assets in proportion – no active network management, real-time monitoring and limited load demand shift day to night through retail tariff incentives.
Active distribution network consists of infrastructure of power delivery, active resources and active network management. It combines passive infrastructure with active resources, ANM functionalities and ICT infrastructure. Active resources are e.g. DERs, Micro-grids, flexibility services from Aggregator, STATCOMs, etc.

Functionalities of active network management are for example asset management, fault management (e.g. fault location, isolation and supply restoration), advanced protection and control, and real-time monitoring and data analysis of system dynamics.

The ICT infrastructure enables collecting information from every point of the distribution network and using it for:

- Network planning and operation,
- Network control and protection in case of fault or congestion,
- Network performance optimization.

The management of power delivery infrastructure is enhanced by utilizing active resources in the ANM and specially by coordinating the operation of DERs from the whole system viewpoint to achieve synergy benefits instead of optimizing their operation individually from a single party’s viewpoint. In order to realize this vision it is very essential to integrate active resources as part of an active network instead of just connecting them to the network with the “fit and forget” principle.

Perhaps the most fundamental difference between passive and active networks is that not only do active networks connect DERs, but they also exploit them to the end of optimizing network asset investments and operational costs. Active networks indeed will have substantial impact on both network planning and the operation.

![Figure 3.1 Active distribution network.](image-url)
3.2 Power Distribution Infrastructure

This section introduces new primary and secondary (monitoring, protection, control and communication) technologies to be applied in active distribution networks.

**Primary Technology**

Primary distribution network technology like primary and secondary substations and components within them, feeders, transformers, etc. form the basis for the distribution network. The reliability of radial distribution network is very much influenced by the outages (faults and maintenance needs) of these components and the configuration of the network. The uninsured reliability of the existing aging network infrastructure and customers' increased dependency on the continuous supply of electricity and have strongly effected many network regulation models. Therefore infrastructure solutions decreasing fault frequency, outage duration and outage area will be needed in the future.

While medium voltage feeders in urban areas are mainly realized with cables, there are long feeders in rural areas which are realized as overhead lines. Fault frequency of feeders might be decreased by replacing bare overhead lines with cables or covered conductor lines. Also relocation of overhead lines from the forest (high fault frequency caused by surrounding environment) to the roadside where it is easily accessible, will decrease overall fault frequency. Another commonly used method is to change network grounding type from isolated to compensated (e.g. Petersen coil) grounding in medium voltage networks. This will decrease the amount of earth faults which are the most common fault types in the overhead MV network. Earth faults may also be reduced by using metal oxide arrestors instead of spark gaps. Fault frequency may also be decreased when caused by environment, animals and vandalism by relocating equipment like pole mounted transformers to indoors or by using animal shields.

Another type of option for enhancing the reliability of distribution networks is to decrease outage duration and area. Relatively high voltage levels like 20 kV in distribution networks enable long feeder lengths in rural areas (low demand density). Due to the radial structure of the MV network, a large number of customers are affected in case of long MV feeders. In the areas where load demand is increasing, the construction of a new primary substation to split long MV feeders to several shorter ones is a very effective method to improve reliability. Simplified primary substation configurations and High Voltage (HV) network connection practices have been developed to decrease investment costs of so-called light primary substations. Similarly reclosers or circuit breakers along the MV line will reduce the outage area when the fault appears after the switching device. In case of permanent fault in the beginning part of the MV feeder, remotely controllable switches and backup connections will decrease the outage area and duration for customers behind the switching device.

Technologies to enhance the supply reliability of a single customer are for example transfer switch and island operation. Transfer switch will automatically and extremely fast switch from faulted feeder to backup feeder in order to avoid outage. The switching should be fast enough to protect sensitive loads (processes) on customer side. Transfer switch may also be applied to switch from network connection to standby generator and/or uninterruptible power supply. Island operation may be realized in customer’s network by utilizing standby generation units, uninterruptible power supply and periodization of loads supplied during island operation. DG units realizing island operation within a public distribution network is typically prohibited today. In case of a permanent fault in a radial distribution network, all DG units should be disconnected from the network. Controlled island operation of a public distribution network utilizing the concept of micro-grid is an interesting opportunity to enhance distribution network reliability.
Primary technology also has a strong impact on distribution network capacity to supply power to loads and host or receive power from DG units. Distribution network hosting capacity is limited by overloading of network components, voltage drop/rise or voltage quality. In addition to replacing e.g. an overloaded component with a higher rated one, there are alternative technologies to enhancing network hosting capacity. Voltage challenges may be resolved by adding a new voltage control zone along the MV feeder by utilizing MV/MV transformer and On-Load Tap Changer (OLTC). Similarly voltage boosting devices have been introduced for long and/or heavily loaded LV networks. Due to large scale PV penetration in LV networks, an OLTC for secondary transformers has also been introduced recently.

Utilization of power electronics in distribution networks is also becoming possible due to development of technology and costs. The idea of Low Voltage Direct Current (LVDC) is to utilize DC for power distribution only and not replace all parts of system with DC technology. LVDC will enhance network capacity and PQ compared to traditional LVAC. DC technology with ±750 V could double the thermal capacity and have seven times higher capacity in case of voltage drop of LV network cable compared to 400 V AC using the same conductors [10]. In addition to capacity enhancement, also the PQ may be improved by controllable inverters on customer side. Another power electronic based option is the application of series (e.g. back-to-back connected converters) and/or shunt (e.g. active filter or STATCOM) units to enhance voltage quality of sensitive customers.

An important question related to primary technology of power distribution network is the appropriate choice of voltage levels. These decisions have extremely long-term impacts on network design and therefore changes are rare. However a few trends can be identified, if a long enough investigation period is considered. First of all uncommon voltage levels like 45 kV, 10 kV, 6 kV or 5 kV will be replaced with 20 kV when these networks come to the end of their lifetimes. The costs and availability of spare parts makes the use of these networks sometimes very expensive. Also the overall investment costs of the network may be minimized by using fewer voltage levels instead of several voltage levels in a distribution network. There is also a trend for at least a national level standardization of voltage levels. For example in Finland the most MV networks are 20 kV networks, but old components rated for other voltages still also exist.

Another trend related to voltage level is the advanced utilization of LV [11]. The maximum voltage for LV is 1 kV. The idea of 1 kV technology is to replace light loaded 20 kV branches with 1 kV technology. This will naturally restrict the maximum loading of the branch, but typically improves supply reliability in the whole MV network area when overhead MV branches are replaced with LV cables and an own protection zone.

**Monitoring, Protection and Control Devices**

Monitoring of distribution networks will extend to the complete network including MV feeders, secondary substations and LV networks. Active distribution networks have clear interest to monitor those parts of networks where the hosting capacity of network may occasionally be exceeded or the continuity of supply is a concern.

In addition to traditional voltage and current transformers, new types of sensors might be interesting for network asset monitoring. Examples of these sensors are temperature sensors, door position indicators, and all kinds of sensors used for visual inspection/ supervision.

Also the number of sensors will increase. At the primary substation, voltages and currents are currently monitored real-time. Fault indicators/locators located along MV feeders provide information for FLISR application to decrease outage duration together with advanced automation solutions. The number of
monitored secondary substations is also continuously increasing. The most extensive monitoring solution is the AMI based on smart metering already realized in a few countries.

Power quality meters, fault recorders, Phasor Measurement Units (PMU) and on-line partial discharge measurements are examples of new measurements providing much more accurate information about disturbances than traditional voltage and current measurements.

The control of a distribution network also requires increasing the number of IEDs to distribute decision making from control centre and primary substation along the MV network (e.g. reclosers and circuit breakers), secondary substations (e.g. AVR of OLTC) and DERs (e.g. AVR of a DG unit).

**Communication**

Distribution automation applies to a variety of communication technologies like fiber optics, wireless networks (2G and 3G), power line communication (PLC) and satellite communication. All primary substations are equipped with communication access for SCADA and possibly other IT systems. Fiber optic and wireless communication are typical examples for primary substation communication. The number of secondary substations and MV switching stations including communication is increasing but still the number is low. Typical communication media to a secondary substation is wireless communication. Communication to smart meters is realised in principle by two alternative ways: PLC or wireless. Metering data is collected by AMR gateway or data collector and stored in a meter data management system.

Ethernet is becoming the prevalent communication standard for all automation devices. Major advantage and pull-through for Ethernet it is the extremely wide usage everywhere in ICT systems. Hundreds of vendors for hardware, software and protocols utilizing Ethernet exist. This also makes it cost efficient. Standard Ethernet is used together with several protocols, being a true bus which can co-exist in the same network integrating heterogeneous IEDs. For substation automation, the most remarkable protocols utilizing Ethernet are IEC 61850 GOOSE and MMS, Modbus/TCP and DNP 3.0 over LAN/WAN.

In future communications, accessibility to all parts of the distribution network is improving further and network management becomes more and more dependent on real-time information about the network. Therefore the reliability, availability and security requirements of communication are tightening and redundant communication infrastructure will probably be dealt with first in primary substation communication. Other reasons for the utilization of multiple communication technologies are the connectivity problems with wireless technology for underground installations and the cost efficiency e.g. in smart meter communication. New technologies like 4G and 5G wireless communication and MV PLC will provide a lot of bandwidth and low latency, thus fulfilling most requirements of active network communication. Short range wireless communication technologies like Zigbee, RFID, etc. may be used to simplify the connectivity of sensors like current sensors, fault indicators, low power switches, thermostats, etc. at the level of substations and buildings.

**3.3 Active Resources and Aggregator Concept**

Distributed energy resource consists of distributed generation, demand response loads, storage, microgrids and units owned by a DSO like STATCOM, OLTCs, distribution automation, etc. Small-scale DERs do not fall under the direct supervision and control of the DSO. These DERs can be grouped under an Aggregator to be able to operate on the energy market as one, or sell services to the DSO and TSO who may
use the services of aggregators to monitor and control DERs. The Aggregator should also verify with the DSO if the intended DER control actions are feasible for local distribution network.

The Aggregator is a service provider and can be characterized in different ways. This kind of flexibility is needed because of different kinds of electricity market settings and rules. The most typical way to implement an aggregator is to supplement the production and consumption portfolios of an electricity retailer by flexible DERs. Another option is to view the aggregator as an information broker who contracts with DERs and provides services e.g. to retailer.

Flexibility services offered by the aggregator for commercial purposes are for example:

- Price elasticity at day-ahead market to manage price risk
- Demand response to manage forecasting risks and to minimize balance costs
- Demand response offer for regulation power market
- Distributed generation offer to day-ahead and intraday markets

The role of the technical aggregator is to provide ancillary and flexibility services for TSOs and DSOs. Ancillary services like control of reserves are nowadays provided by generation units connected to transmission network. In the future, small-scale DERs could provide ancillary services via technical aggregator which would simplify DERs access to the ancillary service market, reduce the cost of ancillary services for TSO and guarantee required predictability for ancillary services. Ancillary services offered by technical aggregator to TSO are for example:

- Reserve market (disturbance and control reserves: virtual inertia, spinning, fast and slow reserves)
- Power flow management (e.g. control offer for regulation power market)
- Back-up power

The technical aggregator might offer flexibility services to the DSO for active network management. Flexibility services offered by technical aggregator to DSO are for example:

- Reactive power support and Voltage control
- Power quality control
- Power flow management (Production curtailment, load shedding or demand response)
Two other methods applied directly by DSO to utilize DERs in network management are grid tariffs and connection requirements. Dynamic or power based grid tariff provide customers with incentives to shift load demand to network off-peak hours. In the future, more dynamic tariffs are expected to be needed because peak demand will not be as predictable as before, thus each network section will have its own peak hours and network loading will vary more due to self-generation and price based control of load demand. Notice in fact that, for example, time-of-use tariffs applied to full storage electric heating customers in Finland efficiently shift load demand to night hours but creates a system level peak during cold days in the beginning of night time.

Connection requirements are an efficient method to establish technical capabilities for the control of DERs. If for example the voltage control capability were a mandatory requirement for the connection of a DG unit and DSOs were able to utilize it, there would not be technical barriers to realize more advanced voltage control in distribution networks. The challenge in establishing connection requirements consists of foreseeing all necessary technical capabilities many years before they are actually applied to network management. However, unnecessary connection costs should be avoided. An example in the opposite direction is the so-called 50.2 Hz problem in Germany where previous rules required PV units connected to the LV network to disconnect when frequency exceeds 50.2 Hz to avoid unintended islanding in the distribution network. Addressing the impact of large-scale PV disconnection on system stability however necessitates increasing the frequency setting which will be costly for units already installed.
3.4 Active Network Management

The aim of active network management is to

- Ensure safe network operation in distribution networks with DERs
- Increase network reliability in networks with DERs
- Maximize the hosting capacity of the existing networks with bottlenecks
- Maintain the required level of PQ despite variable power production or consumption

Overview of ANM concept

Integration of DERs (DG, EV, DR, etc.) in distribution networks provides opportunities to reduce CO₂ emissions, save energy, reduce network losses, improve network monitoring and controllability, utilize existing networks more efficiently and improve the visibility of DERs to TSOs and aggregators. Active distribution network also offers a great potential of reactive power control capabilities by means of DG power electronic inverters and/or FACTS devices. All these devices can be controlled in a centralized or decentralized way in order to actively control their outputs at the point of common coupling and to enhance the operation of the whole distribution network. Additionally, a proper coordinated control of control units of DSO and DERs will improve network efficiency and it will allow the widespread deployment of DG.

Active network management is based on distribution network automation and DERs. Distribution network automation includes the whole chain of electricity network management starting from control centre information systems, substation automation, secondary substation automation and ending at the customer interface (e.g. smart meters). Distribution automation realizes the supervision of the network state, control of network breakers and switches, and monitoring and control of secondary substations, direct control of DERs and end-customers. Distribution automation is also expected to merge information from/to all actors interfaced to the distribution system including TSO, energy retailers, aggregators, and local communities like micro-grids.

Active distribution network will offer significant opportunities for the integration of DERs into distribution network management. A very important challenge is the optimal management of the whole network with different DG scenarios, EV and heat pump penetration levels and DER scenarios that will affect the loading of networks and transformers, the voltage profile of LV network and line overloading. The new scenario of distribution network requires also new functionalities for the operation of the distribution networks like distribution state estimation, automatic FLISR, coordinated voltage control, power flow control, static and dynamic distribution model order reduction to coordinate with TSOs, and the availability of stability indicators – using both models and measurements.

Overview of the IDE4L Automation Concept

The IDE4L automation concept dynamically integrates end-use energy services with real-time network operations, and – in doing so enables network-friendly energy services as ancillary services for TSO’s and spearhead market participation of DERs through Aggregators. Measurement data and controls may be merged, analysed and utilized at different levels to integrate numerous measurement points and DERs also by partly decentralizing the monitoring and decision making process, thus managing the fast changing conditions. The automation concept revolves around three design points:
IDE4L is a project co-funded by the European Commission

- Hierarchical and distributed control architecture in distribution network automation,
- Virtualization and aggregation of DERs via aggregator and
- Large scale utilization of DERs in network management.

Figure 3.3 presents the complete distribution network management system and its interfaces to other actors.

Today all automation systems like SCADA/DMS, monitoring solutions for secondary substations and automatic meter management work as vertical solutions - each silo is to deal with a specific purpose - but they do not interoperate with one another to manage the overall complexity and the new tasks of future distribution networks. Integration of these systems together may enhance the monitoring of the whole distribution network.

From DSO’s viewpoint, the distribution automation system is enhanced with flexibility services provided by the aggregator. The aggregator may interact with DERs via a production management system (gateway for remote monitoring and controlling of DG units), a home energy management system (or building automation system) and micro-grid management system which aggregates data and manages DERs at customer sites. Similarly the data from smart meters is collected by DSO (or by company realizing meter reading), which may be published to national AMR HUB [12] or similar system to be available for market participants and customers.

The hierarchy of distribution network automation includes three levels: primary, secondary and tertiary levels. Primary controllers and protection devices, in general IEDs, operate autonomously and have the fastest response in system disturbances. Secondary level includes cooperation of several IEDs like

![Figure 3.3 Automation architecture for active network management.](image-url)
interlocking schemes in protection or automatic coordination of controllers in the specified network area. Tertiary level manages the whole system typically based on control centre level IT systems and operator actions.

Information about customers and DERs is available at different levels of distribution network control hierarchy. Because some actions of the aggregator might be infeasible from DSO’s viewpoint, the necessary information about DERs has to be presented in the DSO’s control centre information systems. Every time a new DER schedule is published, DSO will validate if such schedule is feasible from the network's viewpoint. For example if very many DERs in the same network area are scheduled for certain cheap hours of day-ahead electricity market, the electricity network may become congested. Congestion management functionality might utilize aggregated DERs to avoid congestion beforehand.

When DERs are needed more urgently for example in case of overloading of network, then it is necessary to speed up the integration of the distribution automation system (e.g. secondary substation automation) and aggregator and automate network management functions. For these purposes direct information exchange is needed between aggregator and secondary substation automation like proposed in the SmartDomoGrid project [13]. Secondary substation automation includes automated network management functions utilizing DERs. Distributed ANM functionalities enable fast coordination of IEDs for example to coordinate voltage reference points of primary controllers in order to maximize network hosting capacity for DG units. Smart meters and different customer level management systems may also have a direct communication link (e.g. a Zigbee interface) to deliver meter data for real-time management of DERs.

The utilization of DERs and outsourced services in distribution network management requires improved integration of these resources and services to DSO's automation and IT systems. Distribution automation may also include more distributed functionalities and existing systems like SCADA, smart metering and PQ monitoring will be merged together to utilize the same ICT system. Therefore the architecture of distribution automation should accommodate concepts of distributed or decentralized systems. Outsourced services like fault repair and maintenance work also require tight integration to DSO’s control centre IT systems. Field crews need information about work orders and outage alarms to start working in the field. They might also need information about network topology and switching state, fault location, estimation of repair need, etc. After finalizing the work order, the information and documentation about repair and maintenance work should be sent to the DSO’s system.

**Asset Management**

The need for real-time information about the network is becoming more important when the penetration level of DER is increasing or when DER units have a strong local influence. Measurements (currents, voltages, PQ, etc.) and fault/outage indication at all levels of the distribution network (HV/MV substations, MV networks, MV/LV substations and LV network) are needed to monitor fast changing conditions like meteorologically induced changes. Therefore the aim is to improve the observability of the whole distribution network by using real-time network monitoring and state estimation. Distribution state estimation should be able to estimate fast changes in network conditions, to estimate network conditions more accurately when measurements are missing or network data is incorrect, and to estimate the status of MV and LV networks.

Nowadays the monitoring of the distribution network is mainly realized at primary substation level. The monitoring of MV and LV networks is still very limited although the number of secondary substation monitoring, PQ monitoring and smart meters is increasing rapidly. Primary and secondary substation
measurements are typically collected by SCADA, while smart meters are commonly utilized only for billing purposes although they may also provide network operational data. Some AMIs are already in use [14] or demonstrated [15], where network operational data like end customer outage indication, real-time measurements, PQ reports, etc. are provided for SCADA/DMS.

The future distribution network monitoring system is not limited to the monitoring of network status. New sensors to monitor and sense network faults (e.g. fault indication/location and IEDs including fault recorders), condition of components (e.g. on-line measurement of partial discharge and transformer hot spot estimation) and new parameters (e.g. dynamic phasors by PMU and dynamic line rating) may also be utilized in distribution network monitoring. The data of these new sensors might be utilized in disturbance management, predictive maintenance of network components and enhancing power system stability and loadability.

The scalability of the monitoring system is a critical question from the distribution network automation system viewpoint. Instead of collecting and analysing a few thousands of measurement points, the future monitoring system should be able to handle millions of measurements and a large volume of measurement data. Therefore the automation system architecture presented in the Figure 3.2 is based on a hierarchical structure, data analysis in the field and server push instead of client pull. The automation system should also be based on standard IEC 61850 to enhance and simplify the integration of subsystems. Data exchange based on standardized messages is an essential requirement of DSOs to develop automation and IT systems for smart grid.

Data handling, storage and analysis is also becoming important due to huge volumes of data. On-line and automatic handling and analysis of data is needed to reduce the amount of data transfer to control centre. Only relevant information should be represented in real-time to the network operator. Distributed data storage allows tracking every detail without real-time communication to control centre. Data may be later replicated to centralized asset management database for off-line data analysis purposes.

Smart meter data combined with MV and LV network model might for example be used to supervise the loading of secondary transformers or other network components in pseudo-real-time. Real-time information about currents and temperatures may be further utilized to predict the remaining lifetime of transformers. The monitoring of circuit breaker and tap changer actions might be used to realize on-demand or predictive maintenance. High frequency partial discharge measurements may be further utilized for condition monitoring of transformers, cables (joints and terminals), etc. Also statistical information about the malfunctioning of protection relays, controllers, communication and IT systems need to be developed due to increasing importance of these systems for active distribution network.

Overhead MV line maintenance (vegetation) may be predicted based on the geographical information of the line, the environment (forest, field or beside a road) of the line and the age of the forest. Geographic information about forest age, type, etc. based on National Forest Inventory is available in [16]. Fault statistics (number, location and type of fault) provide additional information for maintenance planning. Aerial photographs and videos from a helicopter may be used to detect probable fault locations, to detect needs for trimming vegetation, to inspect visually the condition of components and to measure safety margins to nearby buildings. Another source of information is the difference in satellite images before and after a maintenance period, disturbance, etc. Images are nowadays inspected manually, but automatic inspection using image recognition is progressing fast for example in the security industry.
Disturbance Management

Typical distribution network topology is a radial MV network. In urban areas MV feeders form an open ring topology utilizing the same conductor size in each part of the ring. Ring Main Units (RMUs) are also utilized to connect feeders and secondary transformers and to handle the switching status of MV network. In rural areas MV feeder has a tree structure, secondary transformers may be tap connected with a disconnector and MV conductor size is decreasing from primary substation to the tail of the feeder. Backup connections from adjacent MV feeders are available only in selected locations.

The traditional way to enhance the reliability of a distribution network has been to speed up the fault management process. Fault management includes fault location, isolation and supply restoration phase just after the fault, fault repairing and supply restoration to all customers. Nowadays fault management is mostly realized manually by repair workgroups. Fault location may be estimated with fault distance information from IEDs and fault indicators together with a DMS network model. Fault isolation and supply restoration may be enhanced with remotely controlled switches and DMS switching planning algorithms. Fully automatic fault location, isolation and supply restoration may further enhance the reliability by reducing the duration of the interruption. The repairing time will also impact outage duration if power supply may not be restored to all customers. Therefore the workforce management will also have an impact on outage duration. Integration of DMS and the workforce management system may also speed up and simplify the switching and repairing especially in case of outsourced services by providing accurate and fast information related to repair and maintenance tasks.

Intended island operation may also be applied in public distribution network. Nowadays island operation is prohibited in most distribution networks. Sometimes network companies utilize mobile backup generators to avoid outages due to maintenance work for example in secondary substation. The utilization of island operation may be extended also to fault conditions in the future scenario of a large scale penetration of DG and other controllable DERs. The operation and control of the islanded network part becomes possible for
DSO when it is able to balance the islanded network, black-start the island after an outage or automatically disconnect the island from the faulted network and resynchronize the island network with or without outage to the grid after fault clearance.

Overhead lines are vulnerable to environmental events like storms. Situation awareness of the distribution network during a major disturbance is critical for the network management, but also for other stakeholders like customers, rescue and health authorities. Situation awareness is composed of network situation (SCADA/DMS and visual inspection), information about critical customers (defence forces, hospitals, health care at home, clean and waste water, schools, day-care, telecommunication, ...) and access to fault locations (traffic jams, road blocks). Estimation of outage duration for different parts of the distribution network is also necessary information for customers and authorities to decide what kind of actions are necessary to prevent serious consequences or harm for citizens.

Every disturbance should be analysed to improve disturbance management at all levels. The success of the disturbance management process is very much dependent on the organization of different tasks. Therefore the performance analysis of the management process is equally important as the technical analysis of a disturbance. IT systems should therefore support both of these analyses. Post mortem disturbance analysis based on disturbance recordings and PMU data is now becoming possible due to advanced IEDs, telecommunication and automation systems, and automated analysis tools.

Advanced Protection

The increasing amount of DG is raising new challenges for the distribution network protection system. Protection disoperation can lead to dangerous situations and cannot, therefore, be tolerated. In order to overcome these challenges, new ways of network protection need to be considered. Distance and differential protection schemes are now being considered as possible solutions to challenges raised by DG in the distribution networks. Directional overcurrent scheme and sectionalizing circuit breakers could also be used as a means to counter the new protection challenges.

Reliability enhancement of MV network may require changes in network topology. Radial MV feeders with open ring or backup connections might be replaced with a ring topology having always two sources. If one source fails it will be automatically disconnected. Depending on applied protection scheme and number of switches in the network, the fault in the network may or may not cause an outage for customers. For example if a differential protection scheme is applied, each line section may be disconnected individually and therefore outages may be avoided in case of single failure. Another less costly possibility is to utilize directional overcurrent or distance protection to avoid the need for fast communication link between IEDs. Both of these protection schemes may of course be applied to several line sections in order to find a good compromise between investments on IEDs and circuit breakers and reliability enhancement.

Communication based protection, based on IEC 61850 GOOSE messages, provides many possibilities for primary substation interlocking schemes. GOOSE message may also be transferred between primary substation IED and IED along the feeder (e.g. IED of DG unit or recloser/circuit breaker) to realize transfer trip or block schemes. These schemes might be applied in Loss-of-Mains protection, to speed up distance or directional overcurrent protection in meshed network, to curtail production in case of overloading e.g. due to configuration changes in sub-transmission or MV network, or to prevent DG unit disconnection at adjacent MV feeder fault (Fault Ride Through (FRT) requirement).
Loss-of-Mains (LOM) protection, which is also known as anti-islanding protection, is meant for ensuring that no generating units are left feeding customer loads in islanded circuits. The avoidance of unintentional islanding is important due to the associated safety hazards for utility personnel but also because DG units and network components may be damaged as a consequence of unsynchronized reclosing of the islanded circuit. In addition, customer loads in the islanded circuit may be damaged due to poor PQ.

LOM protection methods can be divided into passive, active and communication based methods. Passive LOM protection methods have been used many years but with the penetration of converter connected DG units active LOM protection methods have become interesting. Active LOM detection methods have been claimed to be capable of detecting islanding even when there is no power mismatch between production and consumption in the islanded circuit [17]–[19]. However, it has been observed that many active LOM protection methods may not function properly when multiple inverter based units are connected to the islanded circuit [20], [21] or the islanded circuit contains both converter connected DG and directly connected synchronous generators [22]. Communication based LOM protection methods are in general the most expensive of LOM protection methods.

The LOM protection settings have traditionally been set quite tight in order to reliably detect islanding. The tight relay settings, however, have the disadvantage that DG units will then be easily tripped off when a fault elsewhere in the network causes the voltage or frequency to drop to some degree. This, in turn, poses a risk to system stability since the voltage and frequency will drop even more after the tripping of the DG units. In order to take part in the system services, the protection of the DG units will have to be loosened and the units must have a FRT capability, i.e. they must withstand voltage and frequency fluctuations caused by a fault elsewhere in the network. Due to system level impacts of small-scale DG, FRT and other system requirements will be set to MV and LV network connected DG units too. In that case affordable communication based LOM protection method is needed.

**Congestion Management**

In weak distribution networks, voltage rise is usually the factor that limits the network’s hosting capacity for DG. Similarly, voltage drop limits the network’s hosting capacity for load. At present, voltage drop/rise is usually mitigated either by increasing the conductor size or by connecting the generator on a dedicated feeder. These passive approaches maintain the current network operational principles but can lead to high connection costs. The voltage drop/rise can be mitigated also using active voltage control methods that change the operational principles of the network radically but can, in many cases, lead to significantly smaller total costs of the distribution network than the passive approach. The active voltage control methods could utilize DERs in their control and also control principles of existing voltage control equipment such as the primary transformer tap changer can be altered.

Overloading of transformer or line section is another reason for congestion in the network. Power flow control is not a common practice today, but some heating loads and DG units may be controlled directly by DSO in emergency conditions. Also dynamic grid tariff (time-of-use tariff) might provide incentives for customers to shift load demand to off-peak hours. Flexibility services, like rescheduling of controllable loads, storage devices and DG units, provided by the aggregator are therefore needed.

Congestion management may be divided into three hierarchical levels: primary, secondary and tertiary control. Primary control is based on local measurements and therefore it may operate extremely fast, but it is lacking information about the complete system. Typical primary control actions are reactive power or voltage regulation of a DG unit, reactive power regulation of compensators, voltage control with
IDE4L is a project co-funded by the European Commission

transformer OLTC, and in extreme cases DG unit production curtailment. Power flow control of distribution network based on local measurements is not possible. Many DG units are capable of primary control, but few grid codes at distribution network level require controllability of DG units. The reality today might be that unity power factor control is required from the DG unit.

The objective of secondary control is to process the states provided by the state estimator, to evaluate / verify the state of the MV or LV network, to coordinate primary controllers and direct DER controls (load shedding, production curtailment or utilization of energy storage) in the network area to minimize operational costs within a given voltage range and component ratings. Secondary control will run on-line on an intelligent device at the primary or secondary substation level.

Tertiary control might be located in the control centre and its main tasks are to verify the state of the MV network, set the topology of the entire network, coordinate secondary controllers and order flexibility services from Aggregator to minimize operational costs within a given voltage range and component ratings. The tertiary control will evaluate the current and future states of the network by using the data series provided by the state estimator/forecaster. Day-ahead rescheduling of controllable loads (demand response), production units and storage devices by technical aggregator may be realized by utilizing smart metering infrastructure, home and building automation systems or micro-grid management system. Coordination of controllers provides significant enhancement for distribution network hosting capacity compared to passive network and primary control.

Figure 3.5 Example architecture of coordinated voltage control.
3.5 DSO Interaction with TSO and Electricity Market

Both the increased penetration of RESs at the distribution level, and the lack of observability of the distribution network are posing great challenges to TSOs in terms of network control and power system security. These challenges have been acknowledged by the EEGI in its road map for RD&D 2010-18 [2]. The roadmap strongly endorses increased coordination between TSOs and DSOs in many areas and at different levels. The infusion of intelligence (new ICT architecture and subsystems) and IED’s in the distribution grids can pave the way for a new and increased level of integration and interoperability across generation, transmission, and distribution. At the DSO level, it may be possible to develop functions that provide key static and dynamic measurement observability and summary information to power system operators to enhance their operational security. These functions will allow the TSO to have visibility beyond its operational domain, and allow TSOs to quickly adapt to changes in the DSO (such as those posed by DG, EV, DR, etc.). As a result, these new DSO functions can help the TSO to improve network controllability and guarantee continuity of supply.

Large scale penetration of DG is forcing TSOs to re-consider the contribution of DG units to system services. System services are for example voltage control, reactive power support, FRT capability, frequency control and reserves. The operation of a transmission system becomes impossible if most generation units are connected to a distribution network without supporting transmission system. Another option is to allow DERs to participate in ancillary service markets like regulation power market and disturbance and control reserves. DSO’s role is to enable the support from DG units to transmission system. DSO's responsibility is to provide information for transmission system operation, behave like a "good citizen" (predictability, dynamic performance, ...), and realize emergency controls like power shortage in a smart way by shedding only the least important loads and continuing the operation of DG units.

Interaction and exchange of real-time information between distribution network and electricity market (retailers, balance responsible partners, aggregators, etc.) is also becoming more important due to fast changes in the consumption and production. Improved integration of small-scale prosumers into electricity market requires also enhanced information exchange between prosumers and market players.

DSO's IT and automation systems may provide required information for market operation. Smart meters owned by DSOs might provide information for national AMR HUB. AMR data provided by DSOs is utilized today in some countries for balance settlement. If more real-time information about end customers were available, this information might also be used for balance management of retailers and energy management at customer or higher levels. Also the portfolio management of commercial and technical aggregators requires real-time information about availability and response of controllable DERs. Information about DER control schedules realized by aggregators should also be sent to DSO to verify possible constraints in the operation of distribution network.

Home Energy Management System (HEMS) owned or operated by Aggregator might also utilize the last mile communication infrastructure of DSO in order to minimize the infrastructure costs of the whole system. Broadband PLC could primarily be utilized for smart metering, but the same infrastructure might be shared with aggregator as in the SmartDomGrid project [13]. Demand response might also be realized via a smart metering system like demonstrated by Helen (DNO in Helsinki) [23]. Smart meters in Finland should have interfaces for direct load control and Time-of-Use tariff control. The aim of Helen is to provide demand response infrastructure services for retailers.
4. NETWORK PLANNING/DESIGN INCLUDING ACTIVE NETWORK FUNCTIONALITIES

The design principle applied to active networks implies that network scaling is based on network loading conditions and DER availability for network management. Network loading conditions and availability of DER could be estimated statistically based on the statistical behaviour of consumption and production customers. Intelligent DERs’ control can prevent extreme loading conditions that are posing tough challenges to electricity networks. This drives improved quality of electricity supply; reduced capital investments in the capacity of electricity networks – often required to manage grid anomalies and peaks. Active networks will be planned and designed increasingly based on energy demand and not solely on static hosting capacity parameters. Also the role of the network will change towards a balancing source for independent energy communities which import and export electricity based on electricity supply and demand variations. Active network can forecast these variations and hold DERs under designated limits to keep the network in check.

4.1. Vision for Active Distribution Network Planning

Due to the large number of renewable energy sources (RES), the distribution systems face new challenges. In the past, the main challenge of distribution networks was insuring a secure supply to customers (i.e. the industry, households etc.). In the future, the integration of RES will be one of the new challenges of distribution networks. Hence, the RES should be considered in the future planning process of distribution networks. On the other hand, customers’ energy consumption / behaviour are changing alongside technology development. For instance electric heating which is widely used in North Europe and air conditioning which is often used in South Europe are becoming more and more efficient. This can result in lower electric power consumption. Further, the number of electric vehicles is increasing steadily which can be leading to a significant increase in power consumption. Such future scenarios – and the development of RES – have to be considered in the future network planning of distribution network. However, the problem of these technologies is their uncertain development. The growth of the RES has been motivated by the political aims of the national governments and the European Union and it is an uncoordinated process. However, politically motivated targets of RES will make these technologies cheaper in the long run and it is expected that RES will become competitive compared to conventional power production technologies in the future. [8] Therefore, the future electric power generation as well as the electric demand cannot be predicted very well. The information about location and installed capacity of the future RES as well as demand is not known, especially for distribution networks.

The distribution network planning is a task of the DSO. The DSO is responsible for a secure and reliable network operation. The DSO should also ensure an inexpensive network operation if possible. This trade-off between the secure, reliable network operation and the costs is the main challenge of network planning. The DSO could increase the security level and the network performance by building new lines. However, these measures are always associated with higher network operation costs and investments. The minimum security and reliability levels are defined by the technical constraints for the network operation. These constraints may differ in different countries. The main technical constraints define the limits of the maximum current, the upper and lower limits of voltage as well as the reliability of the distribution network. Due to the development in the ICT, the DSO has new enabling technologies to monitor and control the future network, i.e. create an active network. The active network operation allows the DSO to e.g. manage congestion and control voltage. Because of the large number of network components and customers which resulted in high costs, this form of active network operation was not considered in the
IDE4L Deliverable 2.1

In the past, the high costs challenges are no longer relevant due to the decreasing costs of these components, and therefore considering the implementation of these new technologies could bring further benefits in network planning.

In the past, it could be shown that an efficient way for network planning is to use computer-based methods. The computer based method is an algorithm, which plans network structures under consideration of technical and economical requirements. Nevertheless, many DSOs do not use these methods. The advantages of the computer-based methods compared to human-planned networks are the faster planning process and it has the possibility to consider a lot of different scenarios trying and simulating each of them and then choosing the most efficient one. Taking in consideration the new challenges in network planning and the associated higher number of degrees of freedom, a computer-based method should be preferred.

The network planning could be divided into three time domains:

- Short-term Planning
- Medium-term Planning
- Long-term Planning

These three time domains of network planning face different challenges.

The challenge of the short-term planning is to organise the network operation in the near future. The planning of future short term network operation is also called Operational Planning. Based on information about faults and weather forecasts and on the information provided by aggregators, the DSO plans the operation of active network technologies as well as the measures of maintenance and fault clearing. Therefore, the time domain of the operational planning is the next few hours up to the next few days.

The time domain of the medium-term planning is the next few years up to the next twenty years. The development of the electric power demand and the development of the electric power generation are taken into account in these planning periods. The DSO decides replacement and extension measures to guarantee a secure and reliable future network operation. Therefore the medium-term planning is called Expansion Planning.

In the long-term network planning, strategic development is decided by the DSO to take place in the distant future. The long-term planning is often called a "green-field"-approach. The time horizon of the distant future allows this approach. The present network components will be rebuilt within this time domain, thus allowing the planning of new geographical and technical network structures. Hence, the present network is not considered in the long-term planning. The long lifetime of the network components determines the time domain to extend to 20 or more years in the future. The results of these approaches yield planning projects for a long-term efficient development of the network. Therefore these planning projects should be considered in the expansion planning. Thus, these approaches are also called Target Network Planning.
4.2. Target network planning

The Target Network Planning is used to determine long-term strategies. This approach is usually a “Green-Field”-approach where the present network is not considered in the planning process. Due to the long lifetime of the network components, the time domain of the target network planning will be 20 years or more. This allows the network planner to completely rebuilding the network and allows designing optimal network structures. Therefore, the result of these approaches depends on the electric power demand and generation in the network, as well as the objective function of the planning process. On the other hand, the objective function is defined by the long-term strategy of the network planner. Thus, the target network represents an optimal network structure in accordance with the objective function.

The definition of the objective function is an important factor of the target network planning. This function represents the long-term strategy. Usually, the objective function is the minimization of network lifetime costs. Another possibility is to include fictive outage costs of customers to objective function in order to consider societal impacts of network reliability. This would have the effect of a greater quantity of the network structure which should be enabled by the network regulation.

Technical requirements are also considered in these approaches as boundary conditions of the optimization problem. Thus, it is guaranteed that the target network is a technically feasible network which fulfils all operational requirements. The main technical requirements are voltage stability, thermal current, short circuit current as well as the requirements of reliability and security.
The network planner designs the network structure in the planning process. During this process the dimension and the location of the primary network components like the location and sizing of substations and the line routes and dimensioning will be decided. The planner has to decide the topology of the network (meshed, ring, open ring, radial with backup connections, radial) and the automation degree of the network.

Due to the long planning horizon, the target network planning has a lot of uncertainties which influence the planning process. The main uncertainties of the target network planning are the development of the future demand as well as the installed capacity and the allocation of DER. The development of the future demand and generation is influenced by different effects which also depend on the location of the network. In urban areas the demand of electric power will increase if the population uses more electric vehicles. On the other hand, a lot of electric equipment like air conditioning and electric heater becomes more efficient in the future. The dominating types of DER in the urban areas are combined heat and power generation and PV-plants. However, due to a limited amount of space, the development of RES in urban areas and small-scaled plants, the demand is often bigger than the feed-in of RES in urban areas. In rural areas the development of the RES is more important, there is less electric power demand and the amount of space allows the installation of bigger RES power plants. Thus, the installed capacity of each RES plant is higher in rural than in urban areas and in some areas the installed capacity is multiplied in comparison to the electric power demand.

For a computer-based target network planning, heuristic approaches are proven. A heuristic approach could not guarantee an optimal solution, but due to the dimension of the optimization problem, a closed optimization is not practical.

### 4.3. Expansion Planning

Expansion planning is a process which describes the path of the present network into the future (target) network. The challenges of the conversion into the target are related to the uncertainties in the planning process. The expansion planning process determines planning projects for the conversion of the network i.e. location, type, size and time of investments. These planning projects could be identified by analysing target networks to identify the efficient expansion steps for a certain target scenario.

The start-point of the expansion planning is the present network, considering the life time of the network components. In fact, when one component reaches the end of life, the component has to be replaced. And this may also represent an opportunity for restructuring the network topology. Due to the increasing amount of RES and variation of the electric power demand, the DSO could be forced to expand its network because of violation of the technical restrictions. The expansion planning helps the DSO to identify the best expansion project. Thus, the expansion planning method considers the future development of the electric power demand and generation as well as planning projects, which are identified by the target network planning. These planning projects could be:

- Building of new lines or cables
- Building of new substations
- Reducing lowly utilized network components in case of decreasing load demand
Instead of these conventional measures which were mainly used in the past, the DSO has now the possibility to use active network management for a valid network operation. The non-conventional measures are for example:

- Congestion management by using Demand-Side-Management, Storages or by peak shaving of RES generation (production curtailment)
- Voltage control via RES generation, compensation, substation transformer and active voltage controller
- Reliability enhancement by using FLISR and advanced protection

One of the tasks of the expansion planning is to determine the best of the methods above to ensure safe and secure operation of the network. This is done by considering the cost/benefit ratios to meet the requirements of network expansion and lower the fault probabilities of different methods (for example, replacement of MV/LV-transformer vs. active voltage control).

The result of the expansion planning is the expansion plan which consists of many planning projects for different time of realisation. Depending on the optimization problem, the expansion planning could be realizing planning projects for substitution of a component before reaching end of life even without violation of the technical constraints, if the overall result is better.

4.4. Operational Planning

While network planning aims at the optimal grid for a given level demand and distributed generation in the long term, and the expansion planning sets the optimal way to go from the existing situation to the optimal future grid, operational planning intends to propose the best operational tools for the management of distributed resources and the flexibility of the future smart grid.

Operation of future smart grids with distributed generation would have to tackle different challenges, both at technical and regulatory levels. The change from a passive to active network has strong implications on customers, the retailing business and technical operation. In the future grids, due to unbundling of electricity markets, aggregators and DSO will have to coordinate their activities, enabling the participation of the different resources (flexible demand, generation and storage devices) in the electricity markets while maintaining the security and reliability levels of the distribution networks. Participation in electricity markets will be possible through aggregators and the DSO will be in charge of grid operation.

Aggregators will coordinate the different resources in an optimal way to trade the energy in the wholesale electricity markets with a high degree of uncertainty, seeking their maximum profit within the regulatory framework. Their role goes beyond the present retailer and the already envisaged Virtual Power Plant, since they would merge or coordinate consumption and generation assets. The management of this participation requires producing a schedule for the day-ahead markets. The supply of the consumers should comply with contractual requirements while taking profit of the flexibility agreed between aggregator and consumer and the uncertainty associated to consumer needs. On the other hand, the generation resources such as renewables (solar and wind) depend on meteorology and future market prices are also uncertain. The participation of the aggregators should be based on forecasts of demand, natural resources (solar resources, wind speed), and they must manage the available storage devices, dispatchable generation under their control and demand flexibility to minimize deviation between schedules and actual generation or consumption. This management will go on in the adjustment markets and real time to optimize the
utilization of existing facilities and to further reduce the difference between the scheduled and actual programs.

DSO will have to check if the schedules of the aggregators present in their grids will be feasible and secure, and the regulatory framework should allow them to change this schedule if necessary. This means to reduce the consumption according to the flexibility of the consumer, or decrease the generation (even compelling production curtailment) if this could cause line overloads or voltage problems, when the use of the grid devices (tap changers, capacitors or FACTS) is not enough. Although strictly not needed, since DSO will know the schedules of the aggregators present in their grids, it is also advisable that DSO will make their own estimate of the generation and consumption for the customers in their grids. The problem becomes more complicated because a distribution feeder may have customers from different aggregators, and the aggregators might have customers in different distribution feeders, so a tight coordination to ensure the safe and economically optimal management of all the customers becomes necessary.

There are many different ways in which this scheme could be implemented, with different degrees of complexity. This implementation must be gradual, and the complexity degree should be a compromise between the benefits of this organization and the difficulty of implementation and the computing and communication limits. The benefits of the optimization methods used to this end should have to be checked and evaluated to propose a roadmap to the final operational strategy.

The uncertainty that both aggregator and DSO will have to handle is of first importance. As mentioned before, aggregator and DSO depend on forecasts for the scheduling and grid constraints solution of the next day or following hours. These predictions have a high level of uncertainty since the “portfolio effect” of joint predictions of generation and load is much smaller here than in the transmission network because of the lower number of customers. This is why probabilistic operation methods (probabilistic load flow, optimal power flow, unit commitment, etc.) for deciding preventive and corrective actions become more important.

Operation being a short term activity, operational planning must be made for an existing network (present, mid-term and long-term grids, as designed in the target network planning and the expansion planning) with a given number of consumers and DER, and assuming a share of renewable and storage devices. Since the regulatory framework is not fully developed in many countries, this must also be assumed, and the effect of different degrees of centralization for the management needs to be pondered.

Since in this task we are dealing with future networks and situations, the operational conditions should have to be simulated somehow in the operational planning tasks: for the studied networks, customers, DER share and grid, also the predictions available to both aggregator and DSO must be synthesized with the expected accuracy.

The benefits of the different scheduling and grid constraint solution method must be quantified, as well as the communication and computing needs for each solution in order to get a roadmap of their implementation. This assessment of the benefits of the different management and scheduling techniques will be useful for DSO, aggregators and eventually customers.

The approach of using the flexibility of consumers, renewable distributed resources and uncertainty is needed to grasp the future possibilities and challenges of the future distribution grid, and this will be a step
forward, following previous work of other European projects, whose results are a solid ground for the intended development.

4.5 Planning Principles for Active Network

Worst Case Planning Rule
Distribution network design is traditionally based on the so-called worst case planning principle. For example in radial distribution networks, where no DG is present, the limiting worst case parameter is the voltage drop at the end of the feeder, which occurs during maximum loading of the feeder, and the thermal limits of the conductor used. [24] When DGs are connected to this radial feeder, the worst case may occur in a combination of minimum DG production together with maximum load. In lightly loaded networks, the presence of DG will however also introduce another limiting worst case factor. This is the combination of maximum DG production together with minimum load, which might cause the maximum allowable voltage to be exceeded at the DG interconnection point of the feeder line. [25]

The worst case design principle has been considered satisfactory in networks where only few relatively large DG units are interconnected. The validity of this principle is, however, no longer that obvious when a large number of DG units based on various kinds of energy sources are connected to the distribution network. The worst case planning principle assumes that all DG units behave in the same way. However it is quite unlikely that e.g. all the units would be operating at their maximum output at the same time. The worst case principle utilizes fairly conservative assumptions of DG output for network design with a high DG penetration level. [26]

Stochastic Analysis
Stochastic network analysis offers a more fair way e.g. for assessing the network hosting capacity for DG. With this method, the load curves used in the load flow calculation of Network Information System (NIS) are extended with DG production curves. Due to a lack of actual measurements in network planning phase, the production curves are based on long-term statistics of wind speed, solar radiation and temperature. By performing a load flow calculation with Monte Carlo simulations using the data obtained from the combined load and production curves, the outcomes of simulations are the probability distribution of values of variable of interest for planning, calculated with the time resolution of one hour. The correlation of power production and load demand is a very critical issue in network planning. For example, the operation of CHP unit and load demand correlates very well, hence the worst case planning principle is simply too conservative.

The load flow simulations are used to analyse what kind of network conditions might appear. Load flow calculations can be used to find out the limiting network constraints and their duration. They can also be utilized for DG interconnection studies, and furthermore, for the comparison between network reinforcement and active network management strategies. The hourly load flow information can also be helpful in estimating the DG connection charges. Another advantage of hourly load flow is the possibility to model time dependencies of the components like controllable loads and storages in the planning process.

Flexibility of a Customer
Normally all network customers have firm network capacity available. The non-firm network capacity is however much higher than firm capacity, which enables to increase the amount of generation to be connected and operated under normal network conditions. However the generators will reach their
constraints in extreme operating conditions which are not considered in the rating of firm capacity. The extreme conditions may be e.g. exceptional switching states of network or variety of intermittent DG units producing maximum power during very low demand. The probability of extreme conditions should be low enough in order to have an economically attractive solution. The benefit of e.g. occasional production curtailment comes from the fact that the non-firm network capacity, i.e. the amount of DG to be connected and operated under normal network conditions, is most of the time much higher than the firm capacity. Of course the drawback of production curtailment is the loss of energy production in case of extreme loading conditions. If DG units are used as a means to increase the firm network capacity, active resources should be controlled almost in real-time to reduce power transfer at the overloaded part of the network.

The purpose of the non-firm interconnection is to allow a higher network hosting capacity for DG. The firm interconnection is always available and calculation of interconnection capability is based on the worst case planning principle. The increased hosting capability of non-firm interconnection, in turn, is achieved by utilizing the network more efficiently. This is done by utilizing the DG units e.g. voltage control or production curtailment when the network constraints occur occasionally.

If the reinforcements of the MV network are based on the worst case, this might introduce a severe economic barrier for a DG interconnection in weak distribution networks, due to excessively conservative principles. The non-firm planning principle may allow higher penetration of DG in a distribution network with less network investments and connection charges than with the firm worst case planning principle. The non-firm interconnection may benefit both the network and the production companies by allowing a higher penetration of DG with less network investments.
5. NETWORK OPERATION WITH ACTIVE NETWORK FUNCTIONALITIES

A new type of network with more active devices clustered through the distribution grid is going to be achieved in the future to meet the requirements of increased connectivity, flexibility, increased demand needs, controllability, automation, secure and high quality level. Such network is named “Active Network”, a relevant evolution from the actual passive network and should be a technically and economically feasible solution to cope with the above mentioned challenges.

The integration of advanced ICT technologies in the electricity grids with large share of DERs and RES provide several new capabilities for the operation of the network. New operating modes must be realized for improving network reliability through different concepts such as demand management, smart DER/RES integration into the distribution network operation or charging management of plug-in electric vehicles. In addition to ICT, several technologies provide capabilities for the active network such as system information, high performance computing, and controllability of devices, sensors and instrumentation. However, the lack of common functions and a common framework for information and communication systems in the whole future active distribution network stands in the way of achieving the required goal.

For the operation of an active network, in addition to the operators themselves, also end-users and aggregators need to be considered in order to realize innovative grid functions. Such operation will require coordination from several actors such as DSO and TSO through the use of local market, which acts as a facilitator between infrastructure operators and commercial aggregators of energy resources.

The final goal for such network resides in offering new opportunities in the improvement of the efficiency of power distribution networks. The DERs will be scattered within the existing distribution networks, interconnected in customer areas and operated in their own schedules increasing the complexity of the automatic or smart control functions of the management system. By applying active network operation, one envisions taking advantage of the positive effects of such DER units in the operation. As a matter of fact, monitoring and active operation of DER in distribution networks are essential for its complete integration. In recent years, many studies relating to the smart management of distribution systems have been presented with the advent of the active network.

5.1. Vision for Active Distribution Network Operation

Vision about how Networks are Operated

The active network is foreseen as a relevant evolution of the current passive distribution networks and perhaps a technically and economically feasible solution to facilitate the increased demand and the increasing number of DER interconnections in a deregulated energy market. In order to provide such a step in network topology configuration, it is necessary to evolve the passive network into a more active network. Therefore, it is expected that the future network operation will be based on management systems that incorporate data gathered from a bunch of sensors and instrumentation devices spread through the network.

With the operation of the network, mainly all the automation and active sensor devices included to make it more operational, monitored and functional, will need to include the proper operation of DER units integrated into a network operation system with advanced capabilities. Several technical and economic aspects of the network are expected to improve in comparison to a network without any controllability at
all such as loss reduction during normal operations or the possibility to support local loads during abnormal conditions. So, many of the efforts towards adapting the network for future use must be driven by the focus on integrating DER seamlessly into the system in order to prevent operational problems and to supply high quality electricity.

The existing distribution networks are primarily radial, built for centralized generation with few sensors, and therefore are mainly dependent on manual restoration. The future network will improve its operation, having more observability and controllability to make the network more configurable depending on the situation. This will require accommodating increased customer demands and DER units to ensure a high PQ and energy efficiency. The network operator will have access to more accurate network status with fast and accurate estimations of network security, and other collected data from the network components. Also the active network will provide fewer interruptions by adopting advanced protection and self-healing schemes.

For the active distribution network it is necessary to enable a two-way exchange of real-time information between distribution network management and DER units. The DER units in the active network are expected to take on several roles, some of which are integrated in the centralized/decentralized management system that operates the network. Network can be operated in groups of sub-networks some of them working as energy islands, even in islanding operation mode. Such energy islands should consider a local operation in a similar manner as it is included in the power distribution grid, being totally considered as active micro-grid network. Such operation is also under consideration within the IDE4L project. The following picture describes some of the elements that could be included in the operation of a micro-grid.

**Figure 5.1. Elements included in the operation of an active micro-grid.**

**Actors Involved in the Active Network**

For what concerns the market trends, for the active network, with the advent of the market liberalization and with the possibility to gather short time interval generation-demand information and forecasting data, the price of electricity may become a significant risk to be addressed. In this regard it will be required to allow the participation of DER connected to distribution network into day-ahead markets, adjustment markets, and medium and long-term market mechanisms [27].
From the more technical perspective, in the aggregation of distributed energy resources through the network, an important impact on the dynamic behaviour of the network comes from synchronous generators and other generation units that are interfaced to the power system by means of active power converter units, such as photovoltaic, storage systems, small wind turbines etc.

Such technologies are different from the ones coming from the transmission network. Considerations on the effects of such new technologies on the operation of passive network have to be taken into account carefully. In the past, participation of DER in the market was not considered. In the future, DG units connected both to MV and LV distribution networks can be used as a resource in order to for example overcome some emergency contingencies. They also have to be carefully considered in the management of intentional islanded networks, therefore reliable inverter control strategies for islanded operation are essential. When islanded operation is considered, reliable inverter control strategies for islanded operation plays an essential role. The parallel operation of DER in micro-grid islands is a nontrivial issue, most of all when DER should guarantee a seamless transition from grid connected to islanding mode. As an example in [28] a new procedure for the design of the droop control scheme, commonly used to achieve the power balance criteria, for voltage source converters (VSC) in islanded micro-grids is presented.

Figure 5.3. Left – Micro-grid with DER interconnected by means of Voltage Source Converters (VSC). Right - Electrical representation of a wind turbine connected to the micro-grid.
Different issues are at stake with the advent of DER to the distribution network, such as steady-state and short-circuit current constraints, PQ, voltage profile, reactive power, voltage control, contribution to ancillary services, stability and capability of DER to withstand disturbance, protection aspects, islanding and islanded operation and system safety. Depending on the country, these issues are dealt with in different ways; from the energy policy and regulatory framework to the more technical issues, since distribution networks may be different from a technical prospective such as:

- voltage levels,
- topology and configuration,
- characteristics,
- operation and protection philosophy,
- security regulations and
- types of loads.

In case of disaggregation of the active network in different sub-networks, new agents will appear in the management of such sub-networks. As it is proposed in this project, one possibility consists in operating sub-networks as local micro-grids so by this definition it is even possible to operate some of them in islanding mode, so real energetic islands may appear into the network.

For such networks, local algorithms are applied to their operation named energy management systems EMS, which can be based on several technologies [29], a very important feature for such local grids is the plug-and-play functionality, so they can easily be operated within the network. Some examples of operation for these micro-grids have already been experienced such as the one presented in the following picture [30], with CCU being the Central Control Unit.

![Figure 5.4. Representation of the Central Control Unit for the micro-grid management.](image-url)
Other important actors involved in the active distribution system will be the regulatory agents which should ensure the creation of a proper regulatory framework dealing with the technical challenges to be faced for the large scale integration of distributed energy resources in the grid.

5.2 Future Trends in the Regulatory Framework: the Aggregator Concept

The European Energy Policy aims at promoting the integration of large amounts of RES in the electricity sector. A substantial share of these RES will be connected to distribution networks at medium and low voltage, together with storage systems and other controllable DER.

The growing share of variable generation in Europe is increasing the need for flexibility in the electricity system. In this context, aggregation offers the opportunity to exploit the flexibility potential of smaller customers connected to distribution networks.

Therefore, together with other technical regulations at lower levels (such as standardization or LV facilities grid codes harmonization), the regulation of the aggregator figure can be understood as one of the main topics to be addressed by energy regulators at international level.

European Regulatory Framework and Aggregator Concept Description

As described by Eurelectric in [31], aggregation can be understood as a commercial function of pooling decentralised generation and/or consumption to provide energy and services to actors within the system. Aggregators can be retailers or third parties, acting as an intermediary between customers who provide flexibility (both demand and generation) and procurers of this flexibility.

The aggregation concept has been mentioned in recent European energy law developments:

- **Energy Efficiency Directive 2012/27/EU:**
  - Promotes demand response
  - Imposes that technical specifications for demand response provision must include the participation of aggregation

- **Framework Guidelines on Electricity Balancing (ACER 2012):**
  - Aims to enable provision of balancing reserves from system users connected to distribution networks, including the aggregation of small both demand and/or generation units
  - The need for adjusting today’s balancing market rules that were designed with focus on ‘traditional’ flexibility of large scale generation is highlighted

Eurelectric’s vision on the aggregator’s flexibility uses and its related market levels is described below (Figure 5.5).
1. Portfolio optimization.

Used by market players to meet their energy obligations in the market at minimum costs by arbitrating between generation and demand response on all different time horizons.

2. Balancing markets.

Procurement of balancing services (capacity) and activation of balancing energy by the TSO to balance demand and supply through the balancing energy market.

3. Constraints management at TSO and DSO level.

Network constraints resolution in all timescales, maintaining reliability and quality of service at TSO and DSO levels. Typical constraints refer to thermal ratings, voltage violations, fault levels and transient stability issues.

Technical Framework

Activation of storage devices and other flexibility resources located in distribution network by the TSO for the purpose of system balancing or transmission constraints management may lead to constraints in distribution networks. Similarly, DSO’s use of its grid connected flexibility for local constraint management will also affect the TSO grid and balancing of the system.

DSOs should have visibility of the planned flexibility aggregation or individual actions connected to their networks. This would ensure that market schedules are not in conflict with network operation constrains. Therefore, further collaboration between TSOs and DSOs will be one of the key aspects to be considered when developing the grid codes related to flexibility aggregation.

Previous literature regarding the Virtual Power Plant concept (VPP) has been used for proposing a technical framework for increasing coordination between TSOs and DSOs [32]. Virtual Power Plants can be used to facilitate DER trading in the wholesale energy markets (e.g. forward markets and the power exchange), and can provide services to support transmission and distribution network management (e.g. various types of reserve, frequency and voltage regulation among others).

In the development of the VPP concept, these activities of ‘market participation’ and ‘system management and support’ are described, respectively, as ‘commercial’ and ‘technical’ activities, which derive into the following two roles: commercial VPP (CVPP) and technical VPP (TVPP).

- **Commercial Virtual Power Plants** would be in charge of representing a portfolio of DER in energy markets and balancing and congestion management services (TSO&DSO level). CVPP will receive
IDE4L is a project co-funded by the European Commission

from distribution network prosumers their load curve forecast as well as their flexibility band operating parameters and their flexibility costs (i.e. the cost of modifying their load curve for increasing or decreasing their consumption). Using this information, the CVPP will have to validate their program for the daily market and its participation in the ancillary services markets with each regional DSO (playing the role of TVPP). After this validation, the CVPP will be in charge of sending its bids to the daily market and communicating to the individual prosumers their viable daily schedule (Figure 5.6).

**Technical Virtual Power Plants** provides visibility of DER to the TSO, and allows DER to contribute to system balancing and congestion management both at TSO and DSO level. Carrying out TVPP activity requires local network knowledge and network control capabilities; naturally, the DSO may be best placed to carry out this role. The TVPP will receive from the CVPP the individual load profile of the prosumers connected to its grid, including also their flexibility capabilities and its associated cost. Using this information together with the network status information (load forecast and technical constraints), the TVPP will be responsible for bidding the aggregated flexibility from its distribution network to the TSO. Also TVPP will be allowed to use prosumers capabilities to solve potential technical restrictions within its own distribution networks (Figure 5.7).
IDE4L is a project co-funded by the European Commission

IDE4L Deliverable 2.1

It should be noticed that the VPP concept, introduced at the beginning of the last decade together with the liberalization of most of the electricity markets in developed countries, was mainly referring to geographically dispersed bulk generation and the combination of different technologies for portfolio optimization. Currently, the joint operation of generation devices is mostly focused on the aggregation of smaller devices, together with energy storage systems and demand response. This has led the energy sector participants to change the name of this technical concept to “aggregator” instead of “VPP”. In this document the VPP name has been used following the nomenclature proposed by the authors of [32], but it should be noticed that the “aggregator” name will be the most commonly used now on within IDE4L project.

Using the previous definitions on the technical/commercial VPP (technical/commercial aggregator from now on), the whole picture of the aggregator concept is described in Figure 5.8.
In order to allow aggregators to participate in spot and intra-day markets, system balancing and constraints management at TSO and DSO level, Eurelectric proposes the following issues to be addressed [31]:

- Market rules should be brought in line with the characteristics of aggregated prosumers’ response. The European network code on electricity balancing should provide a level playing field for all flexibility providers.

- Smart meters with a reading interval corresponding to the settlement time period are a technical prerequisite for the participation of small prosumers in balancing markets.

- Constraint management and balancing operational management design should take into account a further coordination between TSOs and DSOs, thus avoiding possible technical restrictions due to the lack of information exchange between both actors.

These recommendations together with other relevant technical topics will be addressed within IDE4L project. In this regard, the following research activities will be carried out within the different working packages:

- WP3: Aggregator definition will be used for the creation of a set of use cases aiming at clarifying its ICT requirements. The aggregator concept will also be further developed within the ICT architecture description to be done within WP3.

- WP5: Demand response model will use the aggregator definition as an input in order to take it into account for defining the flexibility costs of the consumers. Periodical meetings between WP5 and WP6 are planned in order to ensure a strong collaboration between both WPs.
• WP6: The aggregator description included in this section will be used as a reference for building up the following topics:
  o To define the aggregator responsibilities and its boundary conditions. Interaction with TSOs and DSOs.
  o To evaluate aggregators’ business models, contemplating the maximum exploitation of available resources and infrastructure and the feasibility of the participation into the ancillary services provision, either related to active and reactive power.
  o To define optimal management algorithms from the aggregator point of view.
  o To compare distribution network performance with and without the proposed control and monitoring framework (from a technical and economic prospective).
  o To perform specific analyses on the effects of high penetration of certain DER resources on LV networks (e.g. effects of PV in the grid).
• WP7: Aggregator use cases will be considered for being integrated into WP7 demonstration tests.

![Figure 5.9. IDE4L aggregator concept role within the different WPs.](image)

### 5.3. Functionalities of Active Distribution Networks: State of the Art

In order to demonstrate the capabilities of the active network operation, different use cases have been defined taking into account the previous experience elaborated in other projects, as well as the aims of the IDE4L project. Such feedback is important in order to define realistic use cases and adopt the best solution either in real scenarios, part of distribution grids, as well as in a laboratory scenario under controlled and flexible circumstances. This concept will feature a distribution network automation fit for fast changing conditions and the presence of a large number of DERs. The automation system should be able to monitor and control secondary substations, DERs and (monitor) end customers. It should also merge information from/to all actors interfaced to the distribution system, including TSO, energy retailers, aggregators, local
communities. The monitoring will be static and dynamic and will leverage on traditional measurements and models as well as static and dynamic synchrophasor measurements in the distribution grid, and data from PMUs provided by the TSO.

The key architectural blocks should be based upon robust, comprehensive and open standards, to ensure longevity, scalability and interoperability for today's and tomorrow's networks. This automation concept dynamically couples end-use energy services with real time network operations, enabling network-friendly energy services as the ancillary services for TSO and energy market participation of DERs through Aggregators.

Some recent EU projects are briefly described below. They are project FENIX (2005-2009), project INTEGRAL (2011-2015), project ADDRESS (2008-2013) the SEESGEN-ICT project (2009-2011) and ReserviceS project (2012 - 2014).

**FENIX Project**

The objective of FENIX is to boost DER (Distributed Energy Resources) by maximizing their contribution to the electric power system through aggregation into Large Scale Virtual Power Plants (LSVPP) and decentralized management. Its main results include the development of a VPP concept that fits the European power system, an information and communication architecture that is scalable and hierarchically flexible, new hardware components and software applications by leading European manufacturers that realise the VPP concept, a commercial and regulatory framework that allows the beneficial integration of the VPP concept in the future European power system. A cost-benefit-analyses that quantify the economic benefits of the VPP concept was performed, and two field demonstrations in real networks in Spain and the UK were performed. These demonstrations were complemented by laboratory demonstrations and simulations that prove the feasibility of the developed VPP concept.

In the demonstration sites, different kinds of DER (PV, wind, mini hydro, biomass) and consumers were included.

![Figure 5.10. Representation of VPP implemented concept in the European project FENIX (source: FENIX project).](image-url)
The VPP has two sides: commercial and technical. The commercial VPP is defined with a role that can be undertaken by a number of market actors including incumbent Energy Suppliers, third party independents or new market entrants, which represent the DER of a determined location.

The technical VPP is also defined providing:

- Visibility of DER to the system operator
- DER contribution to system management activities
- Optimal use of DER capacity to provide technical feasibility system services incorporating local network constraints

**INTEGRAL Project**

In this European project, the main challenge consists in the lack of common functions and framework for information and communication systems for the whole future active distribution grid.

In this project, the aim was to develop an industry-quality reference ICT-platform for Distributed Control in Electricity Grids at aggregated levels in the electricity grid, based on commonly available ICT components, standards, and platforms. The technology was demonstrated in 3 different field tests under normal, critical and emergency conditions. From the lessons learned, practical industrial guidelines for integrated distributed control were provided.

The demonstration includes a solution for DGs aggregation level control and coordination based on commonly available ICT components, standards and platforms. The demonstration covers three major operation states: Normal, Critical and Emergency operations. In the following picture, taken from the documentation of Integral project, four power system business model context views and scenarios are represented.

![High-level specification of the functionalities for novel electricity distribution grid control. Source: Integral project.](image-url)
In the Figure 5.12, the SCADA interface was developed to validate Agent-SCADA interactions. An important part of the project was the development of self-healing approaches. The objective of the self-healing approach is to evaluate power system behaviour in real-time, prepare the power system to eventually withstand a combination of contingencies, and accommodate fast recovery from emergency state to normal state. When a disturbance occurs in the network, the power system model together with existing operation conditions, the information and communication networks are used to determine the degree of disturbance. Finally, power system operators break up the system into smaller parts to diminish the effect of the disturbances.

Figure 5.12: Developed SCADA interface to emulate the DNO actor. Source: Integral project.

**ADDRESS Project**

The aim of this project was to be a reference for deploying active demand across the entire European electricity industry. Different evaluation deployments were defined identifying under which circumstances an ADDRESS deployment may be more or less desirable and potentially beneficial to the entire supply chain or only to sub-groups of industry actors based on three potential scenarios:

- High consumer density
- High demand for electricity driven chiefly by the needs for space cooling, which is inherently flexible.
- Plug-in electric vehicles making an appearance later in the scenario horizon.

The conclusions of the project, which also include a demonstration part, are addressed also to regulators, giving recommendations about the future role and functionalities of an aggregator, the implications of the new paradigm for System Operators, consumers and other agents, including manufacturers and providers of communication services.
SEESGEN-ICT Project
Devoted to investigate how the ICT can support DER proliferation in the smart grids and what will be the new business mode creation, DER aggregation is one of the most important business activities which can speed up the proliferation of DER and thus lead to a more secure and affordable power system and lower emissions.

The general idea consists of collecting individual DER units and providing their power generation or load adjustment services to power system participants. Also the possible sources of value in aggregator business are assessed, as well as how this business can benefit the society. In commercial operation, part of the generated value is transferred to the owners of the DER units, thus creating an incentive for owning different types of DER. The project also selects nine business models which are either real businesses or developed in research projects and analyses these business models from two perspectives: the current national situation of several European countries and the ICT which is needed in these business models.
REserviceS Project

REserviceS (Economic grid support from variable renewables) is the first study to investigate wind and solar based grid support services at EU level. It will provide technical and economic guidelines and recommendations for the design of a European market for ancillary services, as well as for future network codes within the Third Liberalisation Package.

This project investigates the opportunities and costs of providing ancillary services to transmission and distribution system operators from wind and PV systems by:

- analysing the needs for ancillary services (e.g. voltage and frequency support) in the European power system, with a growing share of variable renewables;
- identifying which ancillary services wind and PV can provide and which are of interest to system operators, today and in the future;
- analysing factors influencing the provision of ancillary services by wind and PV;

creating a European harmonised method to calculate the costs for ancillary services provided by wind and PV.
Table 5.15. Relevant ancillary services from renewable generators. The first row in the table refers to existing ancillary services and the second row to new services.
6. REFERENCES


[38] Data from Bundesministerium für Wirtschaft und Technologie)


[41] BMU report


[47] OPEF, “Primary energy consumption statistics”
http://www.opef.it/index.php?option=com_content&view=article&id=70&Itemid=87&lang=it

[48] TERNA, "Statistical analysis of the electricity sector"
http://www.terna.it/default/Home/SISTEMA_ELETTRICO/statistiche/dati_statistici.aspx

http://www.idae.es/index.php/id.663/relmenu.332/mod.pags/mem.detalle

[50] AEEG, “Disposizioni speciali per l’erogazione dei servizi di trasmissione, distribuzione e misura e del servizio di dispacciamento ai fini della sperimentazione dei sistemi in bassa tensione di ricarica pubblica dei veicoli elettrici - Special disposals for the supply of transmission, distribution and measurement services and dispatching service to test EV public recharge in LV network ”


[52] EN 50160:2011 "Voltage characteristics of electricity supplied by public distribution networks"

[53] CEI-016, “Reference technical rules for the connection of active and passive consumers to the HV and MV electrical networks of distribution Company”

[54] CEI-021, “Reference technical rules for the connection of active and passive users to the LV electrical Utilities"
Annexes

Annex 1 - Acronyms

- ADMS: Advanced Distribution Management System
- AEEGSI: Authority for Electrical Energy Gas and Water Service
- AEEG: Authority for Electrical Energy and Gas
- AMI: Advanced Metering Infrastructure
- AMR: Automatic Meter Reading
- ANM: Active Network Management
- CCU: Central Control Unit
- CEI: Electro technical Committee
- CIS: Customer Information System
- CHP: Combined Heat and Power
- CO2: Carbon Dioxide
- CVPP: Commercial Virtual Power Plant
- DER: Distributed Energy Resources
- DESS: Distributed Energy Storage Systems
- DG: Distributed Generation
- DMS: Distribution Management System
- DNO: Distributed Network Operator (passive)
- DR: Demand Response
- DSO: Distribution System Operator (active)
- EEGI: European Electric Grids Initiative
- EV: Electric Vehicle
- FLISR: Fault Location, Isolation and Supply Restoration
- FRT: Fault Ride Through
- HEMS: Home Energy Management System
- HV: High Voltage
- ICT: Information and Communication Technology
- IED: Intelligent Electronic Device
- LOM: Loss-Of-Mains
- LV: Low Voltage
- LVDC: Low Voltage Direct Current
- MDMS: Meter Data Management System
- MV: Medium Voltage
- NIS: Network Information System
- OLTC: On-Load Tap Changer
- PLC: Power Line Communication
- PMU: Phase Measurement Unit
- PQ: Power Quality
- PV: Photovoltaic
Annex 2 - Trends in the Energy Sector

Trends in Denmark
Since 1985, Denmark have been focusing on decreasing the dependency on central power plants and shifting power generation from a centralized to decentralized way by connecting small and decentralized power generation units into the power system.

Figure A2.1 below illustrates the history of the power production by production form since 1990 in Denmark. Centralized power production take place in the centralized power generation units and the combined heat and power units where power is the primary product. "Secondary producers" in the figure represents producers that energy is not their primary product.
The trend of integrating distributed energy resources into the Danish power system is presented in Figure A2.2. The use of distributed energy resources has been significantly increased in Denmark in the period between 1985 and 2009. A big number of decentralized power plants, ground wind turbines and sea wind turbines have been integrated into the Danish power system since 1985 making Denmark one of the lead countries in integrating decentralized generation into the power system.

Subsequently, the number of wind turbines and their generation capacity has been increasing remarkably as seen in Figure A2.3. In 2012 the wind power production has reached up to 29.8% of the national power production with 1.8% increase from the year before. The wind power capacity reached up to 4163 MW in 2012 with 211 MW increase from the year before.

However, it should be noticed that the increase in the total wind power capacity does not necessarily reflects an increase in the wind power production as the production of wind power is dependant of several factors such as wind availability.
Denmark have also been focusing more and more on reducing the dependency on the non-environmental-friendly power resources such as coal and oil. The energy produced by using coal was 34.4% (38 PJ) of the total energy production in 2012 which is less than the situation in 2011 by 24.4%. Using natural gas produced 13.6% (15.1 PJ) of the total energy production in 2012 with a 28.2% decrease compared to the situation in 2011. On the other hand, energy production based on renewable energy resources was 53.4 PJ in 2012 which increased by 4.6% compared to 2011. Wind power production gave in 2012 the biggest contribution with 37.0 PJ where biomass contributed with 14.6 PJ. See Figure A2.4.
Since 1990, there has been significant change in the way power produced in Denmark. The use of renewable energy resources and natural gas for energy production has been increased where the use of coal and oil has been decreased. This resulted in a remarkable decrease in CO2- emission since 1990 and putting Denmark as one of the leading countries towards meeting the EU-targets of CO2-emission reduction. The actual/measured CO2 emission resulted from energy consumption was 39.9 mio. ton. in 2012 which is 10.3% less than in 2011 and 25.2% less than in 1990. The corrected number of CO2 emission from energy consumption was 43.9 mio. ton. in 2012 which is 28.4% less than the CO2-emission in 1990 (the corrected number takes the yearly temperature difference and the foreign trade of electricity into account). See Figures A2.5 and A2.6 below:
Figure A2.5. CO2-Emission in Denmark. [33]

Figure A2.6. CO2-emission by energy source in Denmark. [33]
Trends in Finland

The trend of total energy consumption in Finland has been presented in Figure A2.7. Total energy consumption has increased steadily from 1970 to 2000. During the last years energy consumption of industry has decreased (see also Figure A2.8) and therefore the growth of total energy consumption has been quite steady. Secondly the figure illustrates the long-term trend to replace fossil fuels with renewable and nuclear energy. Peat is considered a fossil fuel today, but it is a domestic energy source and therefore it is seen important from the security point of view. Energy efficiency actions to reduce space heating consumption are not visible yet because of the huge volume of old buildings and growing volume of new buildings.

The renewable energy sources consist of mainly hydro power and biomass. Figure A2.9 represent the trend of renewable energy sources in Finland. Biomass is mainly used for CHP, district heating and small-scale combustion. Because the black liquor (a side product from paper and pulp industry) has a significant share
in renewable energy sources, the economy of paper and pulp industry is important also for Finland’s 20-20-20 targets. The amount of hydro power has not increased due to a lack of available resources. During the last ten years the heat pumps have also become a significant energy source.

Figure A2.9 Trend of renewable energy sources. [33]

Figure A2.10 represents the electricity consumption by major sectors. The growth of electricity consumption has been more rapid than the growth of total energy consumption. However the electricity consumption of industry is clearly declining indicating the challenges of heavy industry.

Figure A2.10. Trend of electricity consumption by sectors. [35]

Figure A2.11 represents the trend and mix of electricity production. Figure A2.12 represents the energy sources of electricity production during year 2013. The share of RES was 36 %, CO2 neutral was 69 % and domestic energy sources were 42 %. The share of wind power is expected to grow in coming years since
feed-in tariff is valid for 6 TWh of wind power. Taxation and market prices of fuels impact strongly which energy sources are used for CHP.

![Figure A2.11. Trend of electricity production by energy source. [35]](image)

![Figure A2.12. Energy source of electricity production in 2013. [35]](image)

Energy consumption of housing has been strongly regulated to reduce the heat demand of houses. For example the energy consumption limits for new residential houses has been decreased to 50-60 kWh/a per square meter while the limit was 130-140 kWh/a per square meter until 2003. The willingness of end consumers to save energy has recently increased the number of heat pumps in Finland (Figure A2.13). Some investment subsidies have been given to improve energy efficiency of old buildings, but otherwise heat pumps do not have subsidies. Most heat pumps are air-to-air heat pumps which have however
IDE4L Deliverable 2.1

relatively small power (category 0-6 kW). Typical air-to-air heat pump is an additional heat source beside another heat source like direct electric heating or oil. Most air-to-air heat pumps are installed in old buildings. Ground source heat pumps are very popular in new residential houses (see Figure A2.14). Typical power for a ground source heat pump is 7-12 kW and the heat pump typically produces 90-100 % of the heat demand of the building.

Figure A2.13. The number of sold heat pumps. [36]

Figure A2.14. Heating systems of residential houses [37].
Trends in Germany

The German transmission grid comprises the portions at extra-high voltage, 220-380 kV, and at high voltage, 110 kV, with about 350 substations. The distribution grids at medium voltage (MV), 1-50 kV, and low voltage (LV), 0.4 kV, include about 600,000 MV/LV substations. The extra-high voltage transmission system is part of the European backbone, and it connects the bulk generation. The new generation plants based on renewable sources, together with other minor generation sources (e.g., some industrial plants with generation capacity) are instead connected to the MV. Domestic loads and very small generation are connected to the low voltage distribution systems.

The installed generation capacity amounts to 152.9 GW, as of 2009 [38], with wind and solar plants representing a fraction of about 27%. Correspondingly, energy generation in Germany, in 2009, amounted at 593.2 TWh with a consumption of 578.9 TWh. Out of the generated energy, 45.2 TWh came from combined solar and wind sources, thus representing 7.6% of the total. In particular, with the 2011 decision to opt out of nuclear energy and to decommission the last nuclear power station by 2022 at the latest, Germany is setting the path towards an even faster growth of the renewable share.

![Regional Distribution of generation/load](image)

**Figure A2.15. Scenario of strong-wind combined with heavy load in Germany. [39]**

A sample behavior of the power flows within a national transmission grid, the German grid, is visualized in the figure above for the particular case of combined conditions of strong wind, hence large generation from wind farms in the north of the country, and heavy loading. In this scenario, two aspects can be emphasized: the first is the flow from generating areas to loading areas; the second is the consequent “long way” of the power flow, with proportionally large related losses. Furthermore, we point out that in this condition, the status of the grid and of the exchange with the neighboring states depends heavily on a volatile source (see following figure for quantitative data on volatility).
IDE4L is a project co-funded by the European Commission

Figure A2.16. Wind power generation in Germany in 2012. [40]

Figure A2.17. Trend in installed and generated power in Germany. [41]

The actual mixture of sources (conventional, wind and solar) is shown for year 2012 in the following picture.
Germany shows a total installed renewable capacity of 43 GW, predicted to rise to 90 GW by 2020, an average load of 62 GW, with peak around 75 GW, (2012). [43]

The short term trend is exemplified by the following picture, especially in relation to nuclear, gas and coal. This trend is linked to dropping energy prices and coal prices with respect to gas, and the decision to progressively abandon nuclear generation.

---

**Figure A2.18.** Wind power, solar and conventional generation >100 MW in Germany in 2012. [42]

**Figure A2.19.** Percent variation of electrical energy sources in the first 9 months of 2013 compared to the first 9 months of 2012. [44]

The trend of CHPs is illustrated in the following figure, in different scenarios. [45]
The past trend in the market of heat pumps which are installed for the most part in refurbished buildings, showed a fairly steady growth representing about 10% of the market for heating equipment. The prognosis for the future trend of electrical heat pumps shows also an increasing rate with the total installed power as in the following table. [46]

Table A2.1. Forecast of heat pump installation.

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed electric heat pumps [GW]</td>
<td>1.46</td>
<td>2.20</td>
<td>2.86</td>
<td>3.36</td>
<td>3.66</td>
</tr>
</tbody>
</table>

Trends in Italy
The Italian energy scenario [47] has been marked by the economic crisis and the relative industry market contraction that have generated a negative trend in the energy consumption indexes during the last 7 years. Figure A2.21 presents the Italian energy consumption (Mtoe - Million Tonnes of Oil Equivalent) in the 1965-2010 period. In particular in 2010 the total energy consumption has been equal to 172 Mtoe with an increment of 2.3% in respect to the 2009 which has been the worst year in terms of total consumption registering a reduction of 7% respect to 2008. However, also considering this increment registered in 2010, the total consumption is still far from the data obtained in 2005 (186 Mtoe).
Analyzing the distribution of the energy consumption among the final sectors (see Figure A2.22) the increment of the consumption in domestic and services sectors (39% in 2010) can be underlined. The industry sector, most involved in the effect generated by the economic crisis, has registered a marked decrement in the 2005-2010 period (-5%), covering, in 2010, 24% of the final consumption; the transport sector has had a slight reduction remaining more or less stable in the 2005-2010 period.

Regarding the energy resources, in the last ten years, the Italian area has seen a decrement of the oil usage in favour of gas resources and renewable distributed resources (see Figure A2.23).
IDEAL is a project co-funded by the European Commission

Italy is one of the European countries with the lowest energy consumption. In particular in 2010, it has registered a consumption per person equal to 2.4 toe/person in respect to the European average equal to 2.7 toe/person. In the same year, Italy has consumed only 1.4% of the total world energy consumption (European Union has consumed 14.4%).

Similar conclusions can be provided also focusing the analysis only on the electric energy consumption [48]. In this area the total consumption is still below the value registered before the beginning of the economic crisis and, in particular, the most marked reduction has taken place in the industry sector especially in the 2009-2010 period (see Figure A2.24). However, the contraction has involved also the domestic and tertiary sectors sparing only the agriculture which, in general, has a very low impact on the total electricity consumption, 2% (see Figure A2.25).
Concluding the analysis, it is clear that the reduction of the industry energy consumption due to the economic crisis has produced a contraction of the total Italian consumption. The forecast for the next years sees a slight restart of the energy consumption driven by a strong increments of renewable energy resources supported by a set of government subsidies and programs.

**Trends in Spain**

Spain is characterized by a consumption structure based on imported petrol mostly, which, combined with a small amount of own sources leads to a high energetic dependence of around 80% (higher than the European 54%) [49].

This tendency changes after 2005 when a progressive increase of energy self-sufficiency starts, reaching 26% in 2010.
While the energetic dependence is still quite elevated, policies in energy efficiency and renewable resources have increased the Spanish self-sufficiency degree. There are several factors that have led to a decrease in the need of primary energy:

- Higher efficiency associated to power generation technologies based on renewable energy and gas.
- Progressive increase in the participation of these technologies in the energy mix.
- Moderation in energy demand, due to energy efficiency initiatives.
Demand has experienced a progressive increase during the last 20 years due to the economic expansion of the country during these decades, and the consequent increase of the earning power. This leads to an increasing trend until 2004, when a new stage in the demand evolution starts. This behaviour continues until current time, even emphasized by the international financial crisis initiated in 2008. The decrease on the productivity in the sector, and generally on the Spanish economy, has led to a more considerable reduction of energy demand in the last few years.

The distribution of national energy demand has changed during the last decades. This change is clearly shown after the 90s when renewable sources start to emerge and are in the cutting edge of conventional sources like coal or petrol. This is due to the development in power infrastructures to integrate renewable energy. In 2010, the consumption increased to 131.927 ktep, a little more than in 2009, when demand reached a historic decrease (8,3% in respect to last year). In 2009-2010, the crisis impacts the demand with a pronounced fall in 2009, and a slight recovery in 2010. However, the tendency of a flattened consumption is maintained since 2004.
In this context, renewable sources are the only ones whose demand does not decrease, maintaining annual increases of higher than 9% from 2006 to 2009, and even doubling it in 2010 (with an increasing of 23%). To sum up, this increase covers 11.3% of the energy demand, based on wind and solar energy, and biofuel, which have experienced respective increases of 15, 41 and 34%. Biomass is a highlighted case, with more than 30% of the total renewable production.

Annex 3 - Examples of DER Penetration and Changes in Regulation

PV Penetration

As an example, the following paragraph provides a general description and analysis of the DGs mix connected to the MV and LV networks in Milano and Brescia zones (A2A). In particular the reported data refers to three different zones:

1. Milano, which is a dense populated urban area
2. Brescia Urban, which is a medium/high dense populated urban area
3. Brescia Rural, which is a medium/low dense populated rural area

Figure A3.1 shows charts about the number of DG plants and the installed power for each identified zone. In this case the data refers to December 2013.
In this scenario the Brescia area is the most significant in terms of the numbers of plants instead of the Milano area where the DGs scenario is characterized by the presence of few generation resources with a higher installed nominal power. From this point of view the Brescia area is the “most distributed” one.

Charts presented in Figure A3.2 report the DGs mix details.

Table A3.1 presents the actual scenario of DGs connected to the MV and LV networks. 56.32% of distributed generated power is produced by a small set of large cogeneration plants - mainly located in Milan - that can be considered as controllable and predictable production resources. Instead, the majority of DGs - in terms of plant numbers - is represented by PV plants which are also non-predictable RES (see Table A3.1).

### Table A3.1 List and description of DGs connected to A2A MV and LV substations (data related to December 2013).

<table>
<thead>
<tr>
<th>Type</th>
<th>Nº LV</th>
<th>kW LV</th>
<th>Nº MV</th>
<th>kW MV</th>
<th>Nº Tot</th>
<th>kW Tot</th>
<th>% Nº</th>
<th>% kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOMASS-BIOGAS-SUW</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2796</td>
<td>3</td>
<td>2796</td>
<td>0.06%</td>
<td>0.92%</td>
</tr>
<tr>
<td>HYDROELECTRIC</td>
<td>2</td>
<td>495</td>
<td>32</td>
<td>31842.6</td>
<td>34</td>
<td>32337.6</td>
<td>0.65%</td>
<td>10.60%</td>
</tr>
<tr>
<td>OTHER</td>
<td>16</td>
<td>936</td>
<td>47</td>
<td>170888</td>
<td>63</td>
<td>171824</td>
<td>1.21%</td>
<td>56.32%</td>
</tr>
<tr>
<td>PHOTOVOLTAIC</td>
<td>4929</td>
<td>46820.16</td>
<td>164</td>
<td>48416.98</td>
<td>5093</td>
<td>95237.14</td>
<td>97.89%</td>
<td>31.22%</td>
</tr>
<tr>
<td>THERMOELECTRIC</td>
<td>4</td>
<td>22</td>
<td>6</td>
<td>2875</td>
<td>10</td>
<td>2897</td>
<td>0.19%</td>
<td>0.95%</td>
</tr>
</tbody>
</table>
Considering the number and its characteristics, the PV technology is – in A2A scenario - the most interesting and relevant RES technology for the IDE4L scope. For this reason the analysis has been focused only on the penetration of this technology. The following charts present the penetration of PV for the three considered zones: Milano, Brescia Urban and Brescia Rural.

Figure A3.3 PV penetration in numbers and installed power for each identified zone (data related to December 2013).

Table A3.2 reports the data of PV penetration reported in previous charts.

Table A3.2 PV penetration for each considered geographic zone (data related to December 2013).

<table>
<thead>
<tr>
<th>Zone</th>
<th>Nº LV</th>
<th>kW LV</th>
<th>Nº MV</th>
<th>kW MV</th>
<th>Nº Tot</th>
<th>kW Tot</th>
<th>% Nº</th>
<th>% kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRESCIA RURAL</td>
<td>2353</td>
<td>19769.65</td>
<td>64</td>
<td>25900.4</td>
<td>2417</td>
<td>45670.05</td>
<td>47.46%</td>
<td>47.95%</td>
</tr>
<tr>
<td>BRESCIA URBAN</td>
<td>1766</td>
<td>14145.57</td>
<td>49</td>
<td>17696.69</td>
<td>1815</td>
<td>31842.26</td>
<td>35.64%</td>
<td>33.43%</td>
</tr>
<tr>
<td>MILANO</td>
<td>810</td>
<td>12904.94</td>
<td>51</td>
<td>4819.89</td>
<td>861</td>
<td>17724.83</td>
<td>16.91%</td>
<td>18.61%</td>
</tr>
</tbody>
</table>

The A2A PV scenario is characterized by a high presence of small/medium size plants (~9.45 kW/plant for LV installations and ~295.22 kW/plant for MV installations) which have been incentivized by a set of government programs started in 2005 with the first "Conto Energia" program - last one ended in July 2013. Starting in July 2013, government photovoltaic incentives have been changed from incentives connected to the energy production - €/kWh - to a tax relief for the installation costs which however is still supporting the diffusion of this technology.

In view of the fact that Brescia zones have 83.09% of PV plants with 81.39% of installed nominal power, the analysis can be restricted on this area. The next charts report PV penetration trends for Brescia Urban and Brescia Rural zones from January 1994 to December 2013.
In accordance with the beginning of the government incentives, the PV installations have had a big increment from 2005/2006 to December 2013. Next charts report the increments of PV plants and installed power per each month from January 2005 to December 2013.

**Figure A3.4 PV penetration trends for Brescia Urban and Brescia Rural zones from January 1994 to December 2013.**
Figure A3.5 Increments of PV plants and installed power per each month from January 2005 to December 2013.

The increments of PV plants per month highlight the effect of the government incentives and the reduction of PV technology costs. In particular, the majority of PV plants have been installed between 2010 and 2012 when incentives had the most important effects and PV technology had the first and the most significant cost reduction.
Electric Vehicle Penetration

When it comes to the EV, the technology is still at a testing stage in many European Countries. As an example, the Italian Authority (AEEG) released a resolution [50] to incentivize pilot projects aimed at testing public EV recharge infrastructure in a real environment. A2A launched, in 2011, the “e-Moving” initiative to experimentally evaluate: the impact of the EV infrastructure on the distribution grid and understand which drivers can promote EV amongst the citizens of large/medium-size cities.

As a whole, today the EV infrastructure includes 100 public recharging points (64 in Milano and 36 in Brescia) scattered as depicted in Figure A3.6, and 170 private recharging points. The public infrastructure allows fast recharging while the private infrastructure is mainly for a slow recharging.

The statistical analysis of EV usage and penetration is underway.

![Figure A3.6 Public EV recharging infrastructure in the cities of Milano (left) and Brescia (right).](image)

Demand Response Penetration

The evolution of the electrical energy system toward a smart model has already started, as described in the previous paragraph. Smart metering, electric vehicles, renewable resources, transmission and distribution advanced grid automation are some examples of this ongoing change. A further step in this process is the interaction between final customers – often residential – and the distribution grid. These customers shall provide new services to the distribution utility which can help the utility to better and more safely manage the grid. As an example, the SmartDomGrid project – co-funded by the Italian Ministry of Economic Development – is aimed at designing, implementing and testing a possible scheme for the grid-customer interaction in a real operation environment.

To join the DR program, the customer has to buy and install some controllable devices such as Smart Appliances (SA) and sign a contract with a Service Provider which makes available a HEMS. The HEMS is able to optimize the best schedule for SAs according to some boundary conditions set by the customer and considering some requests by the DSO. An example is the peak-shaving.

This function is aimed at avoiding peaks of consumption/production which could lead to a congestion of the LV grid, and – in some cases – to an outage.
The DSO collects real time measures from the LV grid (e.g. voltage on LV busbars, currents on LV feeders, ...). If a congestion is detected on a transformer/feeder, the DSO can ask for the help of those customers who joined the DR program, making a request to their HEMS with the indication of the time frame of the action (tstart, Δt), the power reduction (ΔP) and the economic incentives (Δ€). Each HEMS of those customers decides the best strategy to fulfill the request by: i) scheduling SAs outside the peak-time (load shifting); ii) mitigating the load shifting by exploiting the local storage (if any).

Among the benefits of this function are the improvement of the quality of service (reducing the number of outages) and a money reward for the customer who offers a service to the network.

**Service Continuity**

As an example, in Italy, the national authority for electrical energy and gas (AEEG) has since the year 2000 defined two major indicators related to the number and length of outages per customer. This resolution has pushed DSOs to increase the percentage of tele-controllable secondary substations on their MV grid for about 10 years. The result is a significant improvement in the service continuity as reported in Figure A3.7.

![Trend of Italian continuity of service indicators](image-url)

Figure A3.7. Trend of Italian continuity of service indicators: Duration Index (averaged minutes per customer) and Number Index (average number per customer) compared with the percentage of tele-controlled secondary substations.
Power Quality

Power Quality (PQ) measurement is becoming more and more important at the distribution level due to the increasing presence of renewable energy sources with an intermittent generation. Some regulatory frameworks in Europe – as the Italian regulation – are starting to address this issue. AEEG released in 2011 a resolution [51] upgrading the target for the continuity of service (progressively reduction of the number and the length of disconnections per customer) and mandates to monitor the PQ on the distribution grid starting from MV busbars in Primary Substation before 2015. The focus is on voltage dips because they are the most relevant events after interruptions. Nevertheless, other parameters have to be considered to be ready for a future improvement of the regulation. These parameters are defined by the norm EN 50160 [52] e.g. frequency, voltage unbalance, harmonics, etc. It is reasonable to believe that in the next years a remuneration/penalization mechanisms for the PQ will be introduced as it is today for the continuity of service.

DERs ancillary services

In the past, DGs and DERs were connected to the distribution grid according to the “fit-and-forget” approach, i.e. not considering any possible use of those resources for the management of the grid. Today, as the penetration ration of DGs is getting higher and higher, there is a real need to change this paradigm and turn DGs into active elements which provide ancillary services such as voltage and power regulation.

The concept has been accepted by several national authorities who are now reviewing their regulatory framework. As an example, the Italian Electro-technical Committee (CEI) is updating the technical specification CEI-016 [53] and CEI-021 [54] about the technical rules for the connection of active and passive users to the HV/MV and LV grid respectively.

- The DG protection interface has to keep the DG unit connected to the grid within voltage/frequency windows. Those windows have been widened to avoid the disconnection of the DG when there is an issue on the HV grid.
  - $85\% U_n \leq U \leq 110\% U_n$, where $U$ is the voltage
  - $47.5\ Hz \leq f \leq 51.5\ Hz$, where $f$ is the frequency

The DG protection interface has to accept a trip command by the DSO in case there is a fault of the MV/LV grid.

- During normal conditions the DG unit has to inject active power to the grid with a unitary power factor. However, the DG can inject with a smaller power factor if the voltage level in the connection point has been increased by the DG itself (primary control). The DG protection interface has to accept a reactive power reference by the DSO, in case there is a voltage drift affecting a larger area of the MV/LV grid. As an example, Figure A3.8 reports the capability curve of synchronous DG unit connected in MV with a peak power lower than 400 kW.
Legend:
- $S_n =$ Nominal apparent power at nominal voltage $U_n$
- $P_n =$ Active power at nominal voltage $U_n$ and $\cos \varphi = 0.9$
- $P_{\text{max}} =$ Maximum active power at nominal voltage $U_n$ ($\cos \varphi = 1$)
- $Q_{\text{max}} =$ Maximum reactive power at nominal voltage $U_n$ ($\cos \varphi = 0.9$)

Figure A3.8 Example of the capability curve of synchronous DG unit connected in MV with a peak power lower than 400 kW.