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DEVELOPMENT AND OPERATION OF ACTIVE DISTRIBUTION NETWORKS

Working Group

C6.11

April 2011

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DEVELOPMENT AND OPERATION OF ACTIVE DISTRIBUTION NETWORKS

Task Force C6.11

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ISBN : 978-2-85873-146-9

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Executive Summary

CIGRÉ Working Group C6.11 “Development and operation of Active Distribution Networks” started its activity in August 2006 during the CIGRÉ General Session.

The objectives of the Working Group (WG), as defined in the Terms of Reference were:

- Provide a shared definition of active distribution networks;
- Identify the enabling technologies;
- Identify limits/barriers;
- Assess the actual status of implementation of active distribution networks worldwide;
- Provide recommendations/requirements for the integration of Distributed Energy Resources (and transition towards more active distribution networks).

Firstly, the WG started setting the scene (Chapter 1) in the context of a deeply changing concept of “old” (i.e. passive) distribution networks. At the time, no clear idea of what an “active” distribution network represented was in place, and debate among different stakeholders led to differing views.

Bearing this in mind, it was decided amongst C6.11 members to submit a questionnaire to all relevant stakeholders (distribution companies, research organisations, manufacturers, and customer groups) in order to review the present status of implementation of active distribution networks and provide a global, shared definition of active distribution networks (Chapter 2). Survey results indicated that there was no single definition of active distribution networks. However, key concepts could be extracted and, from these, and the following shared global definition emerged:

> ***“Active distribution networks (ADNs) have systems in place to control a combination of distributed energy resources (DERs), defined as generators, loads and storage. Distribution system operators (DSOs) have the possibility of managing the electricity flows using a flexible network topology. DERs take some degree of responsibility for system support, which will depend on a suitable regulatory environment and connection agreement.”***

The second action of the WG was to review the actual status of implementation of active distribution networks, using the answers to the questionnaires and through a review of the most relevant projects worldwide demonstrating active distribution network concepts. (Relevant projects were selected based on criteria agreed amongst the working group.) This exercise allowed the following to be identified: (i) key features of active distribution networks; (ii) enabling technologies; and (iii) how the researchers and stakeholders at the forefront are addressing the integration challenges. The results are presented in Chapter 3.The majority of respondants agreed that the proliferation of distributed generation was one of the key triggers for a change in operating philosophy of distribution networks. Moreover, they identified integration of distributed generators into system operations, to the extent that they take some degree of responsibility for the reliability and operation of the network, as a vital step for the success of the concept. These results are highlighted as part of the WG’s recommendations, which are provided in Chapter 4. Also is this chapter, recommendations to different stakeholders (distribution companies, manufacturers, decision makers, regulators, DG developers) are provided. These recommendations cover what actions should be taken, in terms of system operation, system planning, regulatory activities, and in general to foster adoption of technologies in the transition towards more active distribution networks.

The added value of this document is that it provides a snapshot of the state-of-the-art of the active distribution network concept, how it is perceived by the industry, and then proceeds to identify the priorities of what should be done to facilitate its deployment by utilities. The document addresses not only skilled, technical people but also decision makers, in developed as well as developing countries, so that each might to benefit from what is being done worldwide on the subject.

Definitions

The following terms are defined in an effort to clearly outline the scope of the report. The definition of active distribution networks, being one of the tasks of the working group, is discussed in the body of the report, in Chapter 2.

Distributed energy resources (DER): a term that refers to energy resources (DG, controllable loads or energy storage) connected to the distribution network at MV (69-1 kV) or LV (< 1 kV).

Distributed generation (DG): Generation connected to the distribution network at MV (30-1 kV) or LV (< 1 kV). Generation connected to the high voltage transmission system (above 69 kV), including large wind parks, does *not* fall into this category.

Distribution network: electricity infrastructure aimed at delivering energy from the transmission system to end-users at MV and LV. For the purposes of this report, distribution networks are delineated from transmission or sub-transmission networks by function rather than by voltage level, that is networks where the intent is to deliver energy to customers. This is to avoid confusion associated with different definitions existing at different utilties and transmission connected renewable energy, which is not treated in the scope of this work.

Distribution network operator (DNO): The organisation responsible for the planning, operation and management of the distribution network. The term is analogous to distribution system operator. Distribution system operator (DSO) is taken to be equivalent with DNO and is used interchangeably.

Demand side integration (DSI): The overall technical area focused on advancing the efficient and effective use of electricity in support of power systems and customer needs. That is, DSI covers all activities focused on advancing end-use efficiency and effective electricity utilization, including demand response and energy efficiency (as defined by C6.09).

Demand side management (DSM): Functions that enable the utility to mange the demand curve for emergency or asset management objectives. Demand-side management includes load control and load monitoring functions.

Demand side resources (DSR): End-use resources on the customer side of the meter that can be relied on to respond in a coordinated fashion to electric power system or market conditions. This may include distributed generation, storage, dispatchable load and other on-site resources capable of impacting demand for grid-supplied electric service.

Low voltage (LV): Voltage levels rated <1 kV. In some utilities, this definition may be different. As mentioned, the definition of distribution network is more related to function rather than voltage level.

Medium voltage (MV): Voltage levels rated < 30kV. In some utilities, this definition may be different. As mentioned, the definition of distribution network is more related to function rather than voltage level.

Smart Grids: A general term widely used in the industry associated with the development of different applications around a newly integrated information technologies layer to the power system. The term applies to both transmission and distribution networks and is avoided throughout the report so as to avoid the use of active distribution networks and smart grids interchangeably. ADNs would be considered by most to be under the Smart Grids umbrella term; however, the relationship is not treated in this report due to the fact that the later is very often used in a colloquial manner rather than in a strict technical sense.

Acronyms

ADN	*Active Distribution Networks*
AMI	*Advanced Metering Infrastructure*
AMM	*Automated Meter Management*
AVC	*Automatic Voltage Control*
CHP	*Combined Heat and Power*
DER	*Distributed Energy Resource*
DG	*Distributed Generation*
DLR	*Dynamic Line Rating*
DMS	*Distribution Management System*
DNO	*Distribution Network Operator*
DSI	*Demand Side Integration*
DSM	*Demand Side Management*
DSO	*Distribution System Operator*
ESS	*Energy Storage System*
FACTS	*Flexible AC Transmission Systems*
FRT	*Fault Ride-Through*
ICT	*Information and Communication Technology*
IED	*Intelligent Electronic Device*
IPP	*Independent Power Producer*
LVRT	*Low Voltage Ride-Through*
OLTC	*On-Load Tap Changer*
PV	*Photovoltaic*
RES	*Renewable Energy Source*
RTU	*Remote Terminal Unit*
SCADA	*Supervisory Control and Data Acquisition*
TSO	*Transmission System Operator*
VPP	*Virtual Power Plant*
VR	*Voltage Regulator*
WG	*Working Group*

1 Introduction

1.1 Changing the old concept of grid

The proliferation of distributed generation (DG) together with load growth, energy storage technology advancements and increased consumer expectations have significantly changed the approach to planning, design and operation of distribution networks. The recent development of information and communication technologies (ICT) in distribution has provided the possibility to coordinate these resources and facilitate a number of advanced applications. Around the globe stakeholders such as: distribution companies, equipment manufacturers, electrical engineering consultants, research institutions, regulatory bodies are dealing with these issues.

The technology development of small size generating systems, the new requirements of efficiency, security and quality of power supply, the liberalisation of the electricity market are driving the evolution of electricity distribution from passive to active distribution networks.

Part of this new paradigm includes the possibility for distribution system operators (DSOs) to control, operate and thereby integrate distributed energy resources (DER) into the network under their responsibility. This vision sees the transition of electricity distribution from passive to active distribution networks.

Several organisations worldwide are addressing these issues (e.g. IntelliGrid in the US, Smart Grids Technology Platform and Microgrids in the EU, among others) and promoting collaborative projects on the electricity networks of the future. The CIGRE C6.11 working group assumed the role of characterizing this new concept and collating information on the status of development and outstanding barriers, results that are detailed in this report.

1.2 New way to conceive the electric market

As a consequence of electricity market liberalization, the electric system is facing a growing diffusion of Independent Power Producers (IPP) and Distributed Generation (DG) in distribution networks. Although generators could be connected either to LV, MV or HV levels, the highest growth is expected in MV and LV distribution networks, usually operated in a radial, unidirectional way. The high penetration of these generators in an electric network designed to be operated as a “passive” load, may produce several problems.

However, more than technical concerns (e.g. quality of service, economic issues, investment remuneration) regulatory aspects seem to be the most important key to the diffusion of DG. In fact, in a liberalized market, the electric market regulation plays a steering role, by fixing rules and economic criteria for connection and operation of the distribution network.

In recent years, energy authorities worldwide focused their activity on quality of supply and connection rules, taking care of the possibility for each single customer to access the network in an economic and reliable way. Connection rules both for passive customers and distributed generators have been revised in order to assure third party access to the electric grid.

However, when considering more sophisticated and optimized ways of operating DG to manage local power flows, clear rules have yet to be established. In fact, there are still many constraints that prevent for Distribution System Operators (DSOs) from operating DG, dispatching energy storage and controlling loads. The transition towards more coordinated operation is one of the major challenges for future distribution networks.

That being said, new opportunities are provided by innovative ICT systems dedicated to DG aggregation and control and electronic metering for all customers. They represent the enabling technologies for local energy dispatching and DSM actions. Examples of current research in the fields will be presented and possible implementation in distribution networks will be discussed.

1.3 Advent of DG and RES

Currently, medium voltage (MV) and low voltage (LV) distribution networks are designed to be operated as a "passive" load in which power is generated at large power plants, flows through the transmission network (HV), and is delivered to consumers through distribution networks (MV and LV).

Energy market liberalization, new incentives for renewable energy sources (RES) and growing attention on environmental aspects resulted in a rise of generators' connection requests directly to distribution network.

While high voltage (HV) grids are suitable to accept large amount of generation, because of their meshed configuration, in many cases MV and LV networks do not have the capacity to accept large amount of DG due to insufficient local load. The result is that the locally generated energy from DG (in particular RES) causes a reversal of power flows in distribution networks, which could ultimately be provided to the transmission network, with the inversion of power flow from MV to HV network. This may affect distribution network operation in terms of:

- Degradation of power quality (continuity of supply and voltage quality);
- Violation of thermal limits in the reverse power flow direction;
- Load and voltage profiles management;
- Security and safety issues.

Furthermore, the operational procedures of DG connected to MV and LV networks are nascent but in many cases have been developed *ad hoc*. In fact, at present the control of DG in MV and LV networks is not allocated to the Distribution System Operator. In many cases, if the size of the generator is above 10 MVA, the TSO is responsible for energy dispatching and power flow management. Usually below 10 MVA no remote control is required. However, as DG proliferates, there is a possibility that the DG could aggregate to a significant level without the coordinated control of the system operator.

Economic issues should be also taken into account: the present regulatory framework provides incentives for new DG installations, but no incentives are given to DSOs for new network investment in order to improve accessibility of new energy sources.

In order to exploit the advantages of DG (and, in particular, RES) it is necessary to follow a "system approach": DG should not feed the network in a stand alone mode, but should be fully integrated into the distribution network. This is indicative of a move towards an "active" network.

An "active network" is a network composed of one or more MV feeders, connected to one HV/MV transformer. The MV feeders and their LV systems connect DG, RES and loads (MV/LV transformers, MV customers, etc). If energy produced by MV generators can be dispatched locally and coordinate to balance the load in the area, it can even be operated independently from the main system. In this context, the active network becomes independent from the transmission system (HV network) which represents a second source of energy feeding in case of emergencies.

DGs are expected to provide local ancillary services to the active network. In particular, participating generators must be able to provide:

- Primary and secondary power control;
- Voltage and reactive power control functions;
- Power quality assurance.

Customers could also be involved in load management and control through demand side management (DSM) or demand side resources (DSR) and automated meter management (AMM) systems.

The necessity of such a requirement, however, is dependent on target size of the active distribution network for balancing supply and demand. If distribution networks, which include significant levels of DG, still rely on the supply power from transmission systems, the DSO does not necessarily need to accomplish local balancing, which is socially, economically and technically more imposing. In this case, these requirements need not be fully achieved, though voltage support is still beneficial. On the other hand, if society seeks utilization of DG to its full potential and to move away from reliance on the transmission systems for power supply, these requirements must be minimum conditions.

In order to reach the solutions, research needs to:

- Identify the overall architecture of the network where the load management and dispatch system will be applied
- Design and develop the required functions. They should basically consist of:
    - Dispatch functions (including forecast of local demand and of available generation, participation of each single generator or of the cluster of DG to the daily market of power supply and ancillary services, operations of storage units)
    - Control/protection functions (including network re-configuration, islanding or connecting the local distribution network to the main network, remote control of generators and storage units for frequency and voltage control and regulation, coordination with control centers at the transmission level)
    - Demand and power quality management functions (including operation of actions for peak shaving and load levelling, power quality monitoring)
- Design and development of suitable communication systems.

1.4 Impact of widespread diffusion of DG on existing distribution networks

1.4.1 Increase of short circuit levels and saturation of existing plants

The connection of large generators to existing plants with high loads may increase the level of short circuit above design values. As a consequence, the connection cost of large generation plants may increase as the replacement of equipment becomes necessary.

The cost allocation in the case of multiple connections to the same substation is a contentious and unsolved issue. Often the last applicant is penalized due to the saturation of the plant's capability by previous applicants.

1.4.2 Reactive power regulation and voltage profiles

The issue is relevant if the generator's size is such that the voltage profile of a portion of the network is driven by it. This could happen especially in rural areas for wind farms connections. Fluctuation of power output and limited reactive power capability can exacerbate the problem. At present, DSOs are not allowed to directly control generators' power factor.

The issue is debated and there are many conflicting interests:

- The Generators ask for remuneration of reactive power generation;
- The DSOs ask for the control of voltage profiles without increasing the investment costs;
- The Customers demand voltage quality and cost effective energy;
- The TSO requires that voltage profiles on transmission network be preserved and prescribe the operation of on-load tap changer (OLTC) systems according to its own rules.

Generic solutions are very difficult and case-by-case analysis may lead to definition of best implementations. However cooperation among stakeholders and clear rules are necessary.

1.4.3 Protection, MV network automation systems and fault clearing procedures

Existing fault clearing procedures on MV distribution networks are based on:

- Automatic reclosures for transient faults;
- Reverse feeding from nearby substations;
- Automation sequences for the isolation of faulted section of the MV line.

The automatic reclosures are commonly used to extinguish transient faults and improve quality of service reducing the number of interruptions to the customers. They function on the principle of opening the three phases for a short while and then closing the phases simultaneously. In the case of DG on the faulted feeder, the automatic reclosures may produce damage to the generator in case of non-synchronous phase closing, if it is islanded. To avoid this kind of damage, synchronism control should be prescribed in connection rules and installed at generator's side. This will increase the connection cost. In most cases, no synchronism check is required for DG but in the case of faults on the feeder, the generators are disconnected from the network. Nonetheless, failure of island detection has been witnessed when inverters meet the local demand. In this case, reclosing can lead to large currents and tripping of the inverters.

The reverse feeding of a faulted MV section is commonly used to reduce the impact of long interruptions to end of the line customers by closing normal open switches and feeding from nearby substations. In some cases, this strategy may no longer be possible due to DGs exceeding the short circuit levels of the alternate feeder. Thus, in these cases connection of DGs through a dedicated MV line may be recommended. Of course connections' cost is higher but flexibility of operation and reliability of service are improved. Furthermore, the dedicated MV feeder connection avoids problems with automatic reclosures. This solution should be encouraged by the market rules and the extra-costs remuneration for generators and DSOs should be assured.

MV network protection system is commonly based on "directional" relays, sensitive to zero-sequence components of current and voltage. Ground fault detectors and on load disconnectors work properly if the flow of energy is unidirectional from higher voltage to lower one. If high penetration of DG is such that power flow is inverted from MV to HV, especially in low load areas (e.g. wind sites), this may produce the misoperation of automation systems and the worsening of actual power quality levels for the end customers. Moreover, the transmission of exceeding energy from the MV to the HV grid may increase the losses of energy.

1.4.4 Intentional islanding of generators

Actual technical standards do not permit intentional islanding of generators in public MV distribution networks. This function may be applied in industrial sites with self-generation units as long as, separated from the public network, they are able to equilibrate the load inside the plant and return in parallel with the public network after the transient has run out. The reasons of such prescriptions are lack of control of DG by the DSO and the safety of maintenance workmen (unexpected return of energy from uncontrolled plants).

Theoretically, the practice used for industrial sites with self-generation could be extended to the public network with DG. This means that a "proponent" should be able to schedule, control and equilibrate simultaneously the load and the generation and keep in reliable service the islanded sub-system. To this aim, investments in remote control, communication and programming systems will be necessary. For that reason a clear scenario for investment remuneration must be granted, the costs for the whole electric systems must be carefully evaluated and stable rules in regulatory framework must be issued.

In particular, at present, DSOs are not allowed to:

- Interact directly with the loads performing load control or reduction, with the exception of emergency conditions and in a scheduled way;
- Directly control the generators connected to the distribution network;
- Dispatch locally the energy provided by distributed generators;
- Operate reserve generation or storage units to equilibrate the load in the islanded system.

Other issues that limit islanded operation of DG are:

- The degradation of voltage quality levels of islanded networks (voltage profile, frequency, harmonics, etc.) because of the differences among capability curves of generators and the different typologies of primary energy sources;
- The possible misoperation of under-frequency load shedding devices that protect the system from critical events in transmission networks.

In conclusion, intentional islanding of the distribution network requires coordination efforts, sustained by well defined rules and practices which involve generators, DSOs and TSOs. Moreover, islanded operation necessitates clear procedures for remuneration of the network investments made by the distribution companies and ancillary services provided by the DG.

1.5 EU and USA approach

Driven by the change in the old concept of electricity network, many countries have started technology initiatives to stimulate research and development (R&D) and collaborative projects on future energy networks. The European Union and the United States are the most active to date.

The EU approach has been stimulated by the Green Paper on "A European Strategy for Sustainable, Competitive and Secure Energy" (2005). The European Commission established a Technology Platform (TP) on Smart Grids with the aim to undertake challenges arising from market liberalisation and technical breakthroughs. The TP Smart Grids created a Vision Document and a Strategic Research Agenda, [1].

The main features of a future network, for the EU TP Smart Grids, are:

- User-centric approach: increased interest in electricity market opportunities, value added services, flexible demand for energy, lower prices, microgeneration opportunities;
- Electricity networks renewal and innovation: pursuing efficient asset management, increasing the degree of automation for better quality of service; using system wide remote control; applying efficient investments to solve infrastructure ageing;
- Security of supply: limited primary resources of traditional energy sources, flexible storage; need for higher reliability and quality; increase network and generation capacity;
- Liberalised markets: responding to the requirements and opportunities of liberalisation by developing and enabling both new products and new services; high demand flexibility and controlled price volatility, flexible and predictable tariffs; liquid markets for trading of energy and grid services;
- Interoperability of European electricity networks: supporting the implementation of the internal market; efficient management of cross border and transit network congestion; improving the long-distance transport and integration of renewable energy sources; strengthening European security of supply through enhanced transfer capabilities;
- DG and RES: local energy management, losses and emissions reduction, integration within power networks;
- Central generation: renewal of the existing power-plants, development of efficiency improvements, increased flexibility towards the system services, integration with RES and DG;
- Environmental issues: reaching Kyoto Protocol targets; evaluate their impact on the electricity transits in Europe; reduce losses; increasing social responsibility and sustainability; optimising visual impact and land-use; reduce permission times for new infrastructure;
- Demand response and demand side management (DSM): developing strategies for local demand modulation and load control by electronic metering and automatic meter management systems;
- Politics and regulatory aspects: continuing development and harmonisation of policies and regulatory frameworks in the European Union (EU) context;
- Social and demographic aspects: considering changed demand of an ageing society with increased comfort and quality of life.

In parallel the US industry and manufacturers established the Gridwise Alliance since 2003 with the mission of: "To facilitate the effective collaboration among all stakeholders, and to promote, educate, and advocate for the adoption of innovative smart grid solutions that will achieve economic and environmental benefits for customers, communities and shareholders".

Specifically, in Grid Wise's vision a smart grid will:

- Reduce peak demand by actively managing consumer demand: The percentage of available appliances and equipment that can respond to both consumer and utility operator priorities continues to grow. The ability to manage power requirements in both directions—to the utility as well as from the utility—will reduce the need for power, especially during high-use periods like hot summer afternoons when the cost of producing and delivering power is extremely high.

- Balance consumer reliability and power quality needs: Although some uses of electricity require near perfect reliability and quality, others are almost insensitive to these needs. A smart grid will be able to distinguish the difference and adjust power reliability and quality accordingly at an appropriate cost.
- Mine energy efficiency opportunities proactively: A smart grid will furnish consumers and utilities with accurate, timely, and detailed information about energy use. Armed with this information, we can identify ways to reduce energy consumption with no impact on our safety, comfort, and security. We'll all gain a new level of understanding and insight into how our energy use affects our environment, along with the national economy and our own pocketbooks.
- Improve overall operational efficiency: A smart grid will become increasingly automated, and smart sensors and controls will be integral to its design and operation. Utility operators will be able to easily identify, diagnose, and correct problems, and will even have the capabilities to anticipate problems before they happen.
- Seamlessly integrate all clean energy technologies: Electric vehicles, roof-top solar systems, wind farms, and storage devices will become a fundamental part of the grid. These clean energy technologies will generate not only energy and power, but serve many other vital functions as well. Although transparent to consumers and utilities, these technologies will bring vast value to society and our economy, and go a long way toward meeting our nation's short- and long-term goals.

1.6 Scope of the document

The CIGRÉ C6 Study Committee considers the different aspects of integration of distributed generation. In this context, the C6.11 Working Group (WG) is specifically focused on "Development and operation of active distribution networks". The WG has 27 members, experts and observers, representing 14 different countries. This WG aims to assess the various requirements to facilitate the transition towards active distribution networks (ADNs).

Specifically, the WG scope includes:

- Assessment of network and generators requirements for the operation of DG and DER (islanding criteria, protection, ancillary services);
- Identification of enabling technologies both for demand and generators;
- Definition of limits/barriers (costs, infrastructures, investment remuneration); and
- Evolution in the regulatory framework.

To assess the state-of-the-art, identify the enablers, and provide a shared global definition of ADN, the WG submitted a questionnaire through its members to national CIGRÉ committees, distribution companies, research organizations and other stakeholders. This was followed by in-depth analysis of the international pilot projects that fell under the classification of ADN. This document describes the results of these two activities in Chapters 2 and 3, respectively. In Chapter 4, a set of recommendations are given to support future development of the active distribution network concept. Chapter 5 summarizes the main results of the working group.

2 Definition and Survey Results

An “active distribution networks” industry survey was circulated by WG members within each of their countries and 27 responses were received during 2007. A summary of the global representation of survey responses is given in Figure 2.1.

The questionnaires were analysed by five sub-WGs during 2007 and the first half 2008, and key results were presented to the C6 study committee at the meeting in August 2008. Here the key findings are provided, organized according to the different sections of the survey.

The survey responses were analysed from the following five perspectives:

1. Definition of active distribution networks, main features, strengths, weaknesses, opportunities and threats (SWOT);
2. The current level of implementation of active distribution networks;
3. A review of actual operating procedures;
4. Future operating practices; and
5. Regulatory barriers to active distribution network adoption.

2.1 Definition, main features and SWOT analysis

Within sub-WG 1, the questionnaire responses were analysed from three perspectives:

1. The definition of active distribution networks
2. The main features of active distribution networks
3. The strengths, weaknesses, development opportunities and threats to active distribution networks

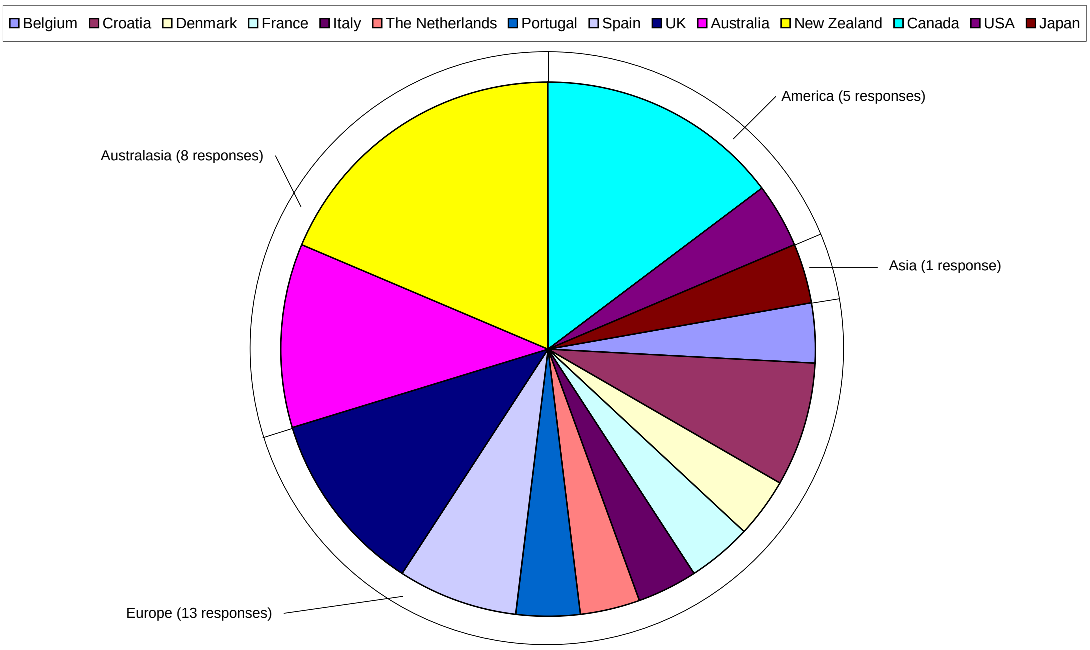

Figure 2.1: Summary of survey responses from across the world

2.1.1 Defining active distribution networks

It is important to define the term *active distribution networks* as this leads to a standardisation of the concept which, in turn, facilitates the sharing of experiences, the communication of ideas and allows appropriate technologies to be developed and transferred. Within the questionnaire distributed by WG C6.11, active distribution networks were defined as follows:

[2.1] "*Active networks are distribution networks with the possibility to remote control and interact with generators and loads in which the DNO* [distribution network operator] *has the possibility to locally manage the electricity flows.*"

[2.3] "*A distribution network becomes "active" when the energy locally generated by distributed generators is greater than the energy consumed by the loads. In this case energy flows may be inverted and power may come from lower voltages to higher ones*."

Figure 2.2 summarises the surveyed response to these definitions and it can be seen that the majority of respondents tend to agree with the definition given in [2.1]. However, the respondents are ambivalent towards definition [2.3]. This highlighted the industry perception in 2007 that active distribution networks should have features to enable DNOs to interact with customers in managing local electricity flows. However, active distribution networks are not necessarily defined by the occurence of reverse power flows.

Respondents were invited to provide their own definition of active distribution networks and these are summarised below:

"*An active distribution system is a distribution system where local or coordinated remote control (further than the conventional voltage regulation by the OLTC* [on load tap changer] *of the primary substation) are used for increasing the capacity of the distribution network for hosting DG and loads, keeping all operation and quality parameters within statutory limits*."

"*Active networks are distribution networks managed by intelligent control systems with ability to recognize power flow streams*."

"*Active Networks are distribution networks (MV* [medium voltage] *and LV* [low voltage] *systems) which can be assimilated to transmission networks because of their constant energy flow from lower to higher voltage levels*."

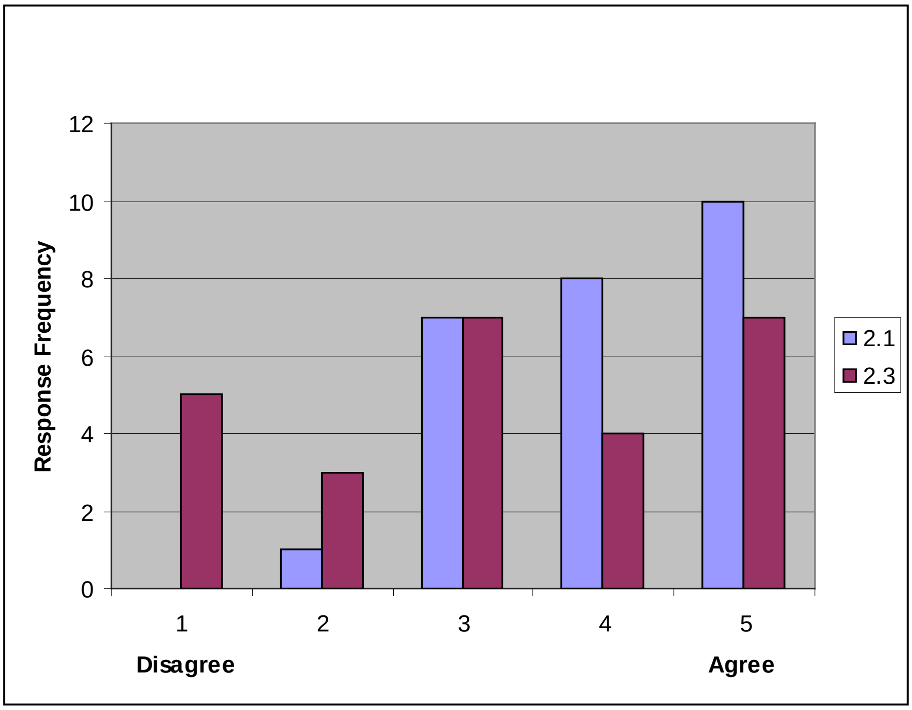

Figure 2.2: Questionnaire 'active distribution network' definition agreement

"*A distribution network becomes "active" when the Distributed Energy Resources (demand and supply) take some degree of responsibility on the system support. Sharing this part of responsibility with the DNO will provide benefits and opportunities to them. The* [greater] *the responsibility DER take*[s], *the more active the network* [becomes]."

"*Active networks are distribution networks (MV and LV systems) in which the DNO has the possibility to automatically or remotely control and interact with distributed generators and/or electrical loads and/or network topology in order to locally safely and efficiently manage and utilize the network*."

"*Active networks are distribution networks (MV and LV systems) equipped with devices located in various locations across the system (not only the substation). These devices provide observability on the network state and also controllability. These devices are able to communicate with other network devices or with centralized control tools, they may have various degrees of autonomy. They can be owned and operated by the DNO or by network users (who manage distributed generators and/or electrical loads)*."

"*Active networks are distribution networks (MV and LV systems) in which the networks will operate in such a way that DG and loads can act without boundaries. The network facilitates this maximum. The main possibility to let it act this way is if DNO has the possibility to remote control and interact either with distributed generators and electrical loads in order to locally manage the energy flows*."

Clearly, from the responses above, there are many opinions regarding the definition of active distribution networks. Furthermore, a definition is provided by the Energy Networks Association (the trade association for UK energy transmission and distribution licence holders and operators) as:

"*The methodology by which the DNO and the Generator monitor their respective plant with the intention of reacting to network or generation changes in order to ensure that the network and generation continue to operate within safe and prescribed limits, where monitoring means manual, electronic or any other form of monitoring that is suitable for the particular installation*."

Each of these definitions was analysed to extract key words and concepts. The following shared global definition emerged from the 2008 WG C6.11 meeting, and was disseminated at the CIGRE 2008 Session in Paris:

"Active distribution networks (ADNs) have systems in place to control a combination of distributed energy resources (DERs), defined as generators, loads and storage. Distribution system operators (DSOs) have the possibility of managing the electricity flows using a flexible network topology. DERs take some degree of responsibility for system support, which will depend on a suitable regulatory environment and connection agreement."

2.1.2 Main technical features of active distribution networks

From the survey responses and the alternate definitions supplied, the main features of active distribution networks were ascertained. These are summarized in Table 2.1.

Table 2.1: Main features of active distribution networks

Infrastructure Needs / Specifications	Applications	Driver/Benefit
• Protection • Communication • Integration into existing systems • Flexible network topology • Active network management capable equipment • Smart metering technologies	• Power flow congestion management • Data collection and management • Voltage management • DG and load control • Fast reconfiguration	• Improved reliability • Increased asset utilisation • Improved access for DG • Alternative to network reinforcement • Network stability • Improved network efficiency (loss reduction)

2.1.3 Enabling Technologies for Active Distribution Networks

This section analyses active distribution networks in terms of their potential advantages and disadvantages when compared to passive distribution networks. In doing so, the opportunities arising from, and the potential threats to, the development of active distribution networks are identified. The full strengths, weaknesses, opportunities, threats (SWOT) analysis, gleaned from questionnaire responses, is appended:

Strengths:

- Economic alternative to network reinforcement
- Increased operational reliability, including power delivery
- Electrical loss reduction
- Automation and control leading to improved network access for DG / load customers

Weaknesses:

- Maintenance issues
- Present lack of experience
- DNOs are not incentivised to take risks
- Existing communications infrastructure

Opportunities:

- Ageing assets could be replaced with active management capable equipment
- Development and implementation of smart metering technologies
- Development of communications infrastructure
- Movement towards a low-carbon economy through the accommodation of distributed renewable energy sources

Threats:

- Regulatory issues impede the development of active distribution networks
- DG continues to grow in size and is connected to the transmission network
- Security of information on the communication infrastructure

- Active networks are not compatible with existing passive networks.

Although the questionnaire did not specifically focus on regulatory and contractual issues, the responses from stakeholders surveyed indicated that these aspects are likely to be determining factors as to whether ADNs are adopted or not [2],[3].

2.2 Current level of implementation

The main feedback related to the current level of implementation was that the present level of development is quite low. Nonetheless, there were a number of pilot installations that were mentioned including those in: Australia, Denmark, the Netherlands, Spain and the UK. Also, a number of pilots known to the WG experts were not mentioned in the questionnaire responses, suggesting that there is a need to disseminate this information. As such, the WG decided to pursue documentation of these existing pilots and collate information related to technologies and applications.

On the issue of factors that would help facilitate future deployment of ADNs, a number of suggestions were received. These included (in level of priority, from highest to lowest): new investment remuneration / regulatory frameworks to foster utility adoption; research and development (including publicly funded demonstration projects), standardisation. Demand growth and environmental factors were perceived to be only minor factors in the adoption of ADN.

The communication medium used by the companies surveyed varied greatly. Table 2.2 summarises the technologies mentioned in the responses received. Only a limited number of companies cited the use of communication for remote operation of DER, with an even smaller percentage of cases cited where the control extended down to low voltage networks.

Table 2.2 : Communication technologies used by surveyed utilities

Method	Wireless	Hard wired
• Voice only (telephone to local operator) • Remote control • Connection to SCADA systems	• Microwave • Radio, UHF radio, radio links • Satellite • GPRS • GSM	• Copper pilot table • Optical fibre • Power line carrier (PLC)

2.3 Review of actual operating procedures

Section 4 of the questionnaire addressed the operational procedures currently implemented, identifying the barriers to a widespread diffusion of distributed intelligence in the networks.

2.3.1 Rules for parallel to the network

There is no general agreement as to the rules for operation in parallel with the network for MV and LV generators. The rules are mandated by National legislation, are published in the Grid Codes, or prescribed by the local utility. As a general rule the DG should not degrade the power quality of the network. In case of a fault or loss of the main grid islanding is generally prohibited and in most cases automatic disconnection is performed, either based on local signals or remotely from the substation.

2.3.2 Fault clearing

Fault clearing procedures are the same as for feeders without DG in 60% of the interviewed DSOs. Dedicated settings for feeders with DG are used by 40% of the respondents but no coordination is granted in the case of embedded MV and LV generation.

2.3.3 Remote control

Only 41% of the interviewed DSOs have the possibility of remotely controlling the DG at the MV and LV level. Few DSOs have the responsibility (or capability) to dispatch or regulate the output power produced by the DG. Most DSOs are obliged to accommodate all DG power injections and as mentioned in the section 2.4.1 the interface protections disconnect the DG in case of voltage transients or faults.

2.3.4 Voltage control

The only experience cited in the responses related to coordination of voltage regulation for MV feeders with DG is done with the adjustable setting of the tap changer of MV/LV transformers. The situation is even less common at the LV in which no contribution of DG to voltage control was mentioned.

2.3.5 Intentional islanding

Presently there is very limited application of intentional islanding; 22% of DSOs interviewed perform intentional islanding of DG under certain conditions. In most cases this represents islanding of the DG owner's load (generally an industrial load) only and consequently the island does not include any utility infrastructure. However, 14% of the DSOs interviewed may perform intentional islanding that includes the utility system, in emergency cases.

2.4 Future operating practices

Present operating procedures reveal that ADN applications are applied in only a limited number of cases. The interviewed DSOs indicated development of the following areas, in order of priority (from highest to lowest) as critical for the success of ADNs: protection approaches, safety, fault management, communications, intentional islanding and ancillary services. This suggests that further development of these different areas is a necessary precursor to widespread implementation.

These responses indicate the utility's position vis-à-vis this technology and the steps required for its adoption. There seems to be a perception that safe operation of a number of DER in a distribution network still requires further consideration. Also, it seems that communications are required before some of the ADN applications (ancillary services, intentional islanding) can be taken advantage of. This supports the view from the previous section that presently there are only a few cases of remote control of DER, something that most probably needs to change in order for ADN to become adopted more universally.

2.5 Regulatory barriers to ADN

Although the survey did not specifically focus on regulatory and contractual issues, the responses from DSOs interviewed indicated that these aspects will likely be the determining factor as to whether ADNs are adopted or not. Even more so than in the connection of single DERs, these can pose significant barriers to ADNs, in that a fundamental prerequisite for ADNs is that DER be integrated and not simply interconnected.

To implement the ADN concept a DSO must be allowed to control and regulate the output of at least the major DG units. A DER that relinquishes some level of control to the DSO will require different contracting and remuneration than those that simply inject real power into the network. Implicit is the varying degrees of responsibility associated with each. Intentional islanding requires an additional level of complexity as, during islanding, participating generators become the sole mechanism for ensuring the reliability and quality of the energy supplied. As such, this will warrant supplemental regulatory and contractual considerations.

Market models, regulations and responsibilities of different actors (TSO, DSO, generators, etc) will likely vary according to the operational procedures of the ADN. Successful treatment of these issues will require an integrated approach including utilities, DG owners and the regulator. Ultimately the system should be optimized in terms of overall energy usage, which would include the use of electricity, heating, and cooling. As examples of this level of integration do exist at present, these should be used as starting points for the discussion.

2.6 Future ADN developments

2.6.1 Relevant research consortiums

Although not highlighted in the surveys, there are a number of international research initiatives that are conducting R&D and implementing pilots in ADNs or related fields. Many have only recently been initiated but others already have significant results.

In an effort to identify gaps and improve coordination, in 2006 the Electric Power Research Institute (EPRI) conducted a mapping exercise of existing programs, [4]. The organizations profiled included: Intelligrid, CEC-PIER, CERTS, Smart Grid Platform, GridWise, NYSERDA, PSERC, Galvin Electricity Initiative, NETL. While there were a number of overlaps in terms of visioning, functional requirements and demonstration, the analysis revealed that a need existed in terms of addressing standards, user groups and integration of different products.

The analysis was recently updated but there were a number of relevant research programs not included in the original report. These include: European initiatives such as ADDRESS, ADINE, FENIX and Microgrids [8]; the Distribution Vision 2010 and the Smart Grid Demonstrations in the US; as well as other more modest national programs such as those from Australia, Austria, Japan and Canada, [6]. While this supplemental list is also not exhaustive, it suggests that there is a great deal of effort being invested in this area that could serve as sources of information for the C6.11 working group.

2.6.2 Standardization

Standardization is a fundamental cornerstone of any successful industry and the power industry is no exception. While it is debatable as to when it is appropriate to begin the process of standardization for emerging technologies, ADNs will benefit from some of the efforts already underway as a result of DG integration.

Communication and information exchange, as with the Smart Grid, is perhaps the most important enabling technology. To this end, the work of the IEC TC 57 is paramount in facilitating the implementation of information and communication technology (ICT). Objectives of this technical committee can be summarized as:

- Extension of IEC 61850 to DER and feeder equipment
- WG 17 – object models for DER
- Common information models (CIM) for distribution automation
- Promoting interoperability (near-term) and plug-and-play (long-term).

In North America the IEEE 1547 has been widely adopted as the interconnection standard for distributed generation. Of perhaps greater relevance to the development of active distribution networks is the series of application guides that accompany the standard. The relevant IEEE 1547 series of guides published and under development (denoted by 'P') include:

- IEEE 1547.2 – Application guide on the use of IEEE 1547
- IEEE 1547.3 – Information exchange and communication protocols for distributed generation
- IEEE P1547.4 – Design and operation of DER Islands
- IEEE P1547.6 – DG in secondary or spot networks.

2.6.3 Active distribution network development priorities

The interviewed DSOs indicated development of the following areas, in order of priority (from highest to lowest) as critical for the success of ADNs: protection approaches, safety, fault management, communications, intentional islanding and ancillary services. Before anything else the new technology must be protected in a similar fashion to the traditional system. Other, less essential functionalities, such as ancillary services, while desired are not priority items in the deployment of the active distribution network concept.

3 Current Status of Deployment of ADN

Presently, active distribution networks are only just beginning to be deployed in power systems worldwide. Many of these pioneering systems are demonstration projects, pilots, and proof-of-concept of some of the components of ADN. Some have even reached the full deployment stage, including commercially available products. With the objective of extracting the salient features of current active distribution networks, a review and analysis of existing projects was performed, the results of which are presented here.

3.1 Methodology

A comprehensive list of ADN projects was compiled and analyzed in order to extract the key features and enabling technologies associated with this innovative approach for operation and control of distribution networks. A subset of the results is presented here, while the balance of the analysis has been relegated to the appendices. The rational is first presented followed by a summary of the results.

3.1.1 Sources of Information

Sources of information were the active network management database, [9] managed by University of Strathclyde, information from additional projects submitted by WG members and their partners, presentations from relevant workshops, and internet research. Those interested in more detailed information are welcomed to consult reference [9] or those pertaining to specific projects by referring to Appendix C. Many of these projects were identified as part of workshops that were organized in collaboration with the CIGRE C6 Study Committee, [6], [7].

3.1.2 Characteristics of ADN projects

Each of the projects was analyzed according to a number of predefined characteristics. The following is the list of categories by which each of the projects was analyzed, together with a short description:

- Project objectives and drivers;
- Technical features – enabling technologies, existing equipment, and type of DER;
- Benefits – quantifiable benefits as well as qualitative;
- Barriers – both technical and regulatory barriers;
- Costs, if available.

3.1.3 Project Ranking Criteria

There are a larger number of projects worldwide that fall under the general term of active distribution networks. As a result, from the larger list of projects, a subset was selected to illustrate the most innovative concepts and cover the different applications presently deployed. The criteria that were used in selection of the projects:

- A deployed project (possibly as part of a pilot or demonstration), which represents a whole system (not a certain product);
- A measurable level of innovation;
- Projects with available (full) documentation and contact information;
- Geographical distribution.

3.2 Pilot Project Analyses Results

The list of projects retained serve as raw data for the analysis of the ADN concept. Here the projects are presented in summary form followed by a description of the enabling technologies and the different ADN applications.

3.2.1 Summary

A total of 27 projects are given in Table 3.1, representing some of the most innovative projects in active distribution networks worldwide. In addition to the information presented here, short summary descriptions with complete references are given in Appendix B.

Table 3.1 Top ADN Pilot/Demonstration Projects

	Project name	**Project Leader (Country)**	**Main objective / driver**	**Enabling technology**
1	Demonstrative project on new power systems	NEDO (JP)	Maintain the power quality of the system even with DG connected to the grid	• Power electronics at distribution level (D-FACTS) and supply-demand balance control
2	Olympic Peninsula project	BPA – PNNL (USA)	Constrained distribution network management through two-way communication of load status and electric price signals	• Advanced metering infrastructure (AMI) • Demand side management (DSM) • Variable pricing structures
3	Fort Collins Demonstration Project	City of Fort Collins (USA)	Peak load reduction and coordination of distributed resources (part of the Zero Energy District project)	• Advanced metering infrastructure (AMI) • Demand side management (DSM) • Aggregation and dispatch of DER
4	Townsville: Queensland Solar City (Magnetic Island solar suburb)	Ergon (AU)	Peak load reduction through installation of smart meters and PV systems	• Advanced metering infrastructure (AMI) • Demand side management (DSM) • Variable pricing structures
5	Smart Distribution Network Operation (SDNO)	ENEL Distribuzione (IT)	Design, development, and field test of a new protection, control, and automation system for HV/MV distribution networks with high DG penetration	• Advanced protection devices • Automatic voltage control (AVC) • Distribution management system (DMS)
6	Active Distribution Network (ADINE) project	Hermia Ltd (FI) – 7 partners consortium	Validate active network management on networks with DG included, while facilitating the connection of new DG	• Advanced protection devices • Remote monitoring and control • Power electronic base voltage control

	Project name	Project Leader (Country)	Main objective / driver	Enabling technology
7	Balls Gap Station	AEP (USA)	2 MVA sodium-sulfur (NaS) battery for islanding during feeder fault and peak shaving	• Energy storage system (ESS) • Microgrid (islanding)
8	Field test on actual Microgrids Gaidouromantra, Kythnos Island (More Microgrids WPF)	Cres (GR.EU)	Development of alternative control strategies and network designs, aiming to increase the penetration of micro-generation	• Energy storage systems (ESS) • Power electonics control • Microgrids (islanding) • Multi-agent control • Aggregation of DER
9	Interruptible contracts for wind-power generation in congested areas	Hellenic Transmission System Operator (GR)	Control of the power flow through congested corridors using power reduction commands	• Intelligent dispatch of DER • Programmable logic controllers and ICT
10	Field test on VPP in Strutensee (Dispower)	MVV (DE)	Communication infrastructure and optimization tool for power quality monitoring and control	• Optimal dispatch of DER • Demand side management (DSM) • Communication infrastructure (ICT) • Power management systems
11	Steyning Primary Registered Power Zone (RPZ)	EDF Energy (UK)	Advanced automatic voltage control (GenAVC) allowing more DER accommodation into the feeders	• Automatic voltage control (AVC) • Real-time measurement • Remote control of tap changers
12	Orkney Registered Power Zone (RPZ)	Scottish Hydro Electric (UK)	Active management scheme for new non-firm generation (output control)	• Dynamic line rating (DLR) • Real time network measurements for network available capacity
13	Active Management of Distributed Generation based on Component Thermal Properties	Parsons Brinckerhoff (UK)	Optimization of network design, operation and control. Active controller using thermal state estimation of the network	• Real time thermal rating
14	Skegness Registered Power Zone (RPZ)	E.On Central Networks (UK)	Weather measurements (ambient temperature and wind speed) for dynamic overhead line rating	• Dynamic line rating (DLR)
15	ADDRESS	ENEL Distribuzione (EU)	Active participation of domestic and small commercial consumers in energy markets	• Demand side management (DSM)

	Project name	Project Leader (Country)	Main objective / driver	Enabling technology
16	Demand Response Programs	ConEdison (USA)	Electric load-reduction programs to manage energy usage (load reduction / price responsive / direct load control)	• Demand side management (DSM)
17	Model City of Manheim	MVV Energie AG (DE)	Integration of renewable and decentralized sources of energy into the urban network	• DSM • Microgrids • Broadband power line infrastructure (ICT) • Variable pricing structures
18	PowerMatcher	ECN (NL)	Intelligent coordination for supply-and-demand-matching (SDM)	• Clustered control of DG by common ICT • Multi-agent market-based control
19	Virtual Power Plant (multi-site remote dispatching software)	Encorp (USA)	Remote aggregation and control of multiple energy systems	• Virtual Power Plant (VPP) • Communication and control "technology-neutral" protocol
20	European Virtual Fuel Cell Power Plant	Vaillant (DE.EU)	Develop, install, test and demonstrate a virtual power plant using 31 residential microCHP fuel cell systems	• Virtual Power Plant (VPP) • DG dispatch • Communication infrastructure (ICT)
21	Cell Controller Project	Energinet.dk (DK)	Advanced power system control and monitoring	• Autonomous grid areas (Cells / microgrids) • Communication and control
22	Development and demonstration of innovative distributed power interconnection and control systems	NREL – Encorp (USA)	Develop cost-effective distributed power grid interconnection products, software, and communication solutions	• Advanced controllers, power sensor modules, revenue grade meters, communication capabilities
23	FENIX (Flexible Electricity Networks to Integrate the eXpected 'energy evolution')	Iberdrola (ES.EU)	Development and validation of Decentralised Energy Management Systems with high penetration of Distributed Generation and Renewable Energy Sources while maintaining the stability and power quality of the distribution networks	• Large Scale Virtual Power Plant (LSVPP) • DG aggregation and dispatch • Ancillary Services Provision • Control (Demand and Energy Management Systems) • Coordination among system actors (TSO, DSO, aggregator, DG)

	Project name	Project Leader (Country)	Main objective / driver	Enabling technology
24	LV distributed generation microgrid	RSE (Italy)	Field test of optimization procedures, centralised controller and communication solutions.	• Optimal dispatch of DER • Demand side management (DSM) • Communication infrastructure (ICT)
25	More Microgrids (Advanced Architectures and Control Concepts for More Microgrids) 8 Test Sites 1. LABEIN - DER Test Facility, Bilbao, Spain 2. CRES – Gaidouromantra, Kythnos, Greece 3. EDP Study Case, Portugal 4. Liander's Holiday park at Bronsbergen in Zutphen, the Netherlands 5. MVV – Mannheim-Wallstadt, Germany 6. RSE - DER Test Facility, Italy 7. Agria Microgrid, F.Y.R.O.M 8. Bornholm Island, Denmark	ICCS / National Technical University of Athens (Greece)	Field trials of operation in: • Interconnected mode • islanded mode • transitions from inter- connected to islanded mode and vice versa Evaluation of centralized and de-centralized control strategies. Tests of advanced power electronic interfaces (Intelligent Load Switch and smart Battery Storage)	• Power Electronics with innovative local controls • Multi-Agent Systems • IEC 61850-7-420 and IEC 61970 Standards • Demand Response, DER integration, Market operation • Java based distributed control • Micro-CHP • Hybrid system with PV fields and storage • Innovative battery energy storage system with inverters • Biogas plant
26	Smart House/Smart Grid 3 Test Sites 1. Aggregating End-user Systems for Energy Efficiency & Enterprise Systems Testing (Netherlands) 2. Domestic Cluster Mannheim - Wallstadt, (Germany) 3. Micro-grid operation Meltemi, (Greece)	SAP (Germany)	Cost / consumption reduction Peak load shaving / shifting,	• Distributed Control • Negotiation Algorithms • Forecast Tools
27	Hydro-Québec Smart Zone	Hydro-Québec (Canada)	Piloting of active distribution network technologies (volts and Var optimization, demand response, distributed generation)	• Integrated VVO • Demand response • Forecast Tools for distributed generation

3.2.2 Enabling Technologies

From the list of projects, the enabling technologies were extracted and grouped according to the integration level, Table 3.2. The benefits and existing R&D needs were also identified and the relevant projects were identified. This serves as the basis for cost-benefit analysis of the different active distribution network concepts.

Table 3.2 Active Distribution Networks Enabling Technologies

Integration Level	Enabling Technologies	Application	Benefits	R&D Needs	Project
Hardware (advanced devices)	Power electronics (applied to distribution networks)	Active and reactive power control	• Grid Stability • Increased power transfer	• Lower cost of power electronics • Reliability of components	1 6 25.1 25.4 25.6
	Intelligent devices and communication media	Information and communication technologies (ICT)	• Active distribution network management • Coordination and control of new and existent elements of the network • Network information collection	• Cost • Reliability • Standards for interconnection • Integration capability	All
	Advanced metering infrastructure (AMI)	Demand side management (with variable pricing structures)	• Reduce consumer costs / consumption • Peak shaving / shifting	• Cost • Regulatory issues • Variable price structures	2 3 4 24 25.2 27
	Advanced protection devices	Active network management with high DG penetration	• Increased DG integration • Network reliability and power quality • FRT and islanding capabilities • Sensitivity and selectivity with communication based protection	•Integration capability • ICT reliability • Protection coordination	5 6
	Energy storage system (ESS) and battery energy management	Islanding, load peak shaving, and intermittent generation integration	• Increased renewable integration • Avoid network reinforcement • Peak shaving • Islanding capabilities	• Cost • Energy management and operation strategies • Power electronics reliability	7 8 25.4 25.6

Integration Level	Enabling Technologies	Application	Benefits	R&D Needs	Project
	Distributed power interconnection and control interface	Power quality control, coordinate grid operation	• Islanding capabilities	• Interaction with protection and other grid assests (e.g. OLTC)	8 9 10 20 23 25
Distributed Monitoring and Control	Power flow management	Optimal network management and active generation constraint for wind farms	• Low cost solution for increased energy export • Avoid network reinforcement • Peak shaving	• ICT and protection devices reliability • Regulatory issues	9 10 23 24
	Automatic voltage control (AVC)	Voltage regulation to allow the increase of DG	• Facilitates increased capacity of DG • Avoid voltage rise on networks	• Lower cost solutions • Increased transformer tap changer operations	5 6 11 23 27
	Dynamic line rating (DLR)	Real-time thermal capacity of the network	• Increased capacity to accommodate DG • Avoid network reinforcement	• Losses increment • ICT reliability	12 13 14
Network operation (procedures / strategies)	Demand side management (DSM)	Load reduction / shifting, price responsive, direct load control	• Frequency control • Reduce consumer costs • Avoid network reinforcement • Peak shaving	• Customers behavior • Regulatory issues • Variable price structures	2 3 4 10 15 16 17 24 25 26 27

Integration Level	Enabling Technologies	Application	Benefits	R&D Needs	Project
	Distributed control of DER	Aggregation of small and medium DG / Virtual power plant (VPP)	• Integration of DG to optimal operation and economic maximization • Balancing of variable generation	• Cost • Regulatory issues	3 18 19 20 23 24 25
	Microgrid / feeder (islanding)	Operation of small communities and buildings or a feeder of a substation in islanded mode	• Autonomous power supply • Avoid network reinforcement • Lower network losses	• Cost of energy storage • Resynchronization with the main grid • Protection schemes	7 8 17 21 25 26
	Distribution management systems (DMS)	Active management of distribution networks with DG integrated	• SCADA • Optimal power flow • Integration with IEDs and RTUs • Web-access	• Costs • Integration with systems already in use • ICT reliability	5 9 10 19 22 25 27

3.2.3 Applications and Tools

Analysis of the different projects also enabled identification of different ADN functionalities and specific applications, around which a business case must eventually be built, that is, once this technology moves beyond the pilot stage. Table 3.3 presents the results of this exercise, where a specific application is linked to the ADN functionality, and the required enabling technologies.

A fourth column was added to note the analysis tools that can be used for the application in question. These tools are those which are used to, firstly to provide a technical analysis of the system and possibly quantify benefits. The second class of tools included were those that can be used for cost-benefit analysis, translating the benefits into monetary values, so that they can be measured against the costs of implementing the project. Traditional tools for analysis and planning of distribution systems are often ill-equipped to conduct the studies associated with active distribution networks.

For the pilot projects analyzed, information on tools used in the planning of these systems was not available. This suggests that there may be an important gap in the availability of tools for analysis of these systems, as is often the case for new technologies or large changes in how an industry is designed and operated. This remains an important issue that warrants further treatment, possibly in future study committee activities.

Table 3.3 Specific Active Distribution Network Applications and Associated Analysis Tools

Functionality	Specific application	Enabling technologies	Tools[i]
Coordinated dispatch of DER	Defer investment in constrained regions	• DER interconnection and control systems • Dynamic line rating • ICT	Dynamic load flow, probabilisitic load flow, asset simulation programs
	Virtual power plant	• DER interconnection and control systems • ICT • Multi-agent market-based control	Dynamic load flow, market simulation
	Islanding	• DER interconnection and control systems • ESS • ICT	Distribution protection and load flow, stability analysis, electromagnetic transients programming
Active participation of demand[ii]	Cost / consumption reduction	• AMI • Grid friendly appliances • Home area networks • ICT • Multi-agent market-based control	Dynamic load flow, probabilisitic load flow, market simulation, economic evaluation
	Peak load shaving / shifting	• AMI • Grid friendly appliances • Home area networks • ICT • Multi-agent market-based control	Dynamic load flow, probabilisitic load flow, economic evaluation
	Direct load control by DNO	• AMI • Grid friendly appliances • Home area networks • ICT • Multi-agent market-based control	Dynamic load flow, probabilisitic load flow, economic evaluation
Distribution management	Coordinated Voltage-Var control	• Distribution sensors • DMS • ICT • Remotely controlled VR devices – VR, capacitor banks, power electronics	Dynamic load flow, economic evaluation

Functionality	Specific application	Enabling technologies	Tools[i]
	Optimal power flow	• DER • Distribution sensors • DMS • ICT • Remotely controlled VR devices – VR, capacitor banks, power electronics based	Dynamic load flow, probabilisitic load flow, market simulation, economic evaluation
Advanced protection	Automatic reconfiguration	• Distribution automation • ICT (in some cases)	Dynamic analysis of short-circuits and protection
	Fault ride through of DG and intermittent sources	• LVRT technologies	Stability analysis tools Electromagnetic transient simulation tools

(i) Tools refers to software packages that permit technical analysis of application as well as those that permit economic analysis of so as to quantify benefits. Actual products are not mentioned here in order to preserve objectivity. In certain cases, the functionalities may only exist in part and therefore, realisation of the functionality in question may require a combination of tools or customizing a .particular tool to meet one's particular needs.

(ii) It is assumed that tools listed in this row must have the appropriate load models in order to perform these studies.

4 Recommendations for the Transition to More Active Distribution Networks

4.1 Introduction

The work from the previous two chapters helps the industry to reach some consensus on the concept of active distribution networks and provides a picture of the progress thus far, in terms of development and deployment of these concepts. This allows the working group to develop a set of recommendations as to future work required to help foster the adoption of this network operating philosophy.

The working group provides recommendations in the areas of: grid operation, system operation, regulatory environment, and awareness building. The chapter is organized according to these classifications.

The target audience consists of the following groups:

- Distribution network operators;
- Distribution network planners/asset managers;
- Equipment manufacturers;
- Academia/Research/Consultants
- Telecommunication providers/software developers;
- Manufacturers;
- Regulation Bodies,
- End-use or consumer representative groups.

Each of the recommendation sections does not neceesarily address to all groups and therefore, readers should refer to the sections that are most pertinent for their own interests.

4.2 Grid Operation

4.2.1 Grid code recommendations

It is recommended that Grid Codes should be simplified to make the documents more accessible to emerging grid users, such as DG owners, load customers or storage developers. Grid codes should be revised and appropriate clauses added to reflect the highly important requirement of grid users to cooperate with the grid operator for the optimal use of DG, controllable loads and storage without compromising the security of supply to electricity consumers. An example clause is given below, which could be adapted as regionally appropriate:

"Grid users of the DNO's distribution system must take an appropriate degree of responsibility for system support, the level of which will be specified through the grid user's connection agreement."

Since Grid Codes vary from country to country, every nation must trigger the introduction of appropriate clauses into their own national grid code. It is suggested that the onus should be on DNOs/DSOs to initiate the Grid Code revision.

Questions still remain to be answered with regard to storage: in terms of regulation will DSOs be allowed to own storage schemes within their network or, in a similar manner to DG, will DSOs be prevented through legislation from owning storage? This will need to be resolved otherwise it will stall any future applications of energy storage.

4.2.2 Protection and Fault Management

The transition to active distribution networks will undoubtedly impact protection of distribution system due to the high level of DG penetration associated with most ADN concepts. However, this is not unique to active distribution networks but is also a consideration in high DG penetration scenarios where the DG is not explicitely coordinated with system operation. Generally, traditional protection practices ensure that the system is appropriately protected up to a certain DG penetration level, beyond which alternate approaches must be used to ensure the same level of performance.

One way of addressing this fact, which has been adopted by various utilities or jurisdictions, is to define certain limiting conditions that represent a threshold, that beyond which the protection practice should be re-evaluated and possibly revised. Rather than analyze at length all the different technical issues, the rule of thumb defines a conservative limit up to which traditional distribution protection settings function without modification.

Along this line of thinking, this report makes the following recommendations concerning protection and fault management in the context of active distribution networks:

- If the aggregate capacity of the DG on the feeder is less than 10% of the short-circuit capacity of the substation then the existing protection strategy is deemed sufficient as long as the DG meet the interconnection requirements of the local utility, [14]-[16] (Rule 21 and DUIT report, FERC document).
- If the system to which the DG is connected is operated as a meshed system and any of the DG's capacity exceeds the minimum load at the PCC then the protection strategy needs to be revisited (see IEEE 1547.6, [13] and Rule 21, [14]).

Over the medium to long-term, it is recommended that utilities engaged in the development of active distribution networks should also work towards the development of advanced distribution protection strategies. These protection strategies ideally would be generic such that they could be adapted to any DG type and penetration level, and scalable so that the strategy does not need to be redefined with each new DG interconnection. Advanced protection schemes may include the requirement for dynamic protection settings, communication based techniques, modifying or replacing protection devices (e.g. fuses, network protectors, current limiting reactors), and advanced relaying functions (e.g. distance relaying). Utility planners should consider these advanced protection concepts together as part of their strategy for transition to active distribution networks, leveraging the infrastructure associated with ADN (e.g. communications, automation and control)

In support of this development, the CIGRE C6 Study Committee should support sharing of information on advanced protection schemes for active distribution networks.

4.2.3 Safety

As in other domains, in the context of active distribution networks, safe workplace practices are used to line workers. In principle, these practices are already in place but their importance increases in the context of DG as each DG represents a potential power source in the network being worked on, which could inadvertently energize the system. The following are safety recommendations for active distribution networks:

- Ensure that the 5 step safety practice is strictly adhered to when work is performed on the network in question. This consists of the following 5 steps:
    - Open line
    - Secure against accidental reclosing
    - Measure voltage
    - Ground the phases
    - Ground neutral wire to ensure it is at the same potential as the phases (if neutral is accessible)
- Utility workers should be informed of the existence and location of DG connected to the network.
- Consider coordination of UPS systems with local DG or any other back-up power approaches associated with active distribution networks. DG should be certified according to applicable standards. Standardization of protection system for the DG connected to low voltage systems is essential for safety of people and distribution crews, particularly in buildings.

4.2.4 Communication

Secure and reliable communication channels (whether they are hard-wired copper, fibre optical or wireless) will be an essential element in future active distribution network operation. The security and reliability of communication channels is particularly important for the control of DG, loads and storage to achieve optimal / more efficient network operation. In either case it is recommended that the projects mentioned in Chapter 3 are considered in greater detail by any DSO looking to develop their communication infrastructure. In addition, it is recommended that the likelihood of future higher-band width requirements are taken into account in present investment decisions and that redundant communication channels could be effective in increasing the reliability of the communication system.

Typical distances to be covered range over 10-15 km length; the creation of a dedicated infrastructure for each utility does not appear at the present time to be a likely solution, but it will be adopted in some specific cases. Alternatively, signals have to be carried out by means of public wired and wireless communication services (xDSL, WiFi, GSM/GPRS, WiMAX,..) or power line (PLC) technologies. Requirements for different services can be found in [10]. Exchange of information over *public communication networks* raises several issues, however, the main concerns are:

Security - Information must be exchanged using encryption techniques. It is outside the scope of this document to provide a detailed description of these challenges; for an indepth analysis, deliverables from the European project CRUTIAL [11] could be referred to. Starting from the well known *tunnelling* technique based on VPN (Virtual Private Network), this issue may profit from developing technologies made for 'telecommuting' and similar applications.

Standardization - In order to avoid the proliferation of several closely related proprietary solutions, it is worth emphasizing that a standard solution could improve participation of medium/small generators. Ideally, this standard solution should be established before a large number of local generators are installed. At present, IEEE 1547 in USA and IEC 61850 in Europe appear as possible candidates for developing a standard communication interface.

The IEC 61850 family standard, originally developed for substation automation, in recent years has been broadening its field of application towards the integration of distributed energy resources, [12]. The GOOSE (Generic Object Oriented Substation Event) publisher/subscriber implements an additional IEC 61850 protocol used for applications requiring an high-speed multicast service, such as the "anti-islanding" messaging that could be useful for ADNs.

The IEEE 1547 establishes criteria and requirements for interconnection of distributed resources, providing a uniform standard. It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection, and guidelines for monitoring and control of DERs, [13]. The associated applications guides, IEEE 1547.x series, address many of the practical issues related to impact studies, DG testing protocols, islanded operation of distribution systems, and communication needs, .

4.2.5 Ancillary service provision

Emerging grid users such as DG, loads and storage have significant potential to provide ancillary services to the DNO/DSO if an appropriate regulatory framework is in place to encourage this engagement. The flexibility of grid users is a key requirement: DSOs should be able to utilise DG, loads and storage as required for system support (e.g. reactive power compensation and voltage control, active filtering, demand side integration, DG black start capabilities etc). The grid users should cooperate with DSO for system support and in turn should receive rewards through appropriate commercial and regulatory mechanisms.

4.3 System Planning

4.3.1 Introduction

The common activities of distribution planning are:

- Develop load forecast,
- Substation location and sizing, and
- Feeder routing and design.

The ultimate goal of distribution planning is to answer: *When? Why? What? Where?* with regards to the construction of new facilities and/or refurbishing the existing ones. Furthermore, distribution planning covers different time horizons. Strategic plans (long term) define the final goal to reach, medium term planning defines the system development harmonized with the master plan, short term (day-by-day) planning solves daily problems within the framework of strategic plans. Traditionally, distribution planning aimed at solving with minimum cost all operational issues at the planning level since distribution systems had few or no operation systems in place (*fit and forget*).

Table 4.1 Desired Planning Methodology Characteristics in Relevant Groupings

Planning Activity Scope	Planning Framework	Planning Process	Planning Future Focus	Planning Data & Information
- Multiple criteria - Multiple and diverse solutions - Whole system solutions	- Modular analysis - Integrated analysis - Automated planning - Interactive planning	- Enhancing productivity - Decision focused - Robust resources - Insightful - Simulation/Optimisation	- Uncertainty focused - Risk focused - Leverages investments - Appropriate time scales	- Bulk data handling - Auditable planning records - Reuse of data and models - Reuse of planning rationale

Active distribution influences all planning activities. Demand response and distributed generation affect load forecasts, active management of distribution resources influences the design of the system. Generally, the planning algorithms and procedures used in distribution companies are not suited for such new duties since they are based on the passive paradigm of distribution. Particularly, they are suited to find an optimal solution in which all operation issues are solved at planning level by designing the system so that the worst cases might be successfully handled. This approach can be no longer used, and new algorithms should be developed for active distribution planning. Planning for active distribution system means integrating—not simply connecting—novel energy resources and storage, at a reasonable cost.

The following sub-sections give recommendations on the future trends in planning.

4.3.2 Future trends in distribution planning

Development of techniques based on heuristics, cases, and tacit knowledge:

- Incorporation of the multiple drivers in present-day electricity distribution planning (e.g., reliability, DG, demand response, storage, etc.);
- Integration of planning techniques with other energy or utility service planning (planning for multi-energy hubs);
- Incorporation of best practice in planning methodology;
- Consideration of customer needs in an environment of changing customer base under restructuring.

Methods and tools to help distribution planners guide the transition from the existing distribution systems to the future ones are necessary. Planning tools have to be efficient and enable maximal utilization of existing assets. The most general recommendation is that novel planning techniques must integrate operation models within planning. Lacking in this point leads to unreliable plans making too expensive the transition to active distribution networks and the integration of novel technologies. In order to plan the system, simulations are necessary and they are performed with commercial and popular professional software tools. Commercial software tools do not have components or models to simulate active networks. Distribution management functions can be simulated with very complicated methodologies that sometimes involve use of more than one software package. It is recommended that software developers include models to simulate active management and communication systems.

The definition of techniques and models to be used is beyond the scope of CIGRE WG C6.11. Recently established CIGRE WG C6.19 has the ambition to identify the most suitable planning techniques for active distribution networks and for the transition to the system of the future. It is a natural follow up of WG C6.11 since it starts working from the recommendations approved in the present document.

4.3.3 *Strategic planning*

4.3.3.1 *Dialogue with politicians and decision makers*

The early dialogue with politicians when they start to incentivize RES and Demand Response is essential for system planning. Politicians and decision makers have to be aware about the impact on the system and the related investments. Distribution planners can provide decision makers with information on the areas where RES are less harmful or more useful. The integration of planning methodologies within Geographic Information Systems allows finding the most promising areas for RES or the areas where, according to the regulatory environment and the incentives, RES will increase with less impact.

Decision makers should be aware that the larger the number and the diversity of small DER in the system the higher the reliability of the system, since the failure of one small generator has little or no impact. Active management combined with blind incentive mechanisms may lead to significant technical problems or inordinate costs that are ultimately borne by society or rate payers. In developing wise system evolution plans, distribution planners and decision makers should avoid such a potentially harmful situation.

4.3.3.2 *Consider all energy forms in energy system planning*

Planning for energy hubs means integrating all energy sources and storage types. The impact of electric vehicles, cogeneration systems, storage devices, and flexible demand on the electrical system has to be assessed with suitable tools. The general recommendation is to make plans that consider those elements and the integration with other infrastructures (e.g. the natural gas network is essential to exploit micro cogeneration and cogeneration).

4.3.3.3 *Choosing the future network topology – Meshed or Radial?*

Active networks may benefit from the adoption of meshed topology in opposition to the dominant radial scheme. Meshed networks may have positive effects on power losses, voltage regulation, network reliability, and on the exploitation of lines and substations, particularly if high shares of DG have to be integrated. It should be recognized that the more DG installed in distribution networks, the fewer are the reasons to keep using radial networks and the greater is the motivation to adopt the meshed structure. This structure has the potential to allow a more seemless integration of DG, avoiding many of the technical challenges associated with integration of DG to radial systems. The transition from radial to meshed distribution system may be achieved by closing the existing emergency ties, thereby avoiding the need for new lines.

Compared to radial ones, meshed networks require more complex operation but the level of complexity is not higher than in radial ADNs or *smartgrids*. On the contrary, with the automation and communication level of ADNs, the operation of meshed systems is greatly simplified. The major concerns are related to the protection system. Generally speaking, the higher short circuit level associated with the move from a radial to meshed networks makes the installed breakers inadequate. Furthermore, protection systems normally based on the coordination of overcurrent relays to achieve selectivity, need be modified by installing directional relays or intelligent protection devices with communication capabilities.

The WG recommendations are:

- Meshed networks should be considered in the transition from passive to active operation. The level of automation in ADN can be used to overcome typical problems of meshed systems (e.g. protection system, operation of the network).
- The cost for the refurbishment of existing breakers due to the short circuit current should be compared with the cost of short circuit current limiters.
- The automation of the meshed network has to be designed to avoid degrading network reliability due to the higher number of customers that could be disconnected in the event of line faults (interconnection with meshed network can propagate faults in wider areas).
- Intelligent protection devices must be used to rapidly isolate the faulted areas. The use of proactive protection systems and network reconfiguration systems are essential to realize meshed network benefits.

4.3.3.4 *Planning ICT facilities*

ICT, network automation and power electronics are the enabling technologies for ADNs implementation. Indeed, the Distribution Management System (DMS), the core of active networks operation, relies heavily upon, control capabilities and automation, that are generally absent in current distribution networks. Planning the evolution of the system without planning the integration of the enabling technologies can lead to diseconomies. Planners should interact with all company functions to harmonize the development of SCADA, databases, communication and automation facilities with the electric power system (protection, machinery, lines and cables, etc.).

4.3.3.5 Take a probabilistic approach

Distribution planning relies on deterministic models. The majority of DSOs adopts deterministic models even with high shares of renewable energy sources. Probabilistic methods seem to be better suited for planning with DG and DER (CIGRE WG C6.04) and should be adopted. The probability to be curtailed and to what extent are useful to producers to assess the profitability of investments and to distribution planners to make decisions regarding reinforcements.

4.3.3.6 Uncertainties and Risk management

Planning in uncertain scenarios causes risks. Most commons uncertainties are:

- Political drivers (subsidies or penalties),
- Regulatory environment,
- Fuel cost,
- Intermittent power production (renewables),
- DER availability, and
- Active management success.

Planning algorithms, particularly in active distribution networks, need to explicitly deal with risks, by allowing planners to make objective and transparent decisions. Planning becomes a decision making process applied in an uncertain scenario.

4.3.3.7 Multi-year planning

The transition to active distribution systems will take several years. Multi-year programming is essential to define a schedule to the development, avoiding long fiscal problems. In multi-year planning, power and reactive power dispatch, demand side response, network reconfiguration should be compared with network reinforcement or refurbishment. The integration of DER often requires a novel multi-year study. The quality of forecasts on load demand and DG exploitation are fundamental.

The general recommendation is to make plans related to investments in equipment that allows for active operation to manage and ideally eliminate the risk of lock-in. Furthermore, plans have to envisage routes for communication systems (e.g., considering the need of empty pipes for communication cables when new power lines are built).

4.3.3.8 Reliability analysis of ADN

The reliability of ADNs is a debated issue. Even though they might improve the quality of service, the share of responsibilities among different players and the massive use of ICT and automation might reduce reliability. The lack of experience, the increase in complexity, and the use of novel communication systems are perceived weaknesses of ADNs. The recommendation is to develop and use new techniques to assess the reliability of the ADNs. The novel planning methodologies have to define development strategies to cope with the inherent risk of active management.

4.3.3.9 Energy losses reduction

DSO’s are worldwide committed to reducing energy losses for environmental reasons. In certain cases, active distribution may cause an increase in losses due to the combination of investment deferment, and power production and load demand growth. Normally, DSO would like to have truly dispersed generators (i.e. small size generators) for loss reduction that follow the load. Producers are often driven by quite different needs, as they strive to fully exploit the local energy resources. From the planners’ point of view, a compromise should be found between these opposing needs. The recommendation is to use multi criteria programming to solve the tensions between DSO and producers. Furthermore, the algorithms for distribution management systems, which should be implemented in planning, have to optimize the network operation to strike a compromise between reducing losses and maximizing production.

4.3.3.10 Ageing

Distribution systems in developed countries are reaching the end of their life cycles, with the majority of electrical infrastructures having been built up to 60-70 years ago. Failure of equipement associated with the ageing of distribution infrastructures is a major issue that could negate the reliability improvements achieved in recent years with the combination of asset management, predictive and corrective maintenance, novel planning strategies and network automation. In the long term, active management strategies could amplify ageing problems due to the deferment of investments. The recommendation is to develop planning strategies that explicitly model the ageing of network components. Planning strategies should be based on the active management only to postpone major network investments in the short-medium term, by reducing the financial pressure on the transition. In the long term, the current level of reliability will be kept or improved only with the strategic and rational refurbishment of the oldest components. Multi-year planning strategies have to deal with those problems and help the planner to determine the appropriate moment to refurbish network components is.

4.3.3.11 Flexible network topology

Network reconfiguration is fundamental to ADNs. The flexible network topology allows reduction of energy losses, minimizing changes in the DG scheduled power production, and achieving a more reliable system (e.g., zones with a good balance between production and demand may be formed for autonomous functioning). As mentioned, some of these benefits may be realized using the meshed topology. During this transition, it is recommended to adopt automation systems and breakers/sectionalisers that can operate not only in the event of faults, but almost continuously for on-line network reconfiguration. The number of devices to be used, as it affects the quality of on-line reconfiguration, should be carefully planned.

4.3.3.12 Protection schemes

DERs increase the short circuit currents and in some cases require alteration to the protection system logic. For this reason, currently the majority of the international standards suggest the instantaneous disconnection of the generators in case of a fault, so that the existing protection system can properly work. This practice prevents islanding, both intentional and unintentional, something that is also not permitted by most standards. Protection schemes should be revised, with active operation in mind, and make protection devices able to communicate with the substation to avoid unintentional islanding or unnecessary disconnection of DER. From the planning point view, proper simulation of the protection system is necessary to capture the opportunities in terms of network reconfiguration capabilities, and reliability enhancement with intentional islanding.

4.4 Regulatory Environment

Political objectives have been set to provide a greater amount of energy from renewable energy in the future, a lot part coming from distributed generation sources. However, this does not by itself guarantee that there will be coordination between DG and operation of the distribution system.

The regulatory frame plays a key role in decisions of the stakeholders: but how is it possible to create business models that help to reach the political goals in a timely manner? Results from questionnaires and the survey of projects came to the conclusion that currently, in many if not all countries, the regulatory framework is perceived as a barrier to active distribution networks. Under the premise that ADN can accommodate larger shares of DG, this indirectly acts as an impediment to meeting these objectives.

This technical document does not focus on regulatory framework. However, the technical recommendations for grid operation can only partly be realized within the current liberalized market. Feed-in tariffs for renewable energy that only consider energy rather than ancillary services do not provide incentives for smart integration.

The following three recommendations were identified as critical for transition towards active distribution networks:

- First, to allow market mechanisms, e.g. cross-selling products and value added services to the grid users, despite of unbundling of distribution system operators and sales departments
- Second, to enable grid operators to co-ordinate dispersed generators with direct or indirect control. This will be fundamental for the secure and reliable operation of the power system and the local networks. System stability is possible the local power capability exceeds the power requested by the loads. If there is no possibility to control and coordinate DG and RES by DNOs, no intentional islanding will be possible, nor will local energy management to optimized network operation. Unbundled energy markets should also include the possibility for DNO to own or at least operate DG for system balancing. The

role of storage is still to be clarified for DNO. At present, only curtailment to maintain grid stability is allowed.

- The following position papers list some of the progress in the area of developing regulation that supports ADN: The WG recommends consultation of these position papers and the open discussion on the websites of the mentioned organisations for further insight:

Europe:

- European Regulators Group for Electricity and Gas (ERGEG) “Position paper on smart grids – An ERGEG public consultation paper” (Ref: E09-EQS-30-04 as of December 10, 2009), available at [17];
- EURELECTRIC: “EURELECTRIC comments on ERGEG position paper on smart grids: A EURELECTRIC position paper”, January 2010, available at [17];
- Praseg, UK: Council to advice government on regulation, Results published by OFGEM, UK, on the internet: “Project discovery”, see [18];
- VDE “Smart Distribution 2020”, Germany, [19];

North America:

- American recovery and reinvestment act, USA, [20];
- Ontario Smart Grid Forum final report, [21].

As electricity markets are opening worldwide and different players are competing at international level, regulations should be harmonized over a stable medium-long term period. At this point, we highlight the importance of this topic and suggest that is should be followed-up in a co-ordinated way on an international level. Stable regulation periods are important for long term investment decisions applied in the energy infrastructure sector.

4.5 Awareness building

In the transition from passive operation of distribution networks to more active approaches it is vital that awareness is built between key players at a number of different levels:

- Grid users need to be engaged in distribution system operation by understanding the benefits this could yield both to them and the system as a whole. For example, a DG scheme that provides voltage support as an ancillary service could see an enhanced revenue stream – an individual benefit – and by doing so ensures that the system as a whole continues to operate within prescribed limits – a system-wide benefit.
- Even more essential than before, there needs to be a formal feed-back loop in place within distribution companies so that operational experiences can inform the power system planning stage. This evolutionary process would also allow the economic impact of active distribution network operation versus passive distribution network operation to be quantified. For example, the meshed operation of distribution networks has the potential to allow greater levels of DG to be accommodated. Therefore, the planning and operational aspects of active distribution networks need to be aligned to facilitate a potential transition from radial to meshed distribution network toplogies.

5 Conclusions and Summary

Following discussion of the context, this working group report reviews the state of deployment of active distribution network, first through an industry survey (Chapter 2) and then through an in-depth analysis of pilot projects (Chapter 3). The industry survey helps to reach a consensus on a definition for the ADN concept and to define general characteristics, while the review of pilot projects provided a cross-cut of the different applications that are current being implemented, along with the associated enabling technologies. Based upon these results and the input of working group members, a series of recommendations to help support further deployment were developed and presented in Chapter 4.

5.1 Added value

In the C6.11 vision, the ADN concept is the one of the necessary building blocks of the future “Smart Grid”. The ADN will be the infrastructure that enables customer participation to the market, matching their needs with new capabilities, and allows the DNO to integrate these resources in operation of the systems so as to optimize the use of its assets, improve energy efficiency and performance. This report showed that many of the leading utilities have spearheaded pilot projects and demonstrations installations, yet this technology is far from commonplace. The lack of incentives of both grid operators and DER owners and appropriate regulatory environments has, for now, stalled the adoption of this concept.

This report provides a number of added values, including:

- Identifies ADN as a vital step in the move towards the Smart Grid;
- Defines the ADN concept and its characteristics;
- Raises awareness on its status and challenges, and;
- Identifies priorities to be addressed in near future, to support further development of ADN.

Bearing the above in mind, any one reading this report, will be brought up to date on what are ADNs, its status of implementation and barriers and what to do facilitate its acceptance by the industry.

5.2 Summary of results

With reference to the WG terms of reference, this report provides results in the following areas:

- Provide a shared definition of active networks – a shared definition was reached in Chapter 2 following and industry survey. The resulting definition of ADN is given by :

  “Active distribution networks (ADNs) have systems in place to control a combination of distributed energy resources (DERs), defined as generators, loads and storage. Distribution system operators (DSOs) have the possibility of managing the electricity flows using a flexible network topology. DERs take some degree of responsibility for system support, which will depend on a suitable regulatory environment and connection agreement.”

- Assess the actual status of implementation of active networks worldwide – the status of deployment was addressed through the industry survey (Chapter 2) and the review of existing pilot projects (Chapter 3). At present, the ADN concept has only really been applied at the pilot level, however, these projects will provide important knowledge that should support the adoption by utilities.
- Provide recommendations/requirements for the integration of Distributed Energy Resources – Chapter 4 provides recommendations for actions that will support the deployment of DER and the adoption of ADN.
- Identify the enabling technologies – Chapter 3 provided a series of tables that summarizes enabling technologies of various ADN applications.

- Identify limits/barriers – these limits/barriers are addressed in Chapter 4 as part of the recommendations. The recommendations speak to future works required in order to address these limitations.

5.3 Summary of recommendations

Chapter 4 provided a series of recommendations, resulting from reflections on the working group results and input from members. The main recommendations are summarized here:

- Grid operation
    - Review protection systems and safety measured in the context of ADNs;
    - Grid codes should be updated to reflect the fact that DER owners need to share responsibility with DNOs for the application of ADN;
    - Communication systems to support data exchange for ADNs should integrate industry standards and security must be maintained;
    - Put mechanisms in place for grid users to provide ancillary services and receive remuneration for this service.
- System planning
    - Planners should dialogue with other stakeholders (government, grid users) and consider their needs in a strategic planning approach;
    - Consider the move to meshed network topologies to simplify the integration of DER and the development of ADNs;
    - Apply probabilistic, risk-base approaches to planning of distribution system. This includes consideration of DER and ADNs for asset management in conjunction with network reinforcement;
    - Develop planning tools that model the impact of new loads, DER and innovative ADNs applications.
- Regulatory environment
    - Develop mechanisms that connect grid users to the market;
    - Enable grid operators to integrate DER into operation of the network;
- Awareness building
    - Educate grid users on the operation of the distribution system, potential benefits and constraints;
    - Develop communication strategies within distribution companies that allow employees from all parts of the business to exchange information and educate each other on the evolution of the system. Furthermore, it is important that is a link with the international community to ensure that the experiences of industry leaders are shared on that same network.

Appendix A: Questionnaire used in ADN Survey

This appendix provides the questionnaire circulated to managers or senior specialists in distribution networks operation and control, including utilities and research institutions. The results were analyzed and were the basis for chapter 2.

Cigre C6.11 - Active networks questionnaire

Overview

The questionnaire comprises 4 parts. Please read carefully the questions and provide simple answers. It will take less than 20 minutes to be completed.

Definitions

Distribution network: electricity infrastructure aimed at delivering energy from the transmission system to end-users at MV and LV

MV: Medium Voltage, rated < 30kV

LV: Low Voltage, rated <1 kV

DG*: distributed generation, connected at MV (30-1 kV) and LV (< 1 kV)*

DNO*: Distribution Network/System Operator, entitled for the planning, operation and management of the network*

DSM*: Demand Side Management, the opportunity to remotely manage the load demand*

1. General information

1.1. Name - Surname:

1.2. Position:

1.3. Email address:

1.4. Tel.:

1.5. Company:

1.6. Office/Division/Unit:

1.7. Country:

1.8. Number of end-users served:

1.9. Energy yearly distributed (GWh/year):

1.10. MV rated voltage(s):

1.11. LV rated voltage(s):

1.12. Total length of MV network:

1.13. Total length of LV network:

1.14. Total number of MV/LV substations (including pole-mounted transformers):

1.15. MV grounding system (please check the appropriate box),

☐ Insulated ☐ grounded with impedance ☐ directly grounded

1.16. LV grounding system (please check the appropriate box),

☐ Insulated ☐ grounded with impedance ☐ directly grounded

1.17. MV system standard configuration

☐ totally radial (open loop) ☐ totally meshed (closed loop) ☐ radial with reclosures (normally open with the possibility to close the circuit)

1.18. LV system standard configuration

☐ totally radial (open loop) ☐ totally meshed (closed loop) ☐ radial with reclosures (normally open with the possibility to close the circuit)

1.19. Existence of Regulatory Authority

☐ Yes ☐ No

1.20. Distributed generation penetration in your MV and LV systems

$$\frac{\text{Nominal Power of DG connected to MV and LV}}{\text{Total power of generators connected to your grid}} \times 100 =$$

$$\frac{\text{Energy yearly produced by MV and LV DG}}{\text{Total energy yearly produced by generators connected to your grid}} \times 100 =$$

2. Definition and features of active networks

2.1. Do you agree with the following definition of "active network":

*A **distribution network** becomes "active" when the energy locally generated by distributed generators is greater than the energy consumed by the loads. In this case energy flows may be inverted and power may come from lower voltages to higher ones .Active networks are distribution networks with the possibility to remote control and interact with generators and loads in which the **DNO** has the possibility to locally manage the electricity flows.*

No 1 2 3 4 5 Yes

2.2. Please provide an alternate definition of active network, if relevant:

2.3. What are, in your opinion/experience, the 3 main features of an active network?

2.3.1. a)

2.3.2. b)

2.3.3. c)

2.4. Please rank, in order of importance, the following features of active networks (most important = 1 to least important =10):

2.4.1. Communication protocols ______

2.4.2. Protection schemes and issues ______

2.4.3. Data collection and management ______

2.4.4. Load forecasting ______

2.4.5. Smart metering/DSM ______

2.4.6. DG and load control by the DNO ______

2.4.7. Network stability ______

2.4.8. Quality of service / reliability ______

2.4.9. Intentional islanding ______

2.4.10. ________________________ ______

2.5. What are, in your opinion/experience, the **advantages** of active networks?

2.6. What are, in your opinion/experience, the **disadvantages** of active networks?

2.7. What are, in your opinion/experience, the **opportunities** associated active networks?

2.8. What are, in your opinion/experience, the **challenges** associated with active networks?

3. Development of active networks

3.1. According to the definition provided in 2.1, what is the present level of development of active networks in your Country?

No implementation 1 2 3 4 5 Entire distribution network

3.2. Are there any pilot installations? How large are they? Please provide details

3.3. What may help the deployment of active networks? (scale 1 to 6)

3.3.1. Investment remuneration/ Regulatory framework _____

3.3.2. Research and development _____

3.3.3. Standardization _____

3.3.4. Other ____________________ _____

3.3.5. Other ____________________ _____

3.3.6. Other ____________________ _____

3.4. What kind of control is performed with MV generators?

Legend

1 = no control; 2 = power and voltage measures; 3 = Q-V regulation; 4 = remote disconnection; 5 = fully remotely operated

1 2 3 4 5

3.5. What kind of control is performed with LV generators?

Legend

1 = no control; 2 = power and voltage measures; 3 = Q-V regulation; 4 = remote disconnection; 5 = fully remotely operated

1 2 3 4 5

3.6. What kind of communication systems are used (if applicable)?

4. Operation of active networks

4.1. **Parallel to the network.** What are present rules for parallel operation of DG with the distribution network?

4.2. **Remote control**. Do present grid codes allow the DNO to control distributed generators (e.g. voltage contol, remote disconnection, power limitation, etc.)?

☐ YES ☐ NO

If yes, please provide a brief explanation:

4.3. **Intentional islanding.** Do present rules allow intentional islanding of distributed generators at the MV level?

☐ YES ☐ NO ☐ In Emergency cases

4.4. **Intentional islanding.** Do present rules allow intentional islanding of distributed generators at the LV level?

☐ YES ☐ NO ☐ In Emergency cases

4.5. **Voltage control.** Which are the prescriptions for voltage control of MV and LV distributed generators?

4.6. **Fault clearing.** Which are the fault clearing procedures on MV and LV feeders with DG?

☐ The same as feeders without DG ☐ Dedicated procedures

Please provide a short explanation

Looking into the future…

4.7. **Future requirements.** Which areas should be covered by future rules for the operation of active networks (scale 1 “not agree” to 5 “fully agree”)?

4.7.1. Protections 1 2 3 4 5

4.7.2. Communication 1 2 3 4 5

4.7.3. Ancillary services 1 2 3 4 5

4.7.4. Fault management 1 2 3 4 5

4.7.5. Safety 1 2 3 4 5

4.7.6. Islanding 1 2 3 4 5

4.7.7. Other ________________________ 1 2 3 4 5

4.7.8. Other ________________________ 1 2 3 4 5

4.7.9. Other ________________________ 1 2 3 4 5

4.8. Please provide any additional comments or suggestions?

Appendix B: Strength, Weaknesses, Opportunities and Threats Analysis for ADN

Strengths	Weaknesses
- Implementing active systems should be an economical alternative to network reinforcement. - Capital works augmentation deferment by providing network voltage support. - Better redundancy - The DNO has the infrastructure and knowledge of the existing system to enable them to have greater control. - Increase in flexibility, quality and reliability of power supply service through better response times and better network visibility - High levels of automation will reduce human error - Easier access to active distribution networks for load customers and distributed generators. - Has the potential to decrease network losses - Improved use of assets and capacity to host distributed generation - Improved load factor - Losses can be reduced and therefore the overall efficiency of distributing electricity can be improved - Increase the quality of supply and availability for sensitive customers	- Active distribution network equipment maintenance issues - Management of offline generators when they are required to be online - Complexity of communications amongst the large number of stakeholders involved - Investment costs (equipment, education, software). - Lack of previous experience on generation management - There are no international standards to set the desired characteristics of an active distribution network - Implementation of active distribution network can be a purely political decision as the additional investment required will affect electricity prices - DNOs are not incentivised to take risks. - Difficulties in upgrading the communication capabilities of existing network devices. - Resistance to changes regarding the day-by-day usual operational procedures. - The capability of existing protocols and communication infrastructure

Opportunities	Threats
- DNOs are user-oriented - possible development of new businesses - Ageing assets could be replaced with active management capable equipment - An open information system that is able to host new observation and controllability functions - Building trust with the owner of the DG to allow the DNO to have control over the operation of the DG - If renewable fuels are used, carbon intensity will decrease. - To handle legacy situations where the DG / load customer could not otherwise afford to connect to the distribution system. - Development of switching / islanding technologies may allow DNO to lower peak system loading - Development of optimised network planning tools - DNO can take advantage of the new communication facilities and provide additional services to consumers (e.g. internet) - Active distribution networks will be facilitated by smart metering technologies	- Utility may have to pay to disconnect customers during maintenance activity. - Ultimate generation export capability dictated by the dynamics of the electrical system. - Remote switching of DG could result in safety issues. - Increase of power supply criteria, possibility of higher and more frequent penalization. - Regulatory issues, safety issues impede the development of active distribution networks - Integration with passive networks - Cost of implementation of active management might be comparable to cost of upgrading/reinforcing the network - It might be difficult to coordinate actions in countries with a very large number of DNOs - Security of information on the communication infrastructure - Reduced reliability and security due to new technologies

Appendix C: Description of Active Distribution Network Projects

This appendix provides additional information of some of the projects reviewed in Chapter 3. All contacts were invited to submit information and what appears are participants that provided the requested information. The order corresponds to the order as presented in Chapter 3.

Project Name: Pacific Northwest GridWise™ Demonstration Project

Project Contact: Don Hammerstrom, Principal Investigator
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Description and objectives:

Program Objectives:

The Department of Energy's Pacific Northwest National Laboratory teamed up with regional utilities and industry partners in the year-long Pacific Northwest GridWise™ Demonstration Project to test the notion that smart grid technologies and consumers can play an active role in managing the grid. The project, funded by the Department of Energy, involved homeowners in two separate studies to test demand-response concepts and technologies designed to maximize the electric grid's ability to provide reliable, affordable and clean energy.

The Grid Friendly Appliance Project demonstrated that everyday household appliances can automatically reduce energy consumption at critical moments when they are fitted with controllers that sense stress on the grid. **The Olympic Peninsula Project** found homeowners are willing to adjust their individual energy use based on price signals provided via information technology tools. Both studies helped reduce pressure on the grid during times of peak demand.

The study found there are no technical hurdles standing in the way of wide-scale adoption of the Grid Friendly Appliance Controller and the automated technologies of demand response that were tested. With wide-scale adoption of these technologies, stress on the grid can be mitigated to prevent power outages during grid emergencies. Additionally, these technologies will help integrate renewable energy onto the grid and are projected to reduce the need to build about $70 billion (over a 20-year period) of new generation, transmission and distribution systems.

Program Background:

The GridWise Demonstration Project consisted of two separate demand response studies – the Grid Friendly Appliance Project and the Olympic Peninsula Project.

Data was collected from March 2006-March 2007.

Pacific Northwest National Laboratory managed the GridWise Demonstration Project.

The Project was funded by the U.S. Department of Energy.

The demonstration projects included the following partners: Bonneville Power Administration, PacifiCorp, Portland General Electric, the City of Port Angeles, Wash., and Clallam County (Wash.) PUD #1.

Large, in-kind contributions from industrial collaborators included appliances from Whirlpool Corp., and real-time event software and analytics developed by IBM Research.

Advantages:

Demand-response technologies can help enhance the reliability of the grid by instantly reducing demand when the balance of supply and demand is at risk. A more reliable power grid can prevent the economic impact of power failure.

An interactive grid management system could lead to smaller electricity bills for consumers – they use less electricity and help alleviate the need for additional infrastructure to meet growing demand for electricity, especially at peak periods.

Demand-response technologies can help accommodate the intermittent nature of renewable resources like wind power, making it possible to more effectively manage their integration into the electric grid.

Enabling technologies:

Olympic Peninsula Project:

Automated control technology was installed to allow residential, municipal, and residential customers to reduce their electricity consumption during times of peak demand or when prices are high and demand response was automated.

Smart appliances, including thermostats, water heaters and clothing dryers that were installed in 112 residential homes.

Internet-based, event-driven software from IBM Research created virtual thermostats and water heaters that could translate between market prices and device settings, and also enabled the devices to submit market bids and react to changing prices.

Existing backup generators for commercial customers were used to displace additional demand for electricity and producer power locally the few occasions prices got above their preset tolerable limits. Interactive grid management system.

Grid Friendly Appliance Project:

The Grid Friendly Appliance Controller (GFAC) is a small electronic circuit board that detects when the electricity grid becomes stressed and could benefit from short-term load reduction (1-2 minutes).

The GFAC controller was configured to react to the alternating current (AC) frequency signals at residential wall outlets.

The GFAC was installed in 150 dryers and water heaters in homes in Yakima, Wash.; Portland, Ore.; and the Olympic Peninsula in Washington.

The dryers in the study were commercially available Sears/Kenmore units modified to include the GFAC.

Planning Tools:

Community outreach and engagement planning

Lessons learned (benefits, challenges, barriers):

Olympic Peninsula Project:

Results

The Olympic Peninsula Project demonstrated that an Internet-based network coordinating demand response can save consumers money on power, and reduce peak load on the grid by approximately 15% over the course of one year.

A significant number of customers, including residential customers, will sign up for and respond to a real-time price that varies on a five-minute interval when they are provided computer-based technology that automates their response and preserves their right to choose their preference for comfort or savings.

On average, consumers saved approximately 10% on electricity bills from the year prior.

A combination of demand response and distributed generation reduced peak distribution loads by 50% for days.

The project demonstrated that utility dispatched demand response can alleviate the need to build expensive new infrastructure to address constraints on the distribution or transmission system during times of peak demand.

The project successfully managed a “virtual” distribution line, or feeder, and an imposed feeder constraint for an entire year using these innovative technologies.

While the technologies and approach proved technically feasible, wide-scale adoption is more limited by regulations than technical limitations.

Implications

The technology used in the Olympic Peninsula Project was capable of making very short-term (approx. five-minute) adjustments in consumption where the impact of customer comfort is negligible and cost is low.

For homes being served by real-time market contracts, the automation also had to read and respond to temperatures and settings, as well as market trends and customer price-sensitivity, and be able to convert device settings to and from market bids and price signals.

Calling upon reductions in demand is much less expensive for utilities and cleaner than ramping power plants up and down to follow load fluctuations. This capability has the potential to help manage the intermittent nature of wind power, helping increase its use in the future.

If all customers were engaged in reducing peak loads at this level, peak electricity prices would be substantially reduced and construction of about $70 billion (over a 20-year period) of new generation, transmissions and distribution systems could be avoided, with the savings passed along to ratepayers.

Grid Friendly Appliance Project:

Results

It is technically feasible to use GFA controllers to manage contingencies on the grid and prevent power outages.

Consumers in the study reported they were not inconvenienced, and generally did not even notice the automatic reduction in their energy use (in hundreds of events).

Most homeowners stated they would be willing to purchase an appliance configured with such grid-responsive controls.

Implications

The GFAC acts as a “shock absorber” for the system by reducing power to dryers, refrigerators, water heaters and other home appliances in times of extreme stress on the power grid.

Up to 20 percent of the nation’s power usage could be put on hold if GFACs were installed in all compatible appliances.

Project Name: The Orkney Registered Power Zone

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Description and objectives:

- The Orkney Registered Power Zone (RPZ) involves the implementation of a commercially available Active Network Management (ANM) technology to solve thermal capacity constraints affecting the connection of additional renewable generators. Smarter Grid Solutions (SGS) and Scottish Hydro Electric Power Distribution (SHEPD) have implemented a multiple generator, multiple power flow constraint ANM scheme, SGi. The installation of SGi is one of the first commercially deployed ANM schemes in the world. SGi has allowed SHEPD to connect additional renewable generators while avoiding investment in new network infrastructure to the tune of £30 million.
- SGi became operational on Orkney in 2009. By the end of 2010, nearly 10 MW of additional renewable generation will be connected to a network that, according to the traditional approach to planning and operation, was previously considered to be full. The total installed capacity of new renewable generators is expected to increase to at least 16 MW in 2011. Also by the end of 2010 Dynamic Line Ratings (DLR) will have been implemented at one of several constraint locations on Orkney, further enhancing the access to capacity for new actively managed renewable generators. In addition, a Real-Time Ratings (RTR) solution will be implemented in parallel with DLR to demonstrate the use of weather monitoring, terrain information and thermal models of the power system to estimate ratings across wider geographic areas.
- Together, SGS and SHEPD have published several conference and journal papers reporting on the background to Orkney and the operation and performance of the ANM scheme.
- The technology implemented is not limited to situations such as that found on Orkney – SGi is being considered for implementation on a number of island, mainland, urban and rural electricity networks. The objective was always to develop an ANM solution that is widely applicable to various network types and for the connection of different types of low carbon technologies.

Enabling technologies:

- ANM algorithms for constraint resolution are implemented on off-the-shelf hardware.
- Normal voltage and current transformers are being utilised for measurements.
- Substation computing platforms and automation controllers are deployed.
- Radio and private wire communications are deployed.
- Wind turbine control systems are interfaced with to provide real power control to the ANM scheme.
- DLR devices and weather stations available on the market are being deployed.
- New algorithms for RTR estimation are being implemented on off-the-shelf hardware.
- The methodology for designing the scheme, including identifying constraint locations, and

algorithms for setting and applying curtailment thresholds are what makes ANM possible.

Planning Tools:

- A new planning tool was created to assess the technical and economic impact of ANM deployment. Generator Curtailment Analysis Tool (GenCAT) was used to model and assess the energy production and curtailment of all new renewable generator units. GenCAT results were provided to renewable generator developers to assist in project planning and the economic assessment of connection to the Orkney network through SGi.
- GenCAT was also used to perform curtailment studies for the deployment of DLR technology and the corresponding benefits in terms of uplift in capacity and reduced curtailment for actively managed generator connections.

Lessons learned (benefits, challenges, barriers)

- The SGi ANM solution can be readily implemented to permit greater connection of renewable generators to existing constrained networks, while avoiding network reinforcement.
- In most circumstances it is likely that significant new renewable generating capacity can be connected to constrained networks through SGi and experience zero or negligible curtailment.
- Communications are crucial to effective ANM scheme performance.
- Participating generators can accommodate a reasonable level of energy curtailment within existing business models without incurring excessive additional risk.
- Robust, simple approaches that provide deterministic ANM operation are necessary.
- Existing methods and standards of network planning and operation require review to incorporate ANM as a “business as usual” alternative to reinforcement.
- ANM can be a platform for further smart grid developments, such as DLR and RTR.

Project Name: Active management of distributed generators based on component thermal properties

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Description and objectives:

Bringing together an industrial research consortium comprising AREVA T&D, Durham University (UK), Imass, PB Power and Scottish Power, this project sought to explore the potential benefits arising from: (a) the improved utilisation of power system assets through the use of real time knowledge of the thermal status of the power system and (b) the development of an active controller to facilitate this exploitation and to balance those issues requiring action by operational staff and those that can be dealt with by machine intelligence.

The intended result of this work was a prototype active controller, using novel thermal state estimation and control techniques, to manage multiple wind-based generation connections to maximise annual energy export and to safeguard power system assets.

Enabling technologies:

Software:

- Web-based service oriented architecture was adopted for the control system architecture, supported by new Information and Communications Technology (ICT) infrastructure within Scottish Power's distribution network. This allowed the control system to be developed with flexibility, interoperability and scalability. A service oriented architecture is an information technology approach that makes use of services (software applications) available in a network. Each service provides specific functionality to the client (another software application). 8 'services' were developed to (i) gather electrical, meteorological and thermal information for the distribution network; (ii) store the information in databases; (iii) process the meteorological information; (iv) estimate the thermal status of the electrical power system; (v) control distributed generation power outputs; (vi) validate the new distributed generation output control signals; (vii) dispatch the signals to the distributed generation schemes; and (viii) orchestrated the other 'services' described above.
- Real-time thermal rating systems were developed to allow the exploitation of power transfer headroom made available through the population of power system thermal models with meteorological conditions. In order to reduce network instrumentation requirements, deal with communication signal losses and make real-time thermal rating systems financially viable, thermal state estimation techniques were developed, based on the Monte Carlo method. The solution developed at Durham University involved the use of data from a limited number of meteorological stations and a series of analytical models for estimating power system ratings. Estimations of conductor temperature and meteorological conditions were validated against measured data in five different locations within the field trial network.
- The wind farm output control algorithm uses techniques provided in Engineering Technical Recommendation 124 to manage the power outputs associated with a single wind farm and power flow sensitivity factors to coordinate and manage the power outputs associated with multiple wind farms. Power flow sensitivity factors are derived from a full AC load flow solution and define the mathematical relationship between changes in wind farm power outputs and changes in distribution network power flows. The control algorithm comprises: (a) An inference engine using rule-based logic to decide when wind farm control actions are required; (b) a set point calculator to compute updated wind farm set points to manage network power flows; and (c) an

on-line simulation tool to validate control actions before dispatch to the wind farms. Both the single and multiple wind farm output control techniques match wind farm outputs to the available network capacity. This increases the active energy yield of wind farms when compared to conventional disconnection methods or control in discrete intervals of the DG installed capacity (for example 66% of full output, 33% of full output, complete disconnection).

Hardware:

- FMC-Tech sensors were installed in this project capturing electrical current, line operating temperature and local meteorological data local to the overhead line conductor. This information was used to validate the real-time thermal rating algorithms developed.

- The electrical and meteorological parameters are measured locally for power system components by AREVA T&D MiCOM protection relay. This information was sent to a substation computer which estimates the real-time thermal rating of components in the network, where there are no local meteorological measurements available, and uses this information to provide wide area protection and control. The protection relays also calculate, in real-time, the thermal rating of local components and provide auxiliary functionality to disconnect wind farms in the case that wind farm outputs are not reduced on command by the main control system.

Planning Tools:

- A methodology was developed for the design of distributed generation output control systems, based on power system real-time thermal ratings. The methodology was generic and allows the knowledge gained from the project to be applied to other applications in a structured manner

- An offline planning tool was developed to aid distribution network operators with the future adoption of real-time thermal rating systems: Joint electro-thermal simulation tools were developed to model the section of the power system identified for field trials, both in terms of real-time thermal ratings and control solutions. This allowed the technical performance of the algorithms to be evaluated and the economic benefits of the algorithms to be quantified.

Lessons learned (benefits, challenges, barriers)

General benefits arising from the work:

- A comprehensive investigation of the influence of environmental conditions on power system thermal ratings was undertaken. A key finding from this research was that, due to their exposure to the environment, overhead lines have a significantly greater potential for real-time thermal rating exploitation than electric cables and power transformers

- The possibility of forecasting real-time thermal ratings was investigated. It was shown that short-term forecasts could be used effectively to develop a pro-active control system

- Presently, multiple distributed generation schemes are operated on a ‘last-in first-off’ (LIFO) basis whereby the most recent generator, historically, to connect is the first generator to be curtailed or disconnected to manage network power flows. It was shown that non-LIFO-based control strategies could lead to aggregated annual energy yield gains for multiple generators in the range 7.1% - 21.0%, depending on the thermal rating system (i.e. static, seasonal or real-time) adopted.

Consortium-specific benefits arising from the work:

- AREVA plan to commercially exploit project results through product development

- Durham University have gained an enhanced reputation through high-quality research publications, this could perpetuate to further government-sourced research funding. The project assisted in generating PhD qualifications for 3 graduates and a Professorship within the School of Engineering at Durham University, UK.

- Imass have an enhanced reputation as a result of the project and technical knowledge for future consultancy

- PB Power have an enhanced reputation as a result of the project and technical knowledge for future consultancy
- ScottishPower are looking to lead the way amongst other distribution network operators. A follow-on project has been identified which entails the use of a control system, based on real-time thermal ratings, to facilitate wind farm connections in Wales

Challenges / Barriers to the future exploitation of the control system were identified as:

- The engagement of wind farm operators to participate and invest in the closed-loop control system
- The legal implications of distribution network operators using real-time thermal ratings, rather than static thermal ratings which are presently widely accepted by the electrical industry
- The interaction of real-time thermal ratings with electrical network protection settings
- The reliability of communication signals for the control system

Project Name: FENIX (Flexible Electricity Networks to Integrate the eXpected 'energy evolution')

Project Leader :
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Description and objectives:

Levels of DER penetration in some parts of the EU are such that DER is beginning to cause operational problems (Denmark, Germany, Spain). This is because thus far the emphasis has been on connecting DER to the network rather than integrating it into overall system operation. In practice, current policy of connecting DER is generally based on 'fit and forget' approach. This policy is consistent with historic passive distribution network operation and is known to lead to inefficient and costly investment in distribution infrastructure. Moreover under passive network operation DER can only displace the energy produced by central generation but cannot displace the capacity as lack of controllability of DER implies that system control and security must continue to be provided by central generation.

In order to address this problem, DERs must takeover the responsibilities from large conventional power plants and provide flexibility and controllability necessary to support secure system operation. Although TSOs have historically been responsible for system security, integration of DER will require DSOs to develop active network management in order to participate in the provision of system security. This represents a shift from traditional central control philosophy, presently used to control typically hundreds of generators to a new distributed control paradigm applicable for operation of hundreds of thousands of generators and controllable loads.

Motivated by the wide range of challenges associated with operating the electricity system of the future, the FENIX project main objective were:

- To conceptualise, design and demonstrate a technical architecture and commercial framework that would enable DER based systems to become the solution for the future cost efficient, secure and sustainable EU electricity supply syste

Enabling technologies:

- Large Scale Virtual Power Plant (LSVPP)
- DG aggregation and dispatch
- Ancillary Services Provision
- Control (Demand and Energy Management Systems)
- Coordination among system actors (TSO, DSO, aggregator, DG)

Planning Tools:

Not used

Lessons learned (benefits, challenges, barriers)

List or discuss any lessons worth sharing from the pilot project thus far. This could be related to technical, organisation or cultural, anything that might be worthwhile sharing with the industry.

- DERs impact on the network is significant. As the share of DERs increases the need for their optimal integration increases.
- DERs and Utilities look suspiciously at each other while there are win-win situations they should be pursued.
- DER owners are a key participant and must be considered. Their participation in projects has to follow a different way of partnership and contracting.
- Visibility of DER enhance a lot the quality of the DPF and the knowledge of what happens in the network.
- FENIX has given a solution to all technical issues. Regulatory issues have been identified, but obviously exceed the project scope.
- FENIX is feasible

Added value for TSO:

- FENIX provides with the visibility and controllability of DER needed for System Operation with high integration of DER power production.
- FENIX provides DER with the opportunity to participate in services that were not affordable due to DER size and distributed nature.
- With FENIX TSOs obtain from DER similar contribution to System support as from conventional plants.
- The most remarkable features supplied by FENIX are:
    - ✓ Voltage control
    - ✓ Tertiary reserve
    - ✓ Wholesale energy markets

Impact of FENIX for the DSO

- With FENIX, the DSO knows DER production on real time and has the opportunity to validate this schedule (e.g. power injection of a certain generation can be rejected)
- This alone will improve the management, planning and operation of distribution grids, and it will allow a higher penetration of DER.
- FENIX enables DER to offer new services, some of them can benefit directly the DSO:
    - ✓ Voltage/reactive power control
    - ✓ Active power control, such as to reduce congestions
- FENIX allows the DSO to see DER as a mechanism to improve quality of service

Achievements:

- With FENIX, the DSO has the opportunity to validate DER schedule (In Spain Generation schedules are validated only by TSO, considering the Very HV network)
- For the first time a DSO has an application Voltage Var Control to optimize Distribution networks that consider DER outputs as control variables (now is non existing)
- FENIX has explored successfully the use of Back-up units to export energy into the network (now not allowed)
- **It's the first time a System Operator uses DER capacities to give system support**

Project Name: RSE Test Facility

Project Leader : Paolo Mora
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Description and objectives:

RSE's Test Facility comprises a real LV configurable distribution network with several distributed resources, connected to a Supervision & Control System (SCS), named URA.

This allows not only testing activities on single resource (generator, storage unit, load) but especially field testing of optimization procedures, centralised controller and communication solutions on a whole microgrid. Total electric power in the test facility is 350 kWh and thermal power 250 kWh.

Enabling technologies:

- Communication technologies: PLC, wireless, wired (ethernet)
- Short term forecast (load, generation)

Planning Tools:

This facility was built on succeeding stages (several years), there was not a general plannig for the entire facility but a design for each specific sub-system.

Lessons learned (benefits, challenges, barriers)

Field testing activity allowed to explore the following issues:

- Optimal dispatch of DER
- Demand Side Management
- Communication infrastructure (technologies, requirements, cybersecurity…)

Results may represent a basis for application of “active network” conceps to real networks.

Project Name: Smart House/Smart Grid

Project Leader : Anke Weidlich
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Description and objectives:

Smart House Smart Grid takes a fundamentally different innovative approach, by introducing a much more holistic concept and technology for smart houses as they are situated and intelligently managed within their broader environment. It takes smart homes and buildings seriously as proactive customers ("prosumers") that negotiate and collaborate as an intelligent network in close interaction with their external environment.

In particular, its target outcome is New and Affordable ICT for Energy-intensive Systems, specifically with a focus on innovative tools as mentioned under point: intelligent and interactive monitoring of energy production, distribution, trading and use, e.g., intelligent metering, network management, in-house consumption management.

The project activities include the testing of the new concepts in three test sites: Netherlands,Germany and Greece.

Enabling technologies:

- Communication technologies:LAN, PLC, wireless, wired (ethernet)
- Web Services
- Multi Agent Systems
- Ancillary Services Provision
- Control (Demand and Energy Management Systems)
- Coordination among system actors (TSO, DSO, aggregator, DG)

Planning Tools:

Not used

Lessons learned (benefits, challenges, barriers)

The project is ongoing.

- Consumer Management
- Distributed Control
- Impact on Distribution Loses.
- Communication infrastructure (technologies, requirements,…)

Project Name: Meltemi Test Site

Project Leader : Nikos Hatziargyriou
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website (if applicable):

Description and objectives:

"Meltemi" is a holiday camp located in "Rafina", comprising 220 cottages which are fully inhabited in the summer (from May to September) and mostly empty in winter. A 40kVA Diesel Generator, a number of PV units with total capacity of 4kWp and a 1kW Wind Turbine are installed.

The test site is used to test new technologies in:

1. DG units such as PV,Wind Turbines
2. New Decentralided control systems
3. Home management systems

Primary objective of this site is to test under real-life conditions the distributed control approach based on intelligent agents. Additionally, the ability of the agents to achieve efficient use of renewable energy sources and environmental friendly technologies, in general, is investigated.

Enabling technologies:

- Communication technologies:LAN, PLC, wireless, wired (ethernet)
- Web Services
- Multi Agent Systems
- Ancillary Services Provision
- Embedded controllers
- Demand Side Management

Planning Tools:

Not used

Lessons learned (benefits, challenges, barriers)

The Meltemi test site has been used in two EU research projects: EU-Deep and Smart House /Smart Grid.

Achievements:

- Development/testing of VPP concept
- Testing of Load Controllers
- Coordination between DGs and Consumers
- Load Curtailement/Sheddind

- Provision of ancillary services.

Project Name: More Microgrids

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Description and objectives:

Microgrids comprise Low Voltage distribution systems with distributed energy sources, storage devices and controllable loads, operated connected to the main power network or islanded, in a controlled, coordinated way. The operation of Microgrids offers distinct advantages to customers and utilities, i.e. improved energy efficiency, minimisation of overall energy consumption, reduced environmental impact, improvement of reliability and resilience, network operational benefits and more cost efficient electricity infrastructure replacement.

The project aims at the increase of penetration of microgeneration in electrical networks through the exploitation and extension of the Microgrids concept, involving the investigation of alternative microgenerator control strategies and alternative network designs, development of new tools for multi-microgrids management operation (involving Distribution Management System architectures and new software adaptation) and standardisation of technical and commercial protocols.

The following test sites have been selected for field trials:

F1. LABEIN - DER Test Facility, Bilbao, Spain

F2. CRES – Gaidouromantra, Kythnos, Greece

F3. EDP Study Case, Portugal

F4. Liander's Holiday park at Bronsbergen in Zutphen, the Netherlands

F5. MVV – Mannheim-Wallstadt, Germany

F6. RSE - DER Test Facility, Italy

F7. Agria Microgrid, F.Y.R.O.M

F8. Bornholm Island, Denmark

The field trials aimed to perform experimental validation of various actual Microgrids (rural, industrial, commercial) in different operating modes. In particular the following has been demonstrated :

- interconnected mode.
- islanded mode.
- transitions from interconnected to islanded mode and vice versa.

Centralized and de-centralized control strategies have been evaluated.
Advanced power electronic interfaces (Intelligent Load Switch and smart Battery Storage) developed within the project have been tested.

Enabling technologies:

F1. LABEIN - DER Test Facility

- Power Electronics with innovative local controls -improved stability and self islanding

- Multi-Agent Systems

- Plug & Play Technologies

- IEC 61850-7-420 Standard

- Demand Response, DER integration, Market operation

F2. CRES – Gaidouromantra, Kythnos

- Power Electronics with innovative local controls -improved stability and self islanding
- Multi-Agent Systems
- Plug & Play Technologies

- IEC 61850-7-420 Standard
- Demand Response, DER integration, Market operation
- IEC 61970

-Java based distributed control

-Embedded controller for consumer management

F3. EDP Study Case

- Micro-CHP

F4. Liander's Holiday park at Bronsbergen

Battery energy storage system with inverters

F5. MVV – Mannheim-Wallstadt

- Multi Agent Systems
- transition from grid connection to islanding mode

F6. RSE - DER Test Facility

- Power Electronics with innovative local controls -improved stability and self islanding
- CCHP Systems control
- hybrid system with PV fields and storage
- innovative battery energy storage system with inverters
- IEC 61970
- IEC 61850-7-420 Standard
- Demand Response, DER integration, Market operation
- C/C++ based distributed control

F7. F.Y.R.Of Macedonia - Agria Microgrid

- Microgrid with biogas plant

Planning Tools:

Not used

Lessons learned (benefits, challenges, barriers)

The field tests showed the technical feasibility of operating Microgrids in island mode and during transition from/to interconnected mode, the effective use of distributed intelligent control, and the effective exploitation of advanced power electronic interfaces.

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