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LESSONS LEARNED: EUROPEAN PILOT INSTALLATIONS FOR DISTRIBUTED GENERATION - AN OVERVIEW BY THE IRED CLUSTER

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SUMMARY

The target for penetration of sustainable energy generators - either based on renewable energy sources or highly efficient combined heat and power (CHP) plants - has been set for the European Union and individual Member States. The European research cluster "IRED" co-ordinates knowledge exchange between research projects that address the integration of these generators into electricity grids.

To date, there are already numerous pilot installations to test performance of generators using renewable energy sources such as photovoltaic systems or wind turbines. Further, there are many field tests for small on-site distributed generators, such as fuel cells, µ-turbines and Stirling engines. However, there are only a few pilot installations in Europe on the interaction of a high number of such distributed generators in low and medium voltage grids. Two concepts for communication between the generation units and the grid operator show promising results in the field: on the one hand virtual power plants with market based control strategies and on the other hand "Microgrids" based on intelligent agents.

This paper gives an overview of lessons learned in 20 pilot installations in Europe, which were identified in annual surveys in the context of the European research cluster "IRED". It clearly indicates the development from lessons learned with the **"connect and forget"** philosophy of individual generators towards the **"integration"** approach, i.e. the intelligent operation of a diversity of generators in the grid. After an introduction, chapter 1 gives an overview of lessons learned in six pilot installations, where small generators were "connected" to the grid. One experience is that even small generators already influence each other if a high number of them is connected into one grid segment. Chapter 2 describes key features of 14 European pilot installations in Austria, Germany, Greece, Spain and The Netherlands. It presents more details of the following sites:

- **"Am Steinweg" estate, Stutensee, Germany** (virtual power plant)
  PV, CHP, battery (Total of 160 kWp)
- **Kythnos island, Greece** (microgrid)
  PV, wind turbine, diesel-generator, battery (Total of 2,75 MWp)
- **San Agustín del Guadalix, Spain** (virtual power plant)
  PV, wind turbine, fuell cell, CHP, battery (Total of 1,67 MWp)
- **Unna, Germany** (virtual power plant) CHP (Total of 5.25 MW), wind and PV to be added

Chapter 3 summarizes briefly lessons learned in these pilot installations. Power quality of grids can be kept stable and even improved if distributed generators connected to the grid are managed properly. Information and communication technologies must cope with many different types of parameters and protocols. As one promising approach, interface boxes communicate between the generators and loads and a central dispatching unit. Socio-economic analyses in the field tests show that economics of renewable energy sources and efficient on-site generators depend e.g. on type of generator, location, legal framework in the year of installation and climatic conditions. The pilot installations show that an intelligent communication of these devices and the grid operator improve economics. Consumers co-operate with the grid operator: They adapt their loads to variable tariffs and thus improve the overall performance.

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KEYWORDS

Energy Management; Monitoring; Forecasting; Pilot Installation; Virtual Power Plant; Distribution Grid; Power Quality; Load Management; Renewable Energy; Distributed Generation; Microgrid

0. INTRODUCTION

The target for penetration of sustainable energy generators - either based on renewable energy sources or highly efficient combined heat and power (CHP) plants - has been set for the European Union and individual Member States. For an efficient evolution towards that targeted sustainable electricity supply system, it is necessary to move step by step from the ideas and concepts, developments, tests in laboratories finally to pilot installations. According to experiences with the innovation funnel, many concepts and laboratory experiments will finally result in very few pilot installations. This is why it is a European interest to exchange knowledge and co-operate well in order to develop further pilot installations efficiently.

The European research cluster on Integration of Renewable Energy Sources and Distributed Energy Resources into European Electricity Grids “IRED” enhances knowledge exchange between different national and European research projects. In the area “Pilot Installations”, every year the latest pilot installations are included with a questionnaire asking their objectives, basic technical data and experiences. Some of them are analysed in-depth in order to elaborate lessons learned and identify needs for further pilot sites. IRED is partly funded by the European Commission under Contract SES6-CT-2004-503770.

This paper gives an overview of lessons learned in 20 pilot installations in Europe, which were identified in annual surveys in the context of the European research cluster “IRED”. It clearly indicates the development from lessons learned with the **“connect and forget”** philosophy of individual generators towards the **“integration”** approach, i.e. the intelligent operation of a diversity of generators in the grid.

Chapter 1 gives an overview of lessons learned in six pilot installations, where small generators were “**connected**” to the grid. Chapter 2 describes key features of 14 European pilot installations in Austria, Germany, Greece, Spain and The Netherlands. All **integrate** renewable energy sources and distributed generators into specific grid segments as significant contribution to the local electricity supply. It presents more details of the “Am Steinweg“ estate, Kythnos island, San Agustín del Guadalix and Unna.

Chapter 3 summarizes briefly lessons learned in these pilot installations. According to the structure of the IRED research cluster, the experiences refer to “Power quality”, “Information and communication technologies” and “Socio-economic aspects”. A conclusion is given in Chapter 4.

1. CONNECT AND FORGET: LESSONS LEARNED FROM INDIVIDUAL DISTRIBUTED GENERATORS

The first part of the survey includes six pilot installations, where distributed generators were connected to the grid in order to provide energy (cf. Table 1). Their individual operation performance, life time and maintenance efforts have been major concern of the operators. The fact that most identified pilots are PV systems is representative: currently, PV systems are first mover as refers the number of individual small systems per grid segment in low voltage distribution grids. Key lessons learned with PV systems can be transferred in general to other distributed generators, even if different distributed generators have other specific characteristics and operation behaviours.

As a starting point, the IRED team collected the key characteristics of these installations and monitored energy flow and grid quality at selected feed-in points based on the monitoring concept elaborated in [5].

Table 1: Selection of six European Pilot Installations, where Renewable Energy Sources and Distributed Energy Resources were "connected" to the Electricity Grid

Pilot Installation, Project Name	**Classification / DG Components**	**Source**	**Country**
Amersfoort - Nieuwland estate	Residential / PV (1.3 MWp, divided into small units for one-family houses)	[1]	The Netherlands
Carl-Benz Stadion Mannheim	Football stadium / PV (106 kWp)	[1]	Germany
Freiburg - Schlierberg estate	Residential and commercial / PV (250 kWp, divided into 40 units)	[11]	Germany
Gelsenkirchen - Bismark estate	Residential / PV (88 kWp, divided into 1.5kW units for row houses)	[1]	Germany
Mont Cenis Academy, Herne	College / PV (1 MWp)	[1]	Germany
PEM Oberhausen	Commercial/ Total of 400 kW (Fuel Cells, µ-turbine, UPS genset)	[1]	Germany

Lessons learned:

- The distribution system operator is mostly blind as refers the current status of distributed generation. For a small number of generators, this is not critical for power quality. However, in the future, efficient remote monitoring of a large number of small distributed generation devices must be developed both for system performance and for grid quality.

- The fact that asset owners of distributed generators are often private customers requires new concepts for education and motivation, information and communication technology and contracts.

- Life times of small generators are 10-30 years, maybe less due to the fact that private owners may decide to shut their devices down for personal reasons. However, planning of central power stations and grid planning has a 40-50 years perspective. If European power supply shall partly rely on small power generators, this uncertainty for planning must be faced.

- If several generators feed into one grid segment, they influence each other´s performance due to quality limits for the distribution grid. This can be easily improved: in a first step by an adequate dialogue between grid operator and DG operator for correct grid connection, and as a second step by an intelligent interaction between loads and generators.

2. INTEGRATION OF DISTRIBUTED GENERATORS INTO DISTRIBUTION GRIDS: SITE DESCRIPTIONS

2.1 Overview

An extract of the IRED survey of pilot installations 2005 is shown in Table 2 [11]. It gives an overview of pilot installations where the integration of distributed generation into distribution grids has been monitored and improved by new developments in information and communication technologies. Most of them apply newly developed energy management systems or agent based technologies in order to improve power quality and economic operation.

2.2 "Am Steinweg" Estate/ DISPOWER

The "Am Steinweg" estate with 400 inhabitants is classified as a typical residential grid segment: residential loads and small distributed generators are integrated into a low voltage (LV) grid which is connected to one transformer. The LV network at the location Stutensee has a ring structure and it is operated in closed configuration. Three main distributed generators for a total capacity of 68,8 kWp are connected to it: a combined heat and power plant (28 kW_{el}), several Photovoltaic installations with a total nominal power of 35 kW_p and a lead acid battery system (880 Ah) with a bi-directional inverter. The DISPOWER project team integrated already existing on-site distributed generators and additional components into a virtual power plant with the newly developed power flow and power quality management system "PoMS" [8].

In this estate, the main added value of PoMS for the energy supplier has been shaving peak loads and avoiding high tariff electricity consumption in the estate. Of particular interest is the proven capability of zero electricity flow at the transformer for several hours in the day. This shows, that regarding the energy flow, the estate could be operated in islanding mode for a certain period of time.

In addition, PoMS can control the battery as additional load. This is an advantage for the operators of the PV systems in the estate, because it avoids that the allowed voltage band is exceeded in case the PV plant provides a high energy yield on sunny days with little load. The development and implementation of PoMS was partly funded by the European Commission (project DISPOWER, ENK5-CT-2001-00522).

2.3 Kythnos/ MICROGRIDS

The Kythnos Microgrid is a 1-phase network composed of overhead power lines and a communication cable running in parallel. It is electrifying 12 houses in a small valley in Kythnos, an island in the cluster of Cyclades situated in the middle of the Aegean Sea. The grid and safety specifications for the house connections respect the technical solutions of the local electricity utility. The settlement is situated about 4 kilometres away from the closest pole of the medium voltage line of the island, it is therefore expensive to connect.

The system is composed of 10kWp of Photovoltaics divided in smaller sub-systems, a battery bank of nominal capacity 53kWh and a diesel Genset with a nominal output of 5kVA. A second PV system with about 2 kWp mounted on the roof of the control house is connected to a Sunny-island inverter and a 32kWh battery bank. This second system provides the power for the monitoring and communication needs of the systems. The PV modules are integrated as canopies to various houses of the settlements. The installation of the grid and the systems was performed in the framework of two EU projects (PV-MODE, JOR3-CT98-0244 and MORE, JOR3CT98-0215).

Table 2: Overview of 14 European Pilot Installations, where Renewable Energy Sources and Distributed Energy Resources have been **"integrated"** into the Electricity Grid

Pilot Installation / Project Name / Project URL	**Classification/** DG components (electric)/ **Energy Management**	**Country**
Am Steinweg estate [7] / DISPOWER www.dispower.org	**Residential /** 35 kWp PV, 28 kW CHP, 100 kWh Battery/ **PoMS**	Germany
Bad Schönborn [1] / EDISon	**Commercial, Hot Springs /** 250 kWel Fuel Cell, CHP/ **DEMS**	Germany
DEMOTEC [12]/ DINAR/ www.iset.uni-kassel.de	**Private Household/** PV, residential loads/ **BEMI**	Germany
Energiepark Clausthal [11]/ www.cutec.de/ energiepark.php	**Commercial, Industrial/** 55 kWel and 20 kWel CHP, 80 kW wind turbine, 8 kWp PV, 30 kW hydro, 10 kWel Stirling Engine	Germany
Jühnde [11]/ www.bioenergiedorf.info	**Residential** / Biogas-CHP	Germany
Hofer [11]	**Residential, Skiing Area** / 600 kWel CHP, 4.6 kWel Fuel Cell	Austria
Energy Park KonWerl 2010 [3]/ www.konwerl.de	**Commercial, Residential, Industrial** / 488 kWel biomass CHP, 12 kWp PV, 1.8 MW wind/ **DEMS**	Germany
Kythnos I [1]	**Residential, Holiday resort** / 2.75 MW wind, PV, genset, battery / **Island operation**	Greece
Kythnos II [2]/ MICROGRIDS/ Microgrids.power.ece.ntua.gr	**Residential, Holiday resort /** 12 kWp PV, 85 kWh batteries/ **MICROGRID**	Greece
Muehlbach & Hollersbach [11]	**Residential, Skiing Area** / 5 MW & 1.25 MW Hydro power plant	Austria
Power Matcher [10]/ CRISP/ www.powermatcher.net	**Residential** / Wind, CHP, emergency generator/ **Power Matcher**	The Nether- lands
San Agustín del Guadalix [4]/ DISPOWER/ www.dispower.org	**Residential, Commercial, Rural/** 1.67 MW total of PV, wind turbine and diesel / **PoMS**	Spain
Supply Centre East [1]/ DISPOWER/ www.dispower.org	**Commercial /** 5 kW CHP, 100 kWh Battery / **PoMS**	Germany
Unna [9]	**Urban** / 5.25 MW Co-generation, 100 kW wind , 400 kWh battery, PV, Micro turbine/ **MAXIMUS-EMS**	Germany
Virtual FC Power Plant [1]	**European "hot spots" /** Several 4.6 kW fuel cells	Germany
Virtuelles Kraftwerk Rheinland Pfalz	**Commercial /** Several CHP plants	Germany

2.3 San Agustín del Guadalix / DISPOWER

The San Agustin test site (DG installed capacity of 1,67 MWp) can be classified as both residential and commercial. It establishes at the same time a "real life electricity grid", providing energy to a number of loads in buildings, and on the other hand is an experimental grid, allowing installation and re-configuration of a number of distributed components which allows the control and monitoring of grid states with different power generating units (PV, wind turbine and diesel). The grid is also equipped with facilities for energy storage. On site there is a large fuel cell system, which is not a controllable device so far. This low voltage grid is supplied through one transformer. Strong variation of the available generation and load parameter conditions, which can cause problems in the grid, can be created. A continuous monitoring of the grid is made through the power quality measurement devices, the communication infrastructure (Ethernet network) and a central data acquisition system. This installation deals with a high penetration of distributed generation in a weak grid, which reflects the typical scenario for the future installation of embedded generators in most of Europe.

In the test site of San Agustín de Guadalix all the necessary infrastructure to the management, control and monitoring of the distribution network with the newly developed power flow and power quality management system "PoMS" has been installed successfully. The team developed a specific solution which has been able to adapt to the predefined topology of network. At the facility of San Agustín del Guadalix, there is a wide variety of grid devices. It has been necessary to develop the infrastructure for PoMS in function of every one, mixing a great amount of signals, communication protocols and technologies, interfaces. At this site, the energy management system now allows the measurement of power quality and energy flows for different grid configurations with a varying penetration of distributed generators, storage systems and loads. This can be actively used to stabilize voltage levels e.g. in weak grids or grids with a high share of distributed generation. The development and implementation of PoMS was partly funded by the European Commission (project DISPOWER, ENK5-CT-2001-00522).

2.4 Unna, Germany

The "virtual power station" in the city of Unna in Germany has been created to interconnect and optimize several combined heat and power plants in order to improve the economic results of these environmentally friendly power generation plants.

Control of four existing plants (CHP I – IV) and one new plant (CHP V) has been interconnected. Taking wind energy, micro turbine and photovoltaic plants into account which will also join the network, the virtual power plant is expected to deliver an annual output of roughly 26 million kWh electricity and 49 million kWh heat. The electrical output per unit is between 100 kW and 3 MW.

The result of this interconnection was an optimised control of the schedule management of the electrical supply. The deployment of this project was funded by the government of North Rhine Westphalia (Germany) in combination with the European Commission.

3. LESSONS LEARNED: REAL IMPACT OF ENERGY MANAGEMENT IN DISTRIBUTION GRIDS

3.1 Power Quality

For the **distribution system operator**, generation and load are time critical parameters for power quality and must be treated jointly. The pilot installations have shown that a high share of distributed generation can be integrated into low voltage grid segments given that the components communicate. In the pilot installations, it was further verified that distributed generation can contribute to improvements in power quality and provide benefits to overall system performance if operated and managed properly.

However, if power supply shall rely on distributed generators on a large scale in the future, their performance, especially as to down-times (due to service, maintenance, faults etc.) must improve. So far, many of the small generators are an "optional" device, i.e. their continuous availability and operation is not necessary for the secure energy supply in general. The current service and maintenance structure is carried out by few experts rather than widely spread.

The field tests successfully applied two concepts for energy management: centrally dispatched by the distribution system operator or decentralized by the consumer.

Pilot installations showed that microgrids based on decentralized agent technologies act like an aggregated load at the transformer and can provide services to the grid.

3.2 Information and Communication Technology

Complexity of different individual components makes interfaces between components and a central control unit necessary. In pilot installations, diverse distributed generation devices have been adapted and supplemented in order to communicate with each other or with a central control unit. Newly developed interface boxes are an adequate solution for allowing standard communication of many different distributed generators and loads which are already on the market.

In general, there are two concepts for energy management in the grid: one concept is based on market principles, e.g. the energy management system acts based on market information, such as price signals. Pilot installations include market based virtual power plants with a central control unit dispatching generators and loads as well as decentralized control units, where each market player can decide individually upon price information whether to offer energy to the market or to use energy [12]. The second approach is the introduction of agents, e.g. in the CRISP project [10].

The energy park KonWerl uses a market based approach with its energy management system DEMS. In the market based virtual power station Unna, the distribution system operator implemented MAXIMUS-EMS [12] in order to improve the economic operation while providing benefits for the environment. In the DISPOWER project, virtual power plants have been established based on the power flow and power management system PoMS [8].

As an outlook, within the MORE MICROGRIDS EU project, the Kythnos Microgrid will be used to test centralized and decentralized (agent based) control strategies in islanded mode and to test communication protocols. In the new control strategies, advanced load management concepts will be realized. A new monitoring system will be installed providing remote connection to the control house via cellular phone, in order to check the state of the operation and be able to transfer data and files.

3.3 Socio-Economic Aspects

In order to analyse impacts of distributed generation on the stakeholders in the energy market systematically, [13] provides a methodology. Part of it could be applied when evaluating results of the pilot installations for energy supplier, distribution system operator, operator of distributed generators, and consumer.

Several pilots have proven the cost reduction potential for the **energy supplier** if energy management systems are in use. E.g. in Unna, KonWerl, Am Steinweg estate and in San Agustín, cost has been saved after implementation of energy management systems.

Consumer response has been successful in this estate: 22 families living in the “Am Steinweg” estate co-operated in the demand side management experiment “Washing with the Sun”: SMS controlled washing in order to privilege PV energy consumption [6]. In a follow-up experiment, one family now adapts its load to variable tariffs.

4. CONCLUSION

The survey of European pilot installations within the IRED research cluster provides an overview of current developments for integrating renewable energy sources and distributed energy resources into electricity grids. The tendency in research to move from the "connect and forget" philosophy towards "integration" of distributed components is clearly visible.

First results are promising: new developments in information and communication technology as well as new power electronics are technological drivers for an efficient interaction of a diversity of generators and loads with the distribution system operator. Legal framework conditions are crucial to path the way for market penetration of these technologies.

Results of ongoing pilot installations will be included continuously in the IRED survey.

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