Case Studies on the Integration of Renewable Energy Sources into Power Systems

R. Belhomme and P. Bousseau / EDF(France), E. Navarro / IBERDROLA (Spain),
A. Badelin and T. Degner / ISET (Germany), G. Arnold / University Kassel (Germany),
A. Berenguer and I. Chocarro / EHN (Spain), C. Materazzi-Wagner/ Verbundplan (Austria), S. White/Econnect (UK), N. Hatziargyriou / ICCS (Greece), S. Tselepis and Aristomenis Neris / CRES (Greece), D. Lefebvre / Aerowatt-Vergnet (France)

1 Introduction

In the context of the DISPOWER European project, case studies have been carried out on the integration of Distributed Generation (DG) and Renewable Energy Sources (RES) into power systems. The main objectives were :

- to apply the tools and concepts developed in the DISPOWER project on national, regional or local power systems in different European countries and to assess their performance,
- to demonstrate the implementation of DG and RES technology both on interconnected grids and on island power systems,
- to contribute to the dissemination and exploitation of the results of DISPOWER.

Eleven case studies have thus been done ([1, 2]): 5 case studies on interconnected grids in Germany, France, Spain and Austria, and 6 case studies on weak grids and island power systems in the United Kingdom, Greece, and the French Caribbean. A summary of the work done and of the main results obtained is given in this paper.

2 Wind generation on the German interconnected grid

In Germany at the end of 2004, more than 16,200 Wind Turbines generated approximately 25,000 GWh with an installed capacity of approximately 16,500 MW, which is almost 15 % of the peak load. Wind power now provides a noticeable share of the electricity generation in Germany. Thus, wind becomes a significant component in electricity supply and in the process of balancing consumer demand with power generation. Moreover, in the grid areas of the German transmission system operators E.ON Netz and Vattenfall Europe Transmission GmbH wind power generation temporarily exceeds the electricity consumption.

A reliable operation of a power system requires an accurate prediction of demand and a thorough planning of its coverage by available resources. Conventional power generating units (coal fired, gas fired, nuclear, hydro, gas turbines, etc.) are scheduled to operate at any time in a certain power mode with respect to technical constraints and economic considerations. The stability of power systems during contingencies, such as unexpected increase of load or an outage of a power system component, is ensured by power reserves.

The rising amount of uncontrollable and fluctuating power production from renewable energy sources, especially from wind power, increases uncertainty in the systems and makes the reserves to grow to cope with a new type of contingencies. In order to reduce these reserves but at the same time to guarantee the reliability of power supply, the wind power generation has been known in advance and included into the system planning.

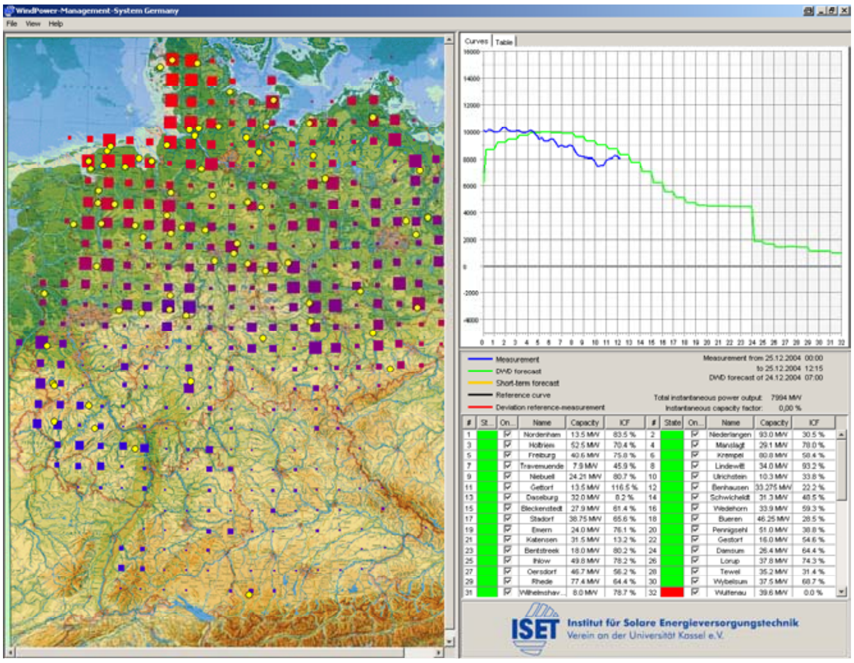

Figure 1: Graphical User Interface of the Wind Power Management System

A well-established and scientific analysis of the time series of wind power as well as the accurate determination of the current and expected wind power lead to an improved integration of distributed wind generation into the electrical power system and reduce CO2 emissions sustainable. In the frame of the DISPOWER project, ISET has further developed a wind power control centre to support large-scale wind power integration into the electrical energy supply system - the Wind Power Management System (WPMS). The WPMS provides assessment of the real-time wind power generation as well as its prediction up to 72 hours ahead for wind farms, network regions, control areas or country-wide. The further development of the WPMS and its application to the German interconnected grid was the subject of the first case study.

3 Advanced Grid Control Unit for DG Integration into the German grid

The second case study was devoted to a new web based SCADA system for the online monitoring and control of RES and DG on the interconnected grid in Germany : the Advanced Grid Control Unit (AGCU).

DG and RES (e.g. Wind Turbine Generators - WTGs) are very often situated in remote places covering a wide geographical area. Due to this they are sometimes difficult to access or even not accessible for service personnel for periods ranging from some hours up to a couple of weeks (offshore wind farms). However, in order to get efficient and profitable renewable energy feed-in or to use them for grid stabilising measures close monitoring and control of large DG “farms” and large single DG units is essential.

The present trend in industrial monitoring and control are web-based monitoring and controlling systems as they are easily available and economical to use. But the most important advantage for the use of web-based systems is the possibility to supervise and control the plants from anywhere at anytime via Internet. This was the main reason to develop and test the “Advanced Grid Control Unit (AGCU)” within the DISPOWER project. The AGCU is a web-based PLC system with a common software and hardware platform, so that not only Wind Turbines but also other Distributed Generation Plants can be monitored and controlled via the same system.

Figure 2 shows the main page of the AGCU website. The first prototype of this web-based SCADA-system for DG is installed at Friedland-Deiderode in Germany. As can be seen in Figure 3, it consists of one Main DG-Farm server and multiple, (widely) dispersed plant controllers, installed at each DG-plant and connected to the farm server via suitable communication technologies (e.g. industrial fieldbus syst.). Modular PLC devices (WAGO I/O System 750) with Ethernet fieldbus port are used as plant controllers. These devices are offering a lot of features for web based applications such as built-in web-server (HTTP), built-in file system (FTP), Real Time Clock and other services. The new software algorithms at the PLC devices for grid control are developed with CoDeSys according to IEC 61131-3. As DG-Farm server one industrial PC with Windows XP is used, the websites are programmed with PHP, the historical database is based on MySQL and the dynamic diagrams are generated with JPGraph.

Figure 2: Mainpage of the AGCU Website

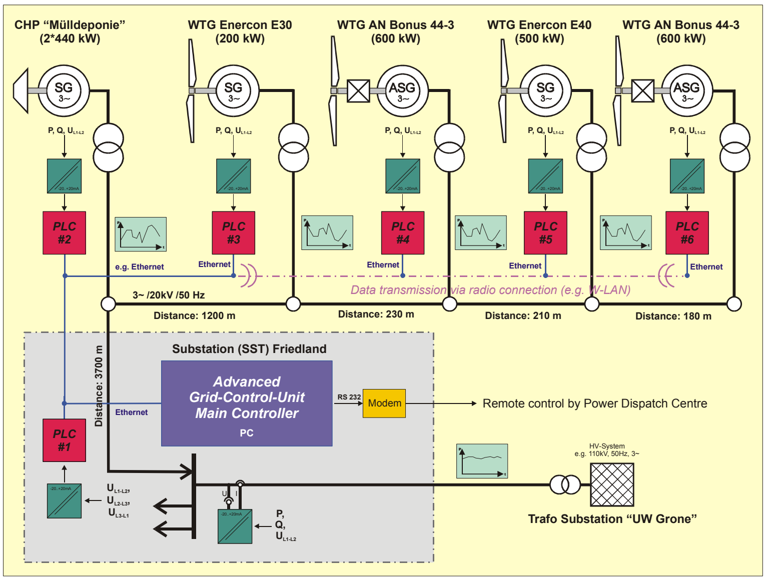

Figure 3: Structure of the AGCU prototype in Deiderode

The first experiences and operational results with the new installed AGCU-prototype in Deiderode are positive, because it is working satisfactorily and it is possible to monitor and to control the operation of the DG-Farm from remote places via Dial-Up Modem or broadband Internet (DSL) connection.

For a safe, economic and automatic operation of renewable energy sources and DG plants it is essential to have the possibility to exchange information with this devices from anywhere at any time. The new developed Advanced Grid Control Unit (AGCU) gives not only grid operators but also manufacturers, service teams and operators of DG-Farms the possibility to monitor, maintain and control the DG-Farms from anywhere at anytime in order to optimise the DG-Farm operation according to the grid requirements or economical reasons.

4 Wind generation on the French interconnected grid

In the third case study, high wind power penetration levels are considered on the French interconnected grid and the impact is studied in terms of the dynamic behaviour in case of large disturbances on the grid (short-circuits and losses of generation).

France, through the new energy policy law, confirms its objective to increase from 15% to 21% the share of renewable energy sources in the electricity produced in 2010. Hence, in the framework of the DISPOWER European project, three scenarios were defined for wind power development in France in order to study the impact of a large scale penetration of wind energy :

- **moderate scenario**: from 2 GW in 2010 to 8 GW in 2020 (wind power penetration between 4.5% and 22% of the estimated total French generation at minimum load);
- **sustained scenario**: from 6 GW in 2010 to 15 GW in 2020 (wind power penetration between 10% and 32%);
- **voluntary scenario**: from 10 GW in 2010 to 22 GW in 2020 (wind power penetration between 15% and 40%).

NB: These scenarios were established by EDF R&D for the purpose of the study and should not be considered as elements of EDF's strategy in this field.

Depending on the wind power development scenario taken into account, minimum required grid reinforcements have been taken into account. They are limited for an installed wind power lower than 10 GW (only one new 400 kV line) but important for a wind power from 15 GW to 22 GW (with between 5 to 8 new 400 kV lines needed). However, these reinforcements have been determined using the basic knowledge of the network and detailed grid development studies would be required.

Dynamic simulations have been performed with the EUROSTAG software with a detailed model of the French grid and a simplified model of the European network. Different types of wind turbines technologies have been considered and different events including 400 kV and 225 kV three-phase short-circuits have been simulated.

The results show that:

- in the worst case (Figure 4), up to 1/6th of France may temporarily have a voltage lower than 0.85 pu and 1/8th of France a voltage lower than 0.75 pu.
- for scenarios with wind turbine technologies without voltage regulation, less than 3400 MW are affected (voltage lower than 0.75 pu temporarily) over a total installed wind power lower than 10 GW, between 5 and 6 GW are affected over a total wind power of 15 or 16 GW, and 10 GW over a total wind power of 22 GW.
- Wind power technologies with voltage regulation enable to decrease efficiently the wind power affected by voltage dips so that less than 3000 MW can be affected.

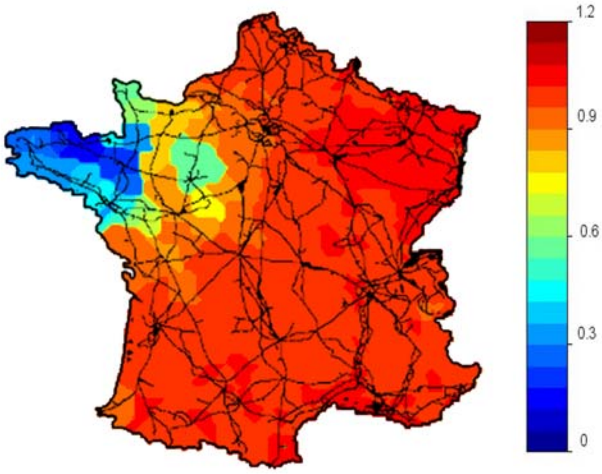

Figure 4: Maximum span and magnitude of the voltage dip in per unit

However, the wind power actually disconnected depends not only on the amount of wind power affected (voltage lower than 0.75 pu temporarily) but also on the voltage protection scheme. For instance, with a voltage protection scheme close to the one currently asked by E.ON and for the voluntary scenario in 2010, the actually disconnected wind power is at most 840 MW whereas 3100 MW of wind power is affected. This amount depends on the wind power technology modelled in the study. Recent wind turbine technologies present a good behaviour in case of voltage dips and the simulations show that with a technology with full power electronics converters and voltage control, no disconnection is observed for this case.

Recent wind turbine technologies generally have (possibly with slight modifications) the required reactive power and voltage control capabilities as well as an adapted protection system with Fault Ride Through (FRT) capabilities. With such technologies the impact of a large scale integration of wind power in France should be limited. In particular the study shows that the risk of loosing more than 3000 MW of wind power can be avoided.

The transmission and distribution grid connection requirements specified in the grid codes have thus to ensure that the wind farms will have the appropriate control and FRT capabilities. Then the impact of a large scale integration of wind power in France will be more to be considered from the point of view of the required reinforcements, and the load follow capacity than the risk of loosing more than 3000 MW (This loss of 3000 MW of generation is the reference event of the UCTE that has been used to determine the primary reserve on the UCTE network).

5 Distributed generation in Spain

Navarra is one of the Spanish pioneer regions on RES&DG technology with more than 800 MW of wind power installed capacity, more than 150 of minihydro and over 500 of small photovoltaic units. In 2004 electricity generated from RES technologies reached the 70% of the demand.

EHN, company born and based in Navarra, is one of the companies that has lead this trend. On the hand, Iberdrola is one of the biggest utilities in Spain and is the second energy distributor in Spain with Iberdrola Distribución. Both companies have joined in the DISPOWER project to perform a case study of the Navarra's interconnected grid with a high RES penetration. An overview of the results are given in [1].

The first part of the study gives an overview of the Spanish electric energy business, and a review of the actual and future legislation for RES and DG generators, the so-called "Special Regime generators". The Spanish electric business has suffered a major overturning with the market liberalisation started in 1997. RES penetration is still far from EU objectives but has been a growing sector especially with the wind generation boom that started in the late 90's. Today more than 9000MW of wind power is installed in Spain and government plans give a 20000MW of installed capacity for year 2010. This increasing wind energy penetration has grown concerns for Transmission and Distribution system operators on how this will affect the grids they operate and maintain. For this reason a correct and optimum RES&DG technologies interconnection legislation is needed. In the study the actual practices and legislation improvement prospects are explained.

The second part focuses on the situation of RES in Navarra, from the generation and kWh demand numbers down to the description of the technologies used: wind, mini-hydro, photovoltaïcs, biomass, sun-thermal, bio-fuel and others. A study of how Iberdrola's distribution grid has changed with this new installed capacity and a load -flow study of the grid for different future scenarios have been done. Future prospects, trends and guidelines are given at the light of the current situation and the aforementioned studies.

Finally the capacity of the RES technologies to provide ancillary services to the network is discussed. The study is focused on reactive power control by wind farms, explaining and documenting the work done to date by EHN on implementing such a capability for their wind farms. The reactive power control is still under test but tests have shown the feasibility and security of this practice. Further work is being done by EHN with Ingeteam Scada and control manufacturer and Ingetur wind turbine manufacturer to achieve this innovative control capability that will ease the integration of non-dispatchable wind farms in the power systems. Other ancillary services such as impact on stability and power quality are discussed as well.

6 Distributed generation from renewables in Austria

This Austrian case study consists of two parts :

- The “Alpine Valley” case study, where the real electricity supply system of a sparsely populated valley with high grid costs and high potential for distributed generation is investigated concerning the planning and implementation of additional distributed generation plants by using a combination of software tools.
- A “National Wind Power” case study, which investigates the possibilities to integrate up to 1 GW of wind in north eastern Austria in the existing power supply system (with all substantial storage plants located in the south west and a weak transmission system), while maintaining a high level of supply security and low energy supply costs.

The selected alpine valley in the Salzburg region features some small hydro power plants, but no noteworthy other DG so far. The valley is supplied by a long MV feeder with some LV distribution networks along.

The focal points of the investigation are the different options for DG additions and the best combination with storage possibilities and grid control techniques for covering the demand of remote alpine valleys. Standard planning tools need adaptation or combination with other software and criteria must be defined for the purpose of developing regional energy strategies.

The current status is described with GIS applications comprising topographic, climate, infrastructure, network and population data. The potentials are calculated separately for different energy sources, starting with small hydro and further on wind, biomass and PV, depending on the quality of the available regional data for GIS. Combined with load flow data from the network calculation software this reveals the feasible sites for further DG plants. The equalisation of the daily sum profiles for generation and demand (calculated out of standardised customer group load profiles, regional demographic and trade data), adjusted by the actual measured power values, provides an indication for the need of storage devices and/or load management. The economic check of the potential generation sites is done with UNIDO's calculation software, to assure also the financial feasibility of these technical feasible sites.

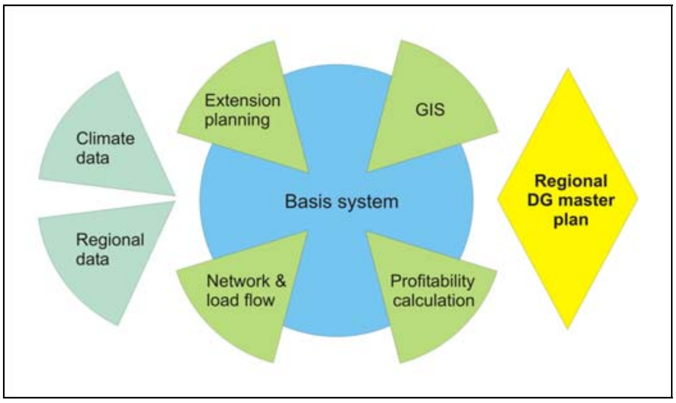

Figure 5: Scheme of the planning tools (Green colours indicate input, yellow indicates output)

The aim of the "Alpine Valley" case study is not only to analyse the situation and to elaborate several scenarios for the selected region, but to develop a versatile planning tool for the design of DG networks.

7 Increased wind energy penetration on weak networks in rural northern England

In the following 3 case studies, the use of load control is investigated for 3 different applications in the UK, namely:

- to enable increased wind energy penetration on weak networks in Section 7,
- to contribute to system frequency control on an island power system in Section 8,
- to assess the viability of islanded operation of a wind farm in Section 9.

In many rural areas that are ideal for wind energy generators the distribution network is weak. This limits the amount of wind energy that can be connected to the network due to problems such as steady state voltage rise. Load management has the potential to enable increased amounts of wind generation to be connected onto a weak distribution network.

Econnect used computer simulations to investigate the load management technique to mitigate voltage rise for a weak network in the North East of England. This technique has the potential to substantially increase the practicable wind energy resource of the European Union. The load control strategies for grid-connected systems developed in the DISPOWER project were applied in this study.

The area of grid used in the study covered a wide and sparsely populated rural region to the west of Newcastle upon Tyne. The primary substation at Hexham was supplied by 66kV circuits. From these, a series of 20kV feeders supplied outlying villages and rural dwellings in the South West of Northumberland.

First, voltage rise was investigated on the network as a result of wind generation, with no load control. Studies indicated that, without any load control, the network could accommodate a 300kW wind turbine without experiencing any voltage rise problems.

If load management is used to control 50% of the total loads on the network, as in the second case study, then the maximum size of wind turbine which the network could accommodate without experiencing any voltage rise problems is about 1.5MW.

If a more realistic 20% of total loads are controlled by a load management system then, as shown in the third case study, the network could accommodate a 900kW wind turbine without experiencing any voltage rise problems.

The results of the study show that if the amount of loads controlled by the load management system is increased, then the maximum size of wind turbines that can be installed on the network will be increased. They have also shown that load control is an effective strategy for mitigating voltage rise on weak rural networks, in order to facilitate connection of an increased capacity of renewable generation.

8 Diesel / hydro generation on the Scottish Island of Rum

The power system on the Island of Rum provides power to a community of residents on the island. During times of abundant rainfall the community is powered entirely by renewable energy from a hydro power scheme. Initial site work had shown that load management schemes could improve the availability of the power system. A detailed investigation on site was then carried out.

A torque based model was used to represent the power system on Rum, which incorporated the existing controller. The model was then amended to investigate new control concepts for the power system using Distributed Intelligent Load Controllers. Modelling results showed that the Distributed Intelligent Load Controllers were able to control system frequency within acceptable limits, although the frequency control was not as refined as with the existing controller.

An extensive programme of site testing was carried out using Distributed Intelligent Load Controllers. The Distributed Intelligent Load Controllers were used to replace the existing controller, and were installed at one site.

It appeared that changes in load, resulting from load switching by the Distributed Intelligent Load Controllers, caused larger changes in voltage than had been anticipated from the model. This behaviour was attributed to the binary arrangement of the loads. On this site the smallest load was 250W and the largest load was 7500W. As the loads were very different sizes from each other different load controller switching actions had very different effects on the power system frequency and voltage. As a result of the site tests, further work is to be carried out to develop a Distributed Intelligent Load Control system for binary loads.

9 Islanded operation of a wind farm in the UK

Safe and stable operation of embedded generation in islanded mode under network fault conditions could offer significant benefits in improving security of supply to customers, especially in remote rural areas. The aim of the work carried out by Econnect was to apply techniques developed in DISPOWER to assess the viability and options for control of a wind farm during islanded operation due to network faults.

A wind farm with 300kW pitch regulated turbines on the Harbour wall at Blyth in Northumberland was selected as a suitable site to demonstrate islanded operation.

Firstly, a design of a synchronous compensator system was undertaken for the site. The main technical operating requirements for such a islanded electrical system are to maintain a continuous supply with voltage and frequency within required limits, operate generating equipment safely and within its limitations, ensure adequate protection against failures within the system and maximise use of the available wind power. A solution was developed to achieve these requirements and to demonstrate the viability of operating such an islanded system. Additional equipment to provide frequency and voltage control of the islanded grid was also specified.

A computer model was developed and simulations were carried out over a range of operating conditions. Overall, the simulation results were encouraging, and gave confidence that the system design would perform satisfactorily when implemented. The results also highlighted areas for investigation during wind turbine testing.

A demonstration synchronous compensator and load control solution was then designed. Equipment was purchased, assembled, installed and commissioned on site. Testing of islanded operation and data collection was carried out during June 2004. The islanded network was entirely composed of test equipment, i.e. no actual consumers were included in the test network. The wind turbine was disconnected from the main grid for the entire period of the testing. The results demonstrated that voltage and frequency on the islanded network could be controlled within acceptable limits when the network was powered only by the wind, although turbine start up was difficult due to automatic shut down of the turbine when experiencing excessive rotor speeds.

Further modelling to investigate the problems of turbine start up indicated that the majority of the power drain on the system during the start was due to the starting resistors. The resistors reduced the instantaneous current demand of the system, but greatly increased the real power demand placed on the backup power source. The model suggested that complete removal of the starting resistors would be likely to result in a smaller underfrequency but a larger voltage drop. The risk associated with such a starting strategy might be that in high winds there would be insufficient voltage at the moment of wind turbine generator connection to "pull in" the wind turbine rotor and prevent an overspeed.

10 Concepts for high penetration of renewable energies on Greek Islands

In this case study, the application of the MORE CARE advanced control software on the economic and secure operation of island systems has been studied. More specifically, the impact of economic scheduling, forecasting and on-line dynamic security assessment functions has been evaluated on two characteristic cases with increased RES penetration, namely the islands of Crete and Kythnos.

Crete is the largest isolated network in Greece with a thermal power installed capacity of 690MW (steam turbines, diesel units and gas turbines and one combined cycle unit). The installed capacity of Wind Turbines at the end of 2003 was 81.19MW. Wind supplies in average 10% of the annual energy.

The MORE CARE software has been applied on actual hourly load and wind time series and the simulated performance has been compared to the actual operation of the system. The results have shown that improvement in wind power forecasting, resulting in

20% (MAPE) forecasting errors (Figure 6), would result in operating cost reductions of 8.5% compared to the actual operation due to a decrease in spinning reserves.

The financial benefits obtained by the Economic Scheduling functions were calculated for the period from August 2001 to February 2002. It was shown that the average relative gain during August 2001, peak month of the year, would be 3.1%, while for lower demand periods cost reduction reached 6%. The economic dispatch functions were similarly evaluated, showing average relative gains of 1.7% during the peak demand month and of 2.7% maximum during lower demand periods.

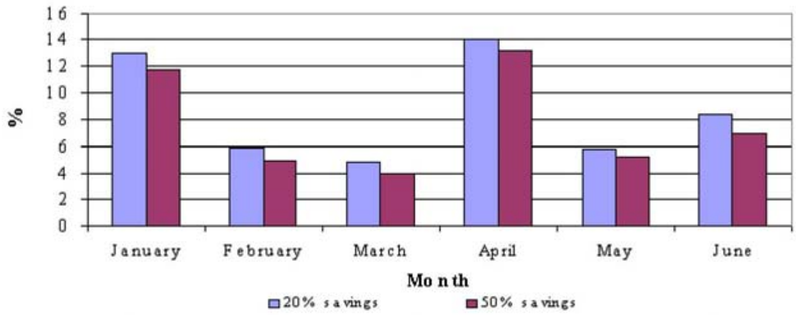

Figure 6: Savings due to improved prediction tools

The evaluation of the on-line dynamic security assessment functions for pre-selected disturbances has shown by simulation over 95% success in assessing insecure operating points regarding frequency excursions. In actual operation the dynamic security functions assessed successfully the potentially insecure operation of the power system on the 25th October 2001, day of a blackout, although its cause was not included in the pre-selected disturbances.

MORE CARE software was also used off-line for the evaluation of the impact of wind power on the economic operation of island power systems. The actual cost of the fuel consumed for the operation of the system in 2000 (including the compensation of the wind power producers) was compared to the cost obtained, if the same load would be covered by the thermal units alone. The monthly cost savings vary from –100 to 600k€, depending on fuel costs variations, units availability, load variations, wind power and its correlation with load, etc. In total, annual savings of 1.45% were obtained amounting to a total cost of 2.6M€.

Kythnos is a small island of 2000 inhabitants with where power is produced by 5 diesel units of 400 kW each, one 500 kW Wind turbine and 5 wind turbines of 33 kW. There are also a PV of 100kW and a battery of 500kW/400 kWh. The annual RES penetration is 11%, for more than 1000 hours per year RES power penetration exceeds 40% and for less than 50 hours operation is based solely on RES.

Application of the MORE CARE functions has shown that improved RES and Load Forecasting would reduce annual operating cost up to 2.63%. The application of the Economic Dispatch functions would also decrease annual operating cost by 0.8%.

The impact of energy storage on system operation has been evaluated. The economic scheduling functions of MORE CARE were applied in two cases: a) thermal spinning reserve to cover trip of one diesel unit, and b) same as case a, but taking into account battery storage. The analysis has shown that operation with energy storage reduces operating cost by 2.16%, while in the actual operation there are 2.72% hourly insecure (inadequate) operating points, even considering the available battery. In general, storage minimizes inadequate operating points, reducing them to zero, when taken into account within the MORE CARE scheduling functions. This level of adequacy cannot be achieved even with the commitment of one additional diesel unit (while operating cost is increased by 11.8% compared to b).

The case studies have shown that advanced control tools, like the MORE CARE software can reduce operating costs of island systems operating with increased RES penetration and can provide significant aid to the operators by forecasting load and wind and by timely informing them about potentially insecure operating schedules. Such tools can be also used effectively to study the effects of RES and storage devices on island system operation.

11 Interconnection of Solar Powered Mini-Grids to the main grid on the island of Kythnos

The introduction of a substantial penetration of RES in the power mix of the Greek islands is of great importance since island grids operate as autonomous power systems and are mainly supplied by diesel generators consuming imported fuel. This dramatically increases the energy cost and the pollution in environmentally sensitive areas. Although the wind and solar potential in these areas is excellent a number of technical issues pose a barrier. The implementation of a hybrid system with battery storage and an intelligent management system in Kythnos island, has been proved to be an effective solution to this problem. The interconnection issues are examined for a number of aspects involving the increased penetration of RES in the island grid, such as: voltage profile, active and reactive power flows, thermal (current) loading on circuit elements, transient stability (maintenance of synchronism), voltage stability and reactive power control, frequency control, …

The examination of the steady state situation of the actual Kythnos island grid was studied as a number of PV systems and wind turbines are connected to the island grid at various points. For the system analysis, a software tool developed in the Information Division of CRES has been used. This tool is basically a GIS application that uses an interface with PSSE® software in order to carry out load-flow analysis. The load flow studies for the examined scenarios show that the voltage increase on the Kythnos grid, due to injection of active power in light load conditions, is well within the limits posed by the European standard EN50160. Under heavy load conditions the injection of active power from RES improves the voltage profile. Additionally, the calculated thermal loading of the lines is well within limits.

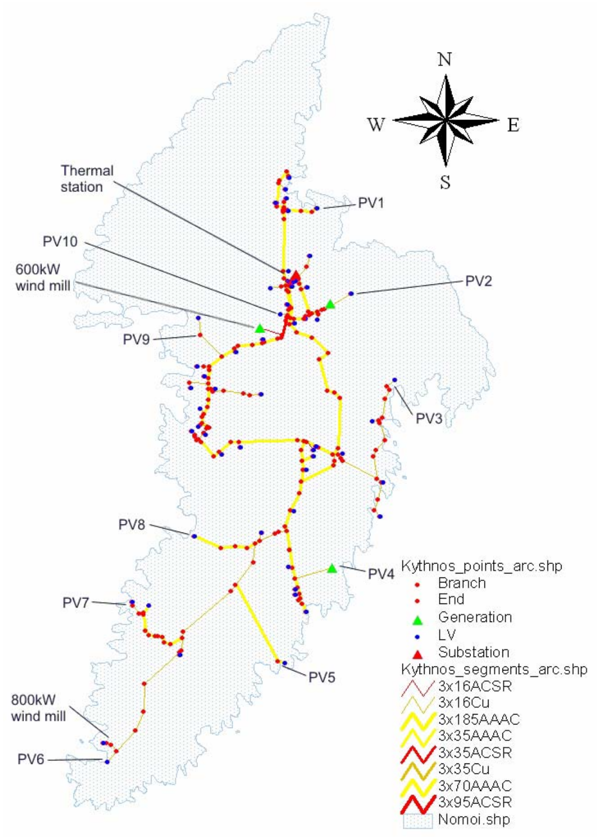

Figure 7: Kythnos Island power system

For the examination of the grid dynamic behavior, a model of the Kythnos power system was developed in the Simulink® environment, using the Power System Blockset ® library. This model utilizes a simplified representation of the grid including only the main nodes, a model of the local power station with the diesel generators and models for the RES (wind turbine and PV systems) as well as for a battery storage inverter. In order to evaluate the system dynamic behavior, two types of disturbances were examined :

- a three-phase short circuit, with different clearing times, applied in a specific node, away from the local power station,
- disconnection of the wind turbine when it is producing maximum power (e.g. due to the activation of the wind turbine protection system because of a high-wind condition).

Simulation results show that the power system, for the examined conditions, presents a stable behavior, as long as an adequate spinning reserve exists. Due to the high cost of the energy produced by the diesel generators it is highly desirable to achieve a reduction of this reserve without sacrificing the safety of the power system operation. Two solutions to this problem were examined.

The first solution is related to the use of PV power electronic inverters with disturbance ride-through capability. Today these grid interfaces are disconnected quickly when a voltage disturbance takes place in order to avoid islanding situations and for self protection. Reconnection takes place several minutes later. Disturbance ride-through capability means, among other things, that the grid interface should stay connected during the disturbance or it should be reconnected quickly after the disturbance. This latter option of rapid reconnection for disturbance ride-through has been simulated and the results indicated that, in this way, it should be possible to operate the power system with a lower spinning reserve without any safety risk.

The second solution is related to the use of battery storage that will replace the spinning reserve provided by the diesel generators. A model of a shelf-commutated battery inverter based on IGBTs with the capability to assist the voltage control of the system was introduced in the Kythnos power system model. Simulation results show that, because of the fast response capability of the battery inverter, the frequency dynamic response of the power system is considerably improved, and in addition there is better fuel utilization for the diesel generators.

12 Renewable energies in the Guadeloupe power system

This case study concerns the grid connection of a wind farms on “Les Saintes” islands, which are part of Guadeloupe archipelago, West Indies. This case is representative of DG connected to small island grid or “end of grid”.

Les Saintes is a group of small islands connected to the main island of Guadeloupe by a 20 kVac 16 km long sea-cable and a 63 kV/20 kV substation on the Guadeloupe island.

The existing grid of Les Saintes and a 2MW wind farm made of 8 wind turbines with induction generators have been modelled and load flow calculations have been performed to identify grid connection problems for various load conditions: load level, wind speed, grid short-circuit power, etc. The main problems identified are voltage rise and high flicker level. The results have been compared to Distribution Network Operator requirements in France, Germany, Spain and Crete.

Existing solutions to improve wind energy penetration on Les Saintes have been studied, using the new control and safety concepts developed in DISPOWER. The following aspects have been considered: voltage rise and deviations, flicker, DG coupling / decoupling, fault ride through capability, short-circuits. In particular, new design and control techniques have been applied in order to decrease the out of limit voltage and flicker level on the island MV and LV grid and the impact of various wind turbine technologies (induction/synchronous machines, fixed/variable speed, reactive compensation...) has been evaluated.

The possible contribution of GIS tools has also been studied. GIS could be used:

- to better understand the grid behaviour and to study various load development or DG impact scenarios in order to define the best options,
- to locate and monitor disseminated DG systems, as individual PV cells,
- to devise a complete decision tool, interfaced with a Network Management System.

In case the sub-sea cable is lost, the wind farm remains connected to an islanded grid fed by a 1.6 MW backup diesel plant. The wind farm must be operated differently, following different constraints and requirements. The islanded operation of the system after the loss of the main cable is then studied, considering:

- parallel operation of the diesel units and the wind farm,
- solutions to allow a high penetration without sub-sea cable, eventually with a reduction of grid quality during limited periods.

13 Conclusions

In this paper, eleven case studies done in the context of the DISPOWER European project were presented. The main objectives were to apply the tools and concepts developed in the DISPOWER project and to demonstrate the implementation of DG and RES technologies on different European national, regional or local grids.

Mainly four types of studies were carried out. The first type dealt with the development, implementation and/or assessment of monitoring and control systems:

- a wind power control centre, the “Wind Power Management System” (WPMS) designed to support large-scale wind power integration into the German electrical energy supply system,

- a new web based SCADA system, the “Advanced Grid Control Unit” (AGCU), for the online monitoring and control of “farms” of RES and DG units on German interconnected grids,
- the MORE CARE control software developed in previous European projects: it was applied on two Greek island power systems with high RES penetration, Crete and Kythnos, and the benefits of its functions were evaluated.

The second type of studies focused on the impact of increased DG and RES penetration levels, the identification of the resulting problems and constraints, and the analysis of possible solutions. Both large interconnected grids and islands power systems were considered :

- the case study on the French interconnected grid has shown the importance of the reactive power and voltage control capabilities of wind farms, as well as of the Fault Ride Through capability, to limit the impact of large scale penetration of wind power;
- future prospects and guidelines were given for RES on the interconnected grid of Navarra in Spain, and the capability of RES to provide ancillary services to the network were investigated, in particular for wind farms;
- grid connection issues for increased RES penetration were examined for different aspects such as voltage profile, flicker levels, stability, etc. on the two island power systems of Kythnos (Greece) and Les Saintes (French Caribbean). Different solutions to the problems identified have been studied : battery storage, use of the power electronic inverters of the RES units, new design and control techniques, improved RES technologies, in particular for wind turbine technologies, …

In the third type of case studies, the use of load management was investigated and tested for 3 different applications in the UK :

- A load management technique has proved to be an efficient strategy to mitigate voltage rise on a rural weak network in the North East of England in order to facilitate connection of increased capacity of wind generation.
- The use of Distributed Intelligent Load Controllers (DILC) was investigated to control system frequency on the Scottish Island of Rum.
- A solution based on load control combined with a synchronous compensator was designed for the islanded operation of a wind farm and testing was carried out on a islanded network entirely composed of test equipment.

Finally, tools and approaches for planning of networks with DG and RES were also examined, in particular :

- in the Austrian case study which dealt with the planning and implementation of additional DG plants and RES at the regional and national levels, the objective was not only to analyse the situation and elaborate scenarios but also to develop a versatile planning tool for the design of net works with DG and RES;

- in the les Saintes case study, the use of GIS tools to devise a complete decision tool was also considered.

14 Acknowledgement and disclaimer

The work presented in this paper was performed in the framework of the DISPOWER European project (Contract No. ENK5-CT-2001-00522) and was therefore supported in part by the European Commission. DISPOWER is a project of the 5th Framework Programme, contributing to the implementation of the Key Action 5 "Cleaner energy system, including renewables" within the thematic programme "Energy, Environment and Sustainable Development".

The members of the DISPOWER consortium are solely responsible for this work, it does not represent the opinion of the European Community and the European Community is not responsible for any use that might be made of data appearing therein.

15 Authors' contact information

R. Belhomme and P. Bousseau
Electricité de France, S.A.,
EDF R&D , 1 Avenue du Général de Gaulle, 92141 CLAMART CEDEX, FRANCE
Tel.: +33 147 65 38 60, +33 147 65 38 18, Fax : +33 147 65 32 18
e-mail : regine.belhomme@edf.fr, pierre.bousseau@edf.fr

E. Navarro
Iberdrola Distribution Electrica, S.A.
Avda. San Adrián, 48, 48003 BILBAO, SPAIN,
Tel.: +34 94 466 55 26, Fax +34 94 466 36 30
e-mail: enavarroa@iberdrola.es

A. Badelin and T. Degner
Institut für Solare Energieversorgungstechnik e. V.
Königstor 59, D-34119 KASSEL, GERMANY
Tel.: +49 561 7294 361, +49 561 7294 232, Fax: +49 561 7294 260, +49 561 7294 200
e-mail: abadelin@iset.uni-kassel.de , tdegner@iset.uni-kassel.de

G. Arnold
Universitaet Kassel
Wilhelmshoeher Allee 71-73, D - 34121 KASSEL / GERMANY
Tel.: +49 561 804 6512, Fax: +49 561 804 6521
e-mail: garnold@iset.uni-kassel.de

A. Berenguer and I. Chocarro
Corporación Energia Hidroeléctrica de Navarra, S.A.
Calle Ciudadela nº 5, 31002 PAMPLONA, SPAIN
Tel: (+034) 948 220747, Fax.: (+034) 948203599, -590
e-mail: aberenguer@ehn.es, ichocarro@ehn.es

C. Materazzi-Wagner
Verbundplan GmbH
Laaer-Berg-Strasse 43, A - 1100 VIENNA, AUSTRIA
Tel.: +43 1 53113 54864, Fax: +43 1 53113 54649
e-mail: christine.materazzi@verbundplan.at

S. White/Econnect (UK),
Econnect Limited
Energy House, 19 Haugh Lane Indust. Est., HEXHAM, Northumberland, NE46 3PU, UK
Tel.: +44 (0) 1434 613600, Fax: +44 (0) 1434 609080
e-mail: Sara.White@econnect.co.uk

N. Hatziargyriou
National Technical University of Athens,
9, Heroon Polytechniou str., 157 73 Zografou, ATHENS, GREECE
Tel.: +30210-7723661, Fax: +30210-7723659
e-mail: nh@power.ece.ntua.gr

S. Tselepis and Aristomenis Neris / CRES (Greece),
Center for Renewable Energy Sources
19th km Marathonos Ave., Pikermi, 19009, ATHENS, GREECE
Tel. +30 210 6603369, Fax +30 210 6603318
e-mail: stselep@cres.gr , mneris@cres.gr

D. Lefebvre
AEROWATT
6 Rue Henri Dunant, 45140 INGRE, France
Tel. : 02 38 88 14 31
e-mail: d.lefebvre@vergnet.fr

16 References

[1] DISPOWER – Deliverable Report, “Distributed generation in European interconnected grids”, October 2005.

[2] DISPOWER – Deliverable Report, “Distributed generation on European islands and weak grids”, October 2005.