A common integrated ICT platform to implement Europe's Smart Grid

Highlights of the EU Smart Grids project INTEGRAL

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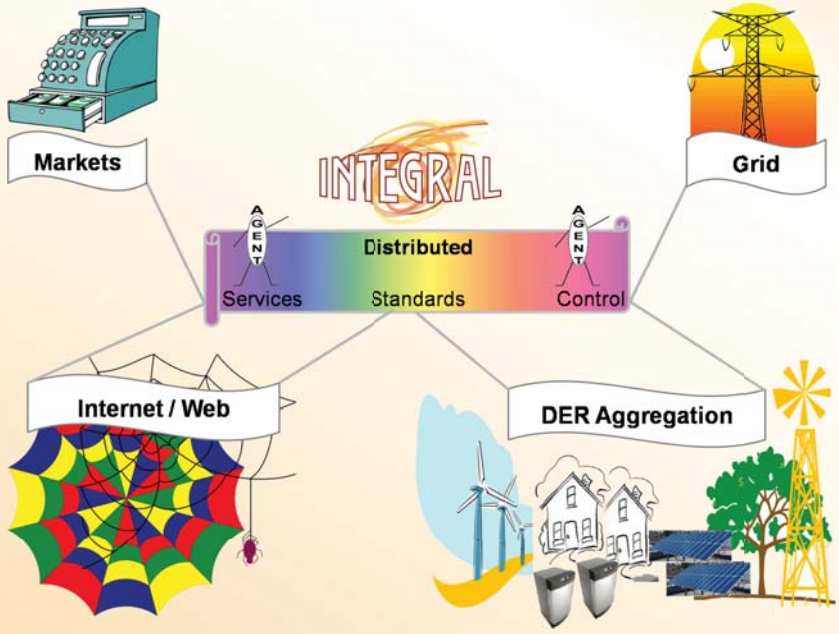
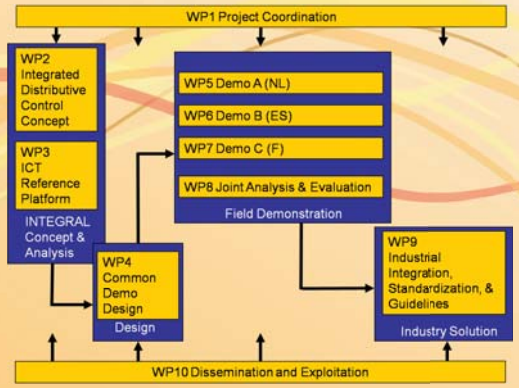
Being smart and sustainable is the key to the future power networks of Europe. Being a Smart Grid means to be able to integrate and manage large numbers of distributed energy resources (DER) in real time.
Renewable energy sources such as PV, wind, CHP and µ-CHP, as well as electrical cars and smart appliances in homes and offices - they all contribute as components of a Smart Grid. The dynamic coordination of active distribution networks, energy trading markets, and active loads of end customers: that's what makes a grid into a Smart Grid.



To implement the future Smart Grids of Europe, information and communication technologies (ICT) play a crucial role. How to achieve this is the contribution of the EU project INTEGRAL. It has built and demonstrated a reference solution for the aggregation, distributed control and optimal coordination of distributed energy resources.

INTEGRAL has shown the practical validity of its Smart Grids ICT solutions by three field demonstrations in different countries - the Netherlands, Spain and France - that together cover the full range of operating conditions: normal, critical, and emergency conditions.

INTEGRAL, an EU project co-funded by the European Commission (No. FP6-038576), with partners from the Netherlands, France, Greece, Spain and Sweden, started late 2007 and finished in March 2011. Highlights and final results are summarized in this brochure.



ICT Smart Grid solutions tested in the field

Highlights of the EU Smart Grids project INTEGRAL: the PowerMatcher field results

Distributed coordination by PowerMatcher agents

The INTEGRAL project provided a learning cycle for ECN for the application of Smart Grid technology in real field test environments such as the PowerMatching City Hoogkerk pilot in the Netherlands. The structured approach followed in INTEGRAL allowed for a conclusive proof-of-feasibility for the PowerMatcher technology developed for agent-based distributed intelligent control of Smart Grids.

The INTEGRAL project has shown that this multi-agent technology can be successfully applied to handle a number of very diverse Smart Grid use cases serving several different stakeholders. We are now able to combine advanced ICT technologies ranging from the millisecond to the minutes level in the grid within a *one-solution* framework.

The INTEGRAL project produced the PowerMatcher Agent core 3.0 and gave a broad exposure to ECN regarding deployment and exploitation of Smart Grid technology in 'living laboratory' environments.

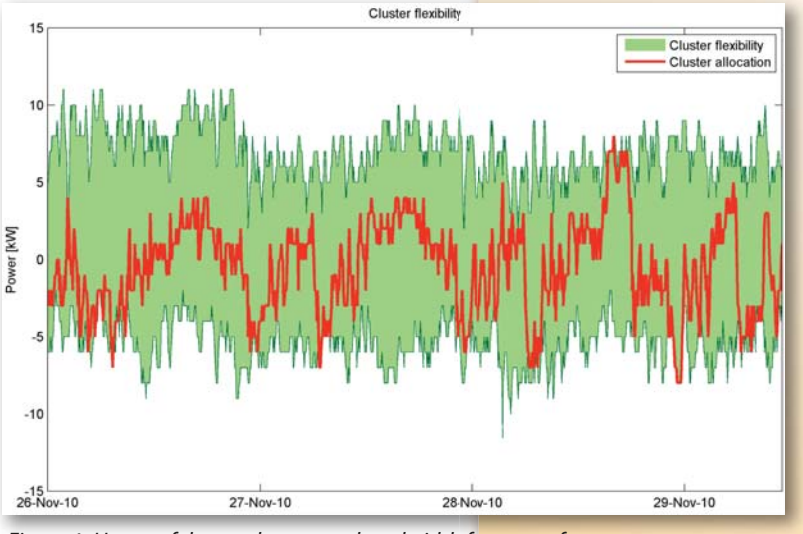


Figure 1: Usage of demand response bandwidth from comfort management systems

Hoogkerk field experiment results

An example of the creation of demand response power bandwidth by heating systems is shown in Figure 1. Due to the thermal latency of buildings and the extra heat storage capacity added to the comfort management systems, a very useful demand response resource is created. The green area indicates the bandwidth limits the PowerMatcher can use. The red line shows the actual power allocated as it came out of the agent negotiation process with agents seeking commercial optimisation. In the Netherlands, the amount of energy involved in heating homes is eight times larger than consumed in the form of electricity. Hence, a very significant amount of demand response at the per kWh cost of water storage is uncovered in this way.

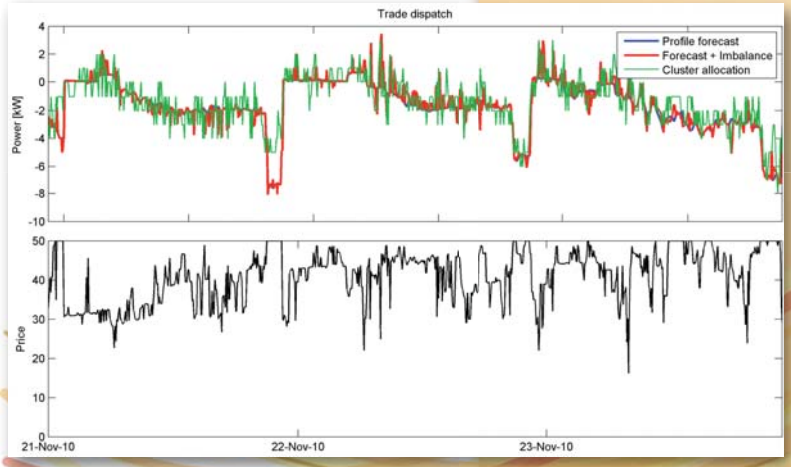


Figure 2: Automatic profile following of the PowerMatcher cluster

Flexibility and scalability achieved

Figure 2 shows the malleability of the Virtual Power Plant (VPP) cluster used in our Netherlands field test by a commercial trade dispatcher. The trade dispatcher desired electricity profile was derived from the heat demand for the cluster from the forecast of the next day temperature. The profile was further adapted to account for ramp-up/ramp-down compensation of large installations in the portfolio of the trader. Without risking desired comfort deviations for the home owners, by a simple auctioneering process yielding a time-varying price, as shown in the lower part of Figure 2, it appeared to be possible to coordinate supply and demand in the VPP cluster.

The World's First Full-Blown Live Smart Grids Demonstration

Highlights of the EU Smart Grids project INTEGRAL: Hoogkerk PowerMatching City

KEMA

Established in 1927, KEMA is an independent knowledge leader and a global provider of high-level services to the energy value chain, including business & technical consultancy, operational support, measurements & inspection, and testing & certification. KEMA provides impartial advice and support to the producers, suppliers and end users of electricity, gas and heat, as well as to governmental bodies. In addition, the company also certifies products, systems and individuals for a wide range of clients.

Smart Grids

With the large-scale introduction of renewables and further electrification of the society the current energy system will change dramatically in the coming decades. In order to be prepared for this future KEMA initiated together with Humiq, ECN and Essent PowerMatching City Hoogkerk. PowerMatching City is the Netherlands Demo from the INTEGRAL EU project, investigating Smart Grids management under normal operating conditions.

PowerMatching City Hoogkerk, the INTEGRAL field demo in the Netherlands, received national tv attention, as these stills show from the Dutch tv evening news on 10 March 2010.

PowerMatching City

Where initially PowerMatching City was set up as a virtual power plant with a large number of decentralized power generators, eventually it grew to the first fully functional smart grid living lab. Apart from the decentralized generators, in the form of micro combined heat and power and PV panels, steerable loads were included with hybrid heat pumps, electric vehicles and smart appliances. What makes PowerMatching City special is the integrated market model that enables simultaneous optimization for the stakes of the utility, the network operator and the end-user. The results from the INTEGRAL project learn that all optimization goals can be achieved.

The design, implementation, roll-out and analysis of the results of PowerMatching City learned many valuable lessons. Field tests, like in INTEGRAL, are essential in the development of the energy system of the future. This is the reason that the consortium of PowerMatching City agreed on continuing the project in a second phase, where the infrastructure is used and expanded in order to extend the knowledge and experience on smart energy systems.

Public and media attention

The project received major (inter)national attention, ranging from utilities to governmental bodies. Numerous visitors have visited PowerMatching City and learned about the implementation of smart grids. Those interested in learning more on PowerMatching City are very welcome to visit the demo center at the laboratory of KEMA in Groningen!

System Integration for Smart Power Grids

Highlights of the EU Smart Grids project INTEGRAL: Hoogkerk Demo system software

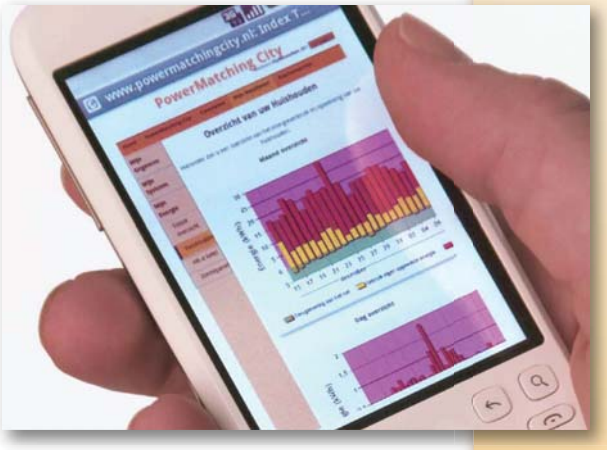
HUMIQ

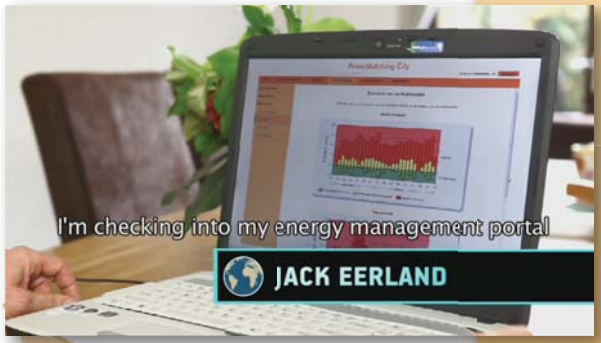
HUMIQ is one of the largest independent Dutch software developers. HUMIQ is listed on the Amsterdam stock exchange. Founded in 1978 under the name ICT Automatisering, we now offer advanced solutions in the area of process automation, product development and advanced Web portals. We serve customers in the sectors industrial manufacturing, energy & utilities, logistics, communication & multimedia, defence, healthcare and traffic & automotive.

The transition to a more sustainable energy provision requires changes in the current energy system. Making distribution grids more intelligent by turning it into Smart Grids will play an essential role to embed intermittent sources like wind and sun. Smart Grids make it possible to match the supply and demand of electricity in the most efficient way.

A Smart Grid is the place where electricity and information technology come together. This makes a Smart Grid also a perfect platform to enable new services that can add value to the stakeholders in the energy supply chain, like for example reduction of imbalance and remote asset management. That is why HUMIQ sees a lot of opportunities for Smart Grids, and we want to be a key player in this area. This is the main reason for HUMIQ to invest in Smart Grids and to participate in projects such as INTEGRAL.

Customer interface of the mobile and Web portals, as built by Humiq for the PowerMatching City Hoogkerk smart grid demonstrator in the Netherlands





PowerMatching City Hoogkerk

The main contribution of HUMIQ within the INTEGRAL project has been in developing needed software for the Demonstrator in the Netherlands, PowerMatching City Hoogkerk. HUMIQ fulfils the role of system integrator, taking care of the complete information and communication infrastructure. This includes remote reading of smart meters, controlling the distributed energy generators and consumers, controlling the charging process of electric cars, collecting all data in central databases and the creation of Web and mobile portals for different stakeholders.

Flawless operation

PowerMatching City Hoogkerk turned into the first large-scale implementation of an autonomous Smart Grid in Europe. We are very proud that we achieved this together with the partners Kema, ECN and Essent. The role of HUMIQ was essential. The infrastructure designed and implemented by HUMIQ connects all the parts that make up the Smart Grid and makes it possible that the Smart Grid works as intended.

HUMIQ gained a lot of experience through participating in the project and it gave us the opportunity to show our knowledge, experience and quality. The designed system operated flawlessly for more than one year already.

It is the goal of HUMIQ to extend that knowledge and experience and put it to practice in more Smart Grid type projects. HUMIQ wants to become a key integrator in the Smart Grid field. We will achieve this by working closely together with other partners like Kema, ECN and Essent, participating in follow-up projects (like PowerMatching City II) and participating in programs such as the "Smart Energy Collective".

Dealing with Critical Conditions in the Smart Grid

Highlights of the EU Smart Grids project INTEGRAL: the Mas Roig Field Demonstration

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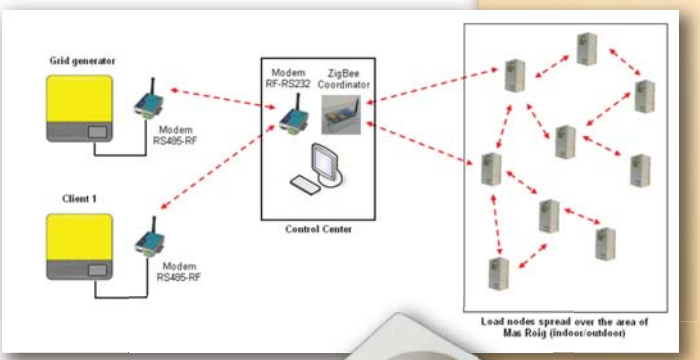
Critical grid conditions

CRIC has acted as the coordinator of the INTEGRAL Field Demo at Mas Roig, an estate about 10 km from Girona, Spain. This Demonstrator aimed to provide solutions under critical operation conditions for the Smart Power Grid. An integrated ICT platform has been built in order to improve the microgrid design and performance in realistic critical situations that the Smart Grid will encounter.

In the demo, Smart Grid critical conditions have been reproduced for an energy production or consumption random situation and also for critical meteorological conditions or potential grid cut-offs. In order to guarantee the right performance and stability of the microgrid under critical conditions a new intelligent Demand Management System has been designed, developed and tested at Mas Roig by CRIC, Wattpic and NTUA.

Architectural view on the Mas Roig Smart Grid critical-conditions demo.



The Mas Roig Zigbee nodes.

ZigBee

This Demand Management System is able to anticipate and predict potential critical situations and, subsequently, make the proper decisions such as, for instance, connecting emergency generators or battery pack or cutting off non-priority loads, and it does so in a fast and reliable way while taking into account user-defined constraints.

CRIC has developed the distributed wireless data acquisition and control network that feeds the demand-management software application with the data necessary for decision making processes and executing the required actions. This data-and-control network is the interface of the Demand Management System with the physical world. For the most part, it consists of devices called meter nodes, which sense diverse electrical parameters from the grid at those points where electrical loads are connected and breaks its connection if necessary according to Smart Grid system decisions. The communications amongst the meter nodes relies on the ZigBee protocol, a high level communication protocol using small and low-power digital radio based on the IEEE 802.15.4 standard.

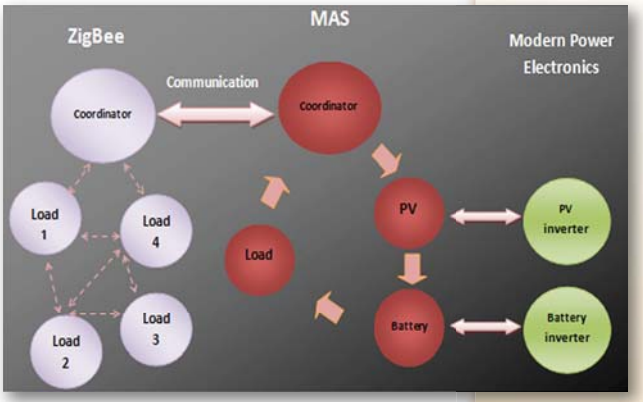
Lessons from Mas Roig

The Mas Roig Demo of the INTEGRAL project has proven that incorporating an ICT-based intelligent automatic Demand Management System in a microgrid results in improved stability when the Smart Grid is subject to critical conditions. We have achieved the creation of an energy-efficient Smart Grid solution that increases the satisfaction of the microgrid's users. This approach establishes a promising way to the introduction of new energy management systems at the local level that will extend the acceptance of microgids as a primary source of electrical energy for households, as a vital component of the European Smart Grid of the future.

Agents to control the Smart Microgrid

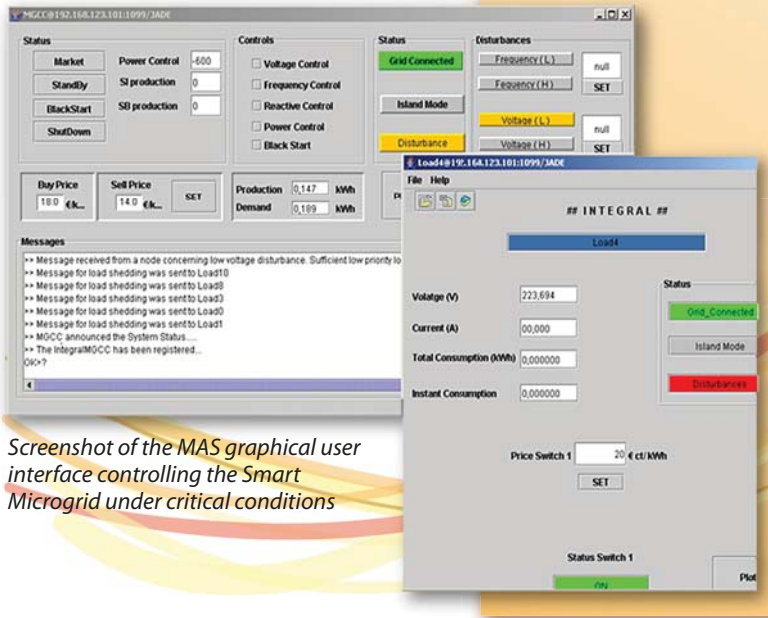
Highlights of the EU Smart Grids project INTEGRAL: MAS-based control under critical conditions

ICCS-NTUA



ICT-enabled Multi-Agent System architecture used in the Mas Roig field demonstration in Spain

The origin of the Microgrid idea



Screenshot of the MAS graphical user interface controlling the Smart Microgrid under critical conditions

ICCS/NTUA

The participation of ICCS/NTUA in the INTEGRAL project has focused on the development of a Multi-Agent System (MAS) for the smart operation of controlled parts of grid, called Microgrids, to support the grid under critical conditions while minimizing the end-user's discomfort. The developed MAS was evaluated within the framework of the Mas Roig Spanish Demonstration Site. The field test results prove that the cooperation of multiple local distributed energy resources (batteries, photovoltaics, wind turbines and controllable loads) can handle critical states of the system, such as large disturbances or voltage support.

Multi-agent software based control

The concept of Multi-Agent based control is quite popular nowadays for application in power systems focusing especially on the consumer and Renewable Energy Sources (RES) management. All approaches adopt the concept that the entity agent controls a consumer load, a DG (distributed generation) device or any given client appliance or device, and tries to achieve a goal such as optimizing an objective function. In this schema some general role-based agents are also included that represent the retail company, the DNO or any other actor in the system. A key issue that should be highlighted in this research is designing the control and coordination algorithms in a decentralized environment.

Smart Grid MAS

The MAS architecture allows for the cooperation of the developed MAS with different ICT technologies and power electronics creating an integrated platform that enables the operation of Microgrids under normal or critical situations. This design caters for the adaptability and the extensibility of the system.

A Graphical Interface has been developed in the INTEGRAL project that provides users with an overview of the operation of the system, and that informs them about the consumption of each controllable load and the production of the distributed generators. Monitoring the system enables the users to manage their consumption by adjusting the operation of the controllable loads through the graphical interface. Moreover, the interface informs the user when a grid disturbance has occurred and in addition it indicates

Smart Grid Protection and Control under Emergency Conditions

Highlights of the EU Smart Grids project INTEGRAL: Self-Healing of Smart Grids

The self-healing concept in Smart Grids

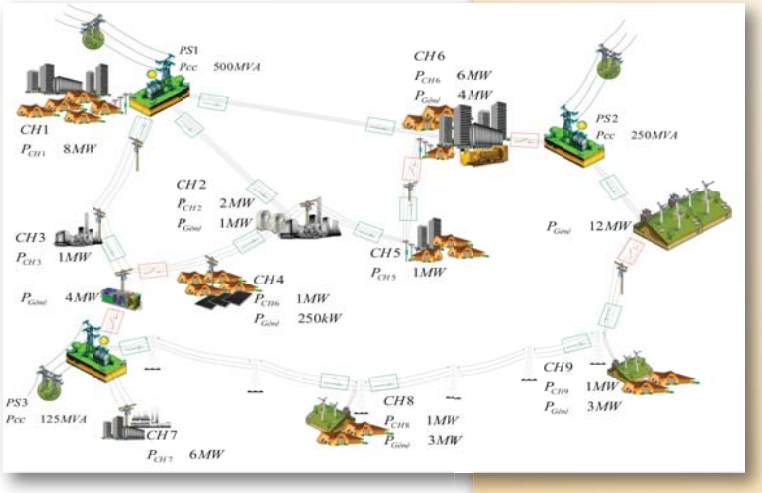
France has been the host of the INTEGRAL field demonstration focused on emergency operating conditions, showing self-healing capabilities of DER/RES aggregations. The aim of this demo was to provide solutions to reduce outage time and operation costs, due to a fault occurrence within the network, by applying the concept of self-healing approaches (SHA).

In general, SHA is expected to include the three following high-level functions:

- fault distance computation,
- fault location and isolation by combination of fault indicators (FI) states with fault distance computation,
- fault isolation and service restoration.

In order to precisely determine the faulty section, a novel approach that combines FI states with fault distance computation has been developed.

Topology of the real French EDF distribution feeders from three different substations (PS)



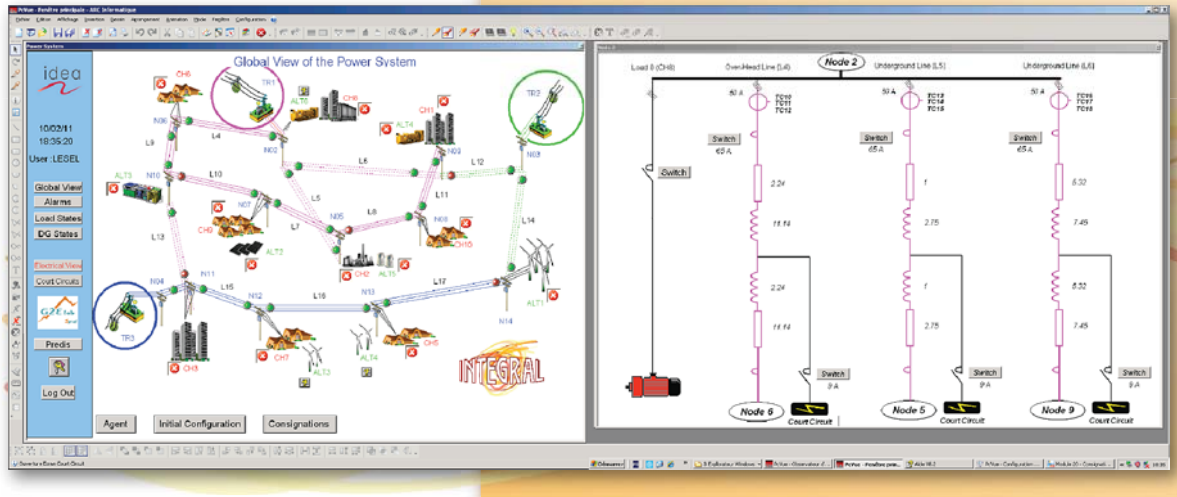
Dealing with real-life networks

In order to represent the behaviour of the real network during a fault and to satisfy economical conditions, a test bench network of 30kVA, 0.4kV was constructed (power ratio 1:1000 and voltage ratio 1:50). It includes 18 lines, 14 nodes, 9 loads, 5 sources. This analogical emulation allows testing real Remote Terminal Units fed by real fault currents and voltages.

Software and systems to find and correct faults

The fault passage indicators (FIs) are key elements of our architecture. They are micro-processor based measurement devices, including various interface units to communicate with both the SCADA and the local agent. They are real RTUs from Schneider Electric Telecontrol.

Developed SCADA interface to emulate the DNO actor



A real Supervisory Control and Data Acquisition (SCADA) has been developed (through the PCVue software) to validate Agent-SCADA interactions.

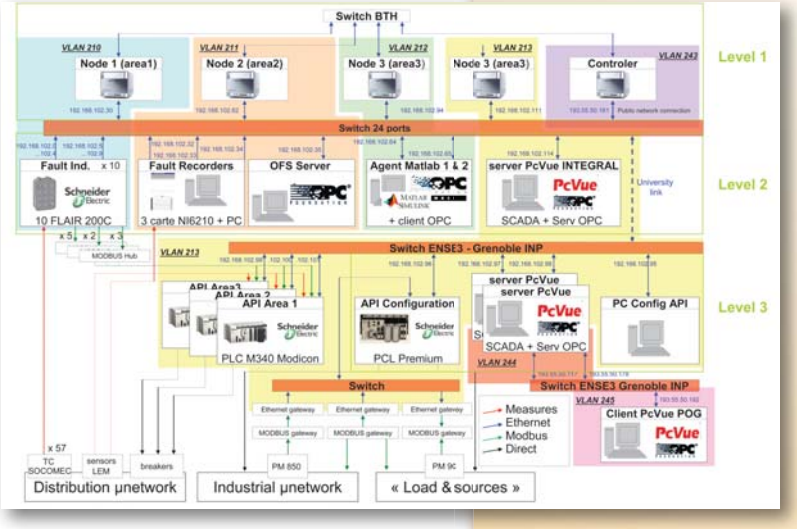
Smart Grid Protection and Control under Emergency Conditions

Highlights of the EU Smart Grids project INTEGRAL: Self-Healing of Smart Grids

Experimental set-up and summary results

To evaluate the ICT performances requested by the self-healing agent, different layers of communication (RTU to SCADA/intra substation/PAC to SCADA/RTU to agent to SCADA) and associated monitoring were developed. The communications are completely controlled by an emulated ICT system based on TCP-IP. This network (Level 1 in the Figure) is able to control bandwidth, latency and even error rates but also supports analyzing all protocols used between RTUS, agent and SCADA during a fault. Level 2 contains the different RTUs (FI, fault recorders), a distributed database, the agent and the SCADA server. Level 3 contains the PACs and other controllers of the test bench.

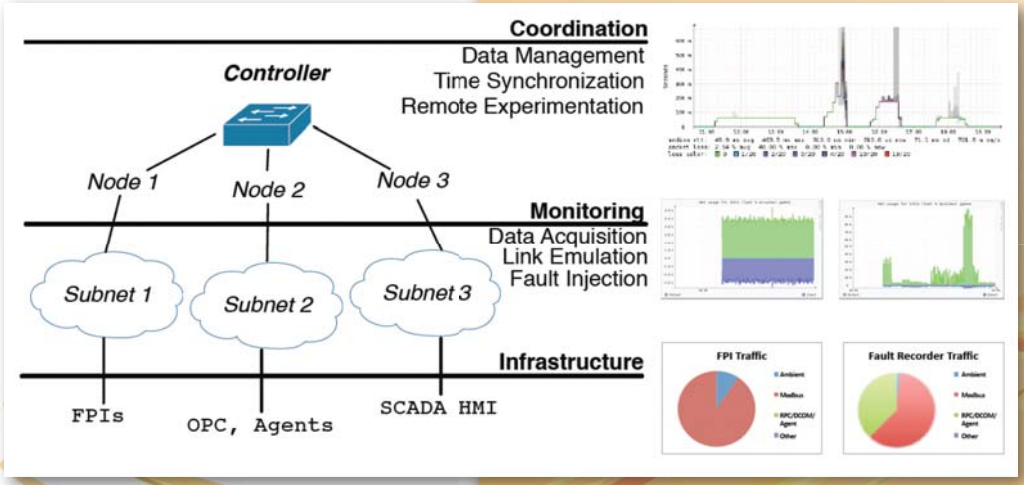
Developed ICT infrastructure to assess the emergency communication performance



The agent has shown, during the different scenarios, a good robustness and a high adaptability to the network configurations.

Regarding ICT facilities, the monitoring used for the demonstrator was partly the HMI of the SCADA as such, which was used to verify the function of the agents, the fault injection in the micro-network, and so on. This monitoring was further complemented by having the routing nodes continuously log all traffic that was passed through each respective subnet and by generating real-time graphs of the number of packages and amount of traffic (custom scripts), and by having the controller repeatedly sending out latency probes to the nodes.

Snapshots of monitoring present in the demonstrator



Outlook for the future

New challenges arise from the various scenarios that were tested during this emergency-condition Demo in France. As a major concern with respect to low impedance faults, the reaction of synchronous generators could modify the short-circuit currents and might impose an evolution in the fault passage indicators (FPIs). Master to master protocols should also be preferred to increase the performance of the agents distributed in the Smart Grids.

EU 20-20-20 and the structured approach towards Smart Grids

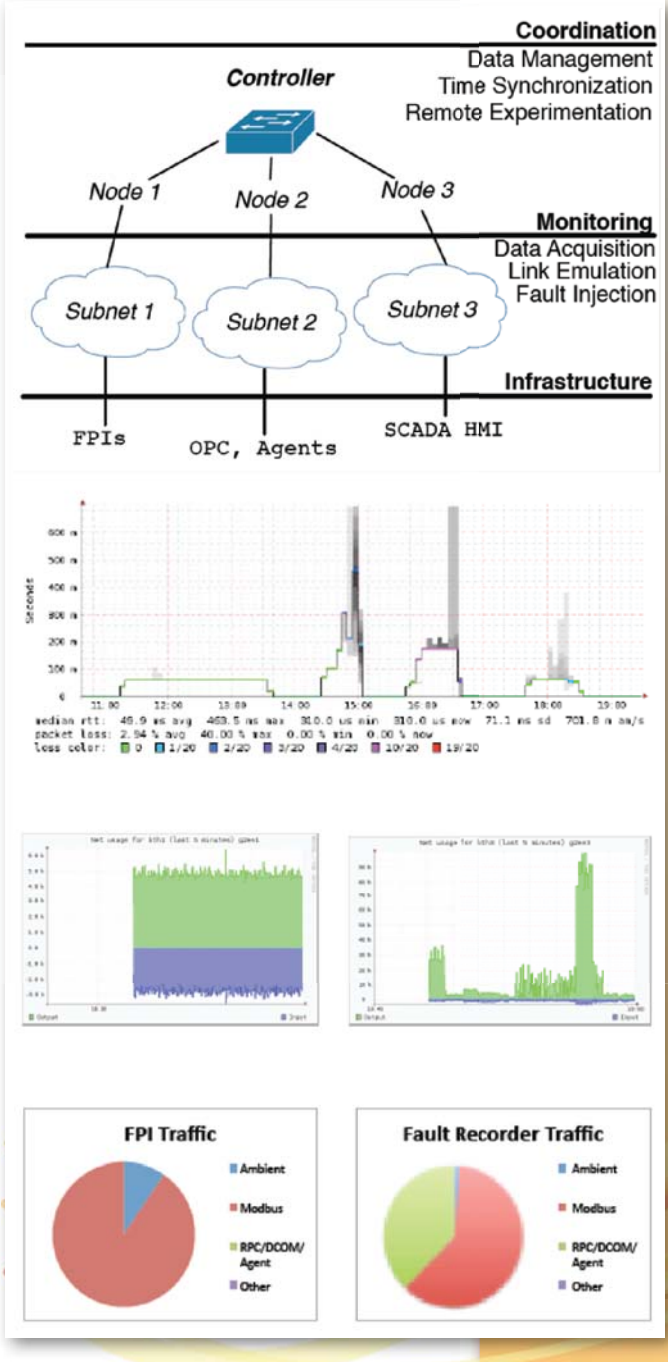
Highlights of the EU Smart Grids project INTEGRAL: A Structured Approach towards Smart Grids

EU 20-20-20 targets

In the EU Climate and Energy package it is stated that by 2020 the EU should meet the targets of:

- At least 20% decrease in EU greenhouse gas emissions related to 1990 levels.
- 20% of EU energy consumption to come from renewable resources.
- A 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency.

A roadmap to meet those targets includes a transition from grids to Smart Grids.



Some characteristics of Smart Grids

To meet these EU targets, Smart Grids must have the following capabilities and characteristics:

- Controlled massive inclusion of Distributed Energy Resources (DER) in the grid while maintaining high quality of service.
- Empowerment of end users to enable increased energy efficiency and new energy based services
- Implementation of distributed intelligence in the grid to enable trustworthy, secure and resilient operations.

Implementation and evaluation of pilots

The figure illustrates some collected traffic patterns from experiments. Analysis reveals patterns related to protocols for different traffic types and infrastructures.

A structured approach towards Smart Grids

The BTH approach to configuring and evaluating experiments and pilots on Smart Grids has been manifested in INTEGRAL by efforts in the INTEGRAL field test in Grenoble, France, studying emergency situations in the Smart Grid.

Smart Grids are enabled by:

1. Development and implementation of a **configurable platform** allowing integration of Energy Distribution systems, SCADA systems and complementary ICT systems;

allowing

2. **Monitoring and control** supporting the two main processes of:
   a. Production, distribution and protection of energy including **integration of DER**
   b. **Information management** related to novel energy-based business processes
   c. Implementation and assessments of **mechanisms** supporting, e.g., "self-healing"
3. Development and implementation of tool **chains** enabling experiments and assessments related to improving **resilience and security** in smart grids. Analysing:
   a. Protocols and data flows
   b. Injection and analysis of faults

and this is achieved by

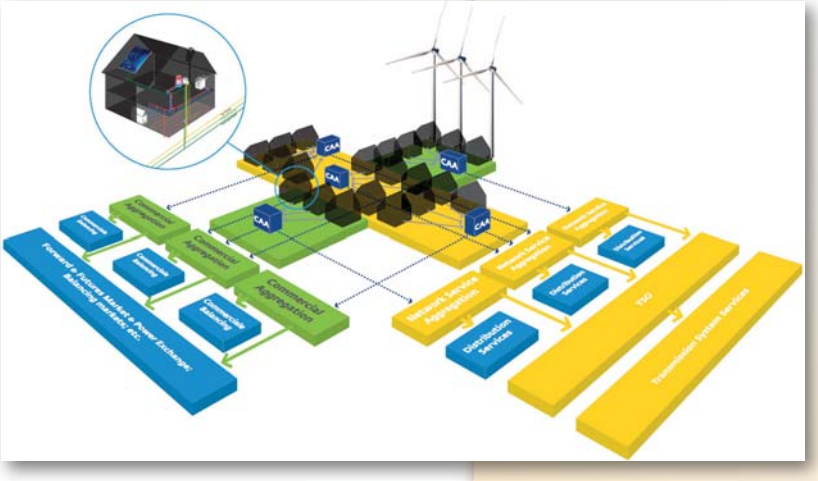
4. An **agent-based methodology** supporting design and implementation of flexible and resilient distributed intelligence.

PowerMatcher: ICT Solutions to manage Smart Grids

Highlights of the EU Smart Grids project INTEGRAL: the PowerMatcher innovation

Decentralized Coordination and Control of the Smart Grid

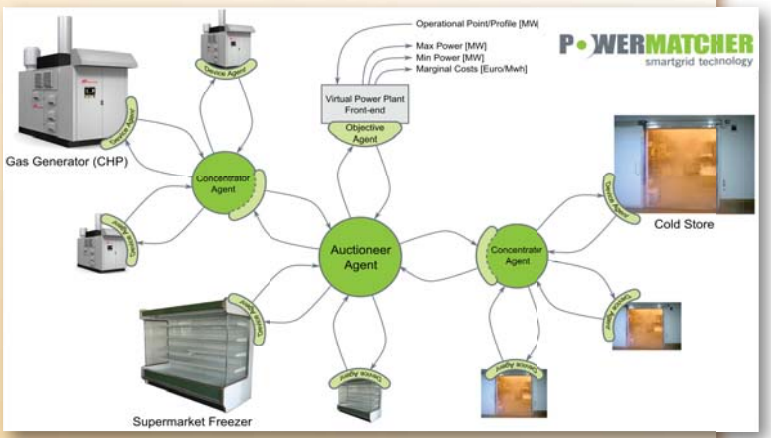
An important innovation resulting from our EU research is the PowerMatcher multi-agent systems technology. It enables smart devices and appliances to communicate and negotiate over the Internet/Web as a Virtual Power Plant (VPP). Thus, networks of devices are able to optimize themselves with respect to energy production and consumption in a fully decentralized way, via a negotiated mutual agreement achieved by so-called agent-based electronic markets.



Coordination and optimization of energy production and demand in real time is done using a PowerMatcher cluster. In field pilots, dozens of households and their appliances are connected with sustainable energy sources such as PV solar panels, wind turbines, µCHP / heat pumps with heat storage, electrical vehicles, and so on. Together they offer their operational flexibility to the VPP. The VPP is embedded in a wider active power distribution network, and is linked to energy trading markets and services, including real-time portfolio management.

From invention to innovation and valorization

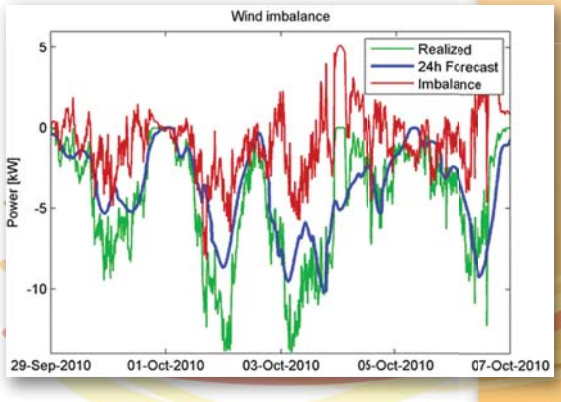
The PowerMatcher technology has its roots in extensive foundational work done by EnerSearch and partners in Sweden. Next, ECN developed and field-tested the first versions of the PowerMatcher in the EU FP5 CRISP project. Now, subsequent EU projects such as INTEGRAL have resulted in the PowerMatcher Agent core 3.0, and this is the baseline version for current *commercialization* of the technology by a global player in the ICT and utility industry.



The PowerMatcher is designed for flexibility and scalability through its multi-agent architecture that includes different types of agents such as concentrator and objective agents.

Field deployment and the business case

One of our PowerMatching City Hoogkerk field experiments involved the reduction of the imbalance caused by a wind turbine. Imbalance is caused by the difference between the predicted power output (24 hours ahead) and the realized power output. Reduction of imbalance is beneficial for everyone. There are less costs for the operator of the wind turbine, as imbalance is normally compensated for by (expensive) gas fired turbines. Furthermore, reduction of imbalance is also a business opportunity for the end-customers of CHPs and heat pumps as they can share in these savings. During a two-week measurement campaign, the PowerMatching City cluster was able to reduce the imbalance of a single 15 kW wind turbine by 58%. To put this excellent experimental result into a financial perspective: in the Dutch balancing market, a 100 MW wind farm suffers from approximately 1 M€ imbalance costs on an annual turnover of about 10 M€.



Smart Grids: Spreading the Word

Highlights of the EU Smart Grids project INTEGRAL: Dissemination

The INTEGRAL project has made significant efforts to disseminate its Smart Grids results to a wide audience.

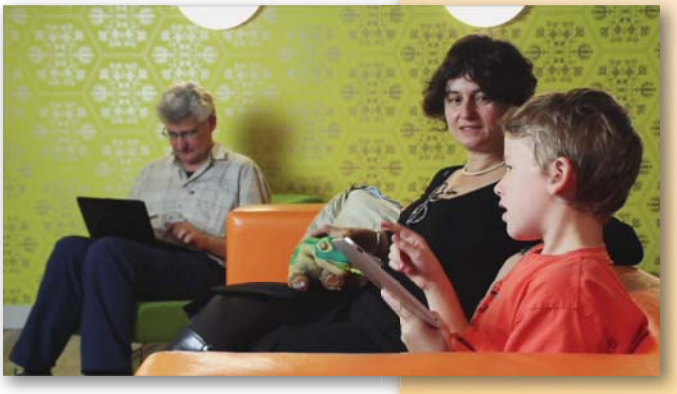
In particular, INTEGRAL has produced two videos, one aimed at the general public and at policy makers, and a second one addressing colleague researchers and engineers. These videoclips show the developed ICT solutions, with animations how the technology works, and they give an overview of all field experiments by onsite footage and interviews.

These videos are available on the Web, for example, at the following addresses:
http://vimeo.com/17438611 (video1 English version)
http://vimeo.com/20083704 (video2 English version)

Moreover, these two videoclips have been made available in several languages, including English, French, Spanish, Dutch, Greek, Swedish, and Catalan.

You can also find all other languages' videos at the *vimeo* video-sharing website: search for the videos of Pepijn Borgwat, the filmmaker.

Finally, you can (also with your Web browser) download all videos in all languages via ftp at the address: *ftp://akmc.biz/Public/INTEGRAL-videos/*



INTEGRAL = ICT for Smart Grids

Highlights of the EU Smart Grids project INTEGRAL

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The EU 20-20-20 goals ....

Europe has set far-reaching energy and climate goals.
Its ambition for the year 2020 is to achieve:

- A 20% increase in energy efficiency;
- A reduction of greenhouse gas emissions by 20%;
- And 20% of the EU energy consumption to come from renewable sources.

Surely, these EU 20-20-20 goals are laudable, but can we make it really happen?

.... cannot be achieved without Smart Power Grids

According to the EU project INTEGRAL, Smart Grids are essential to achieve the EU 20-20-20 goals. Therefore, with partners from the Netherlands, France, Spain, Greece, and Sweden, the INTEGRAL project has delivered ICT solutions for creating and operating the future Smart Grids of Europe, and it has validated these solutions in several field pilots in different countries.

This brochure offers some key results.

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