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Selected domain specific enablers specification

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Abstract:

This document reports the selected domain specific enablers and the experiments of these enablers conducted in different experimentation environments. The experimentation results have been compared with the initial selected domain specific enablers and the final domain specific enablers are documented.

Keyword list:

FI-PPP, FINSENY, Experimentation Lab, Domain Specific Enablers, Experimentation

Disclaimer:

N/A

Executive Summary

A main objective of work package 8 is the selection of most prominent domain specific enablers. The final part of this selection process was supported by experiments. The experimentation in work package 8 considers also the technical usability's and feasibilities called also practicabilities of most prominent domain specific enablers. This deliverable summarizes first the five selected domain specific enablers ("Gateway for Secondary Substations using S3C GE", "IEC 61850 Protocol Adapter", "Supervisory Controller as Service", "Electric Vehicle Supply Equipment" and "Demand Side Manager") initially specified by the scenario work packages. The experiments following this initial specification were conducted on the selected experimentation facilities.

These experiments are either partly coupled with the selected domain specific enablers or show the necessity for these:

The future distribution system has to support functionalities such as monitoring of the grid status, automation of grid operations, automatic detection of fault conditions and restoration etc. This requires managing and controlling a multitude of connected devices as well as the automation of processes. In order to support this, a lot of communication technologies will be applied in electricity networks. These communication technologies should be as reliable as possible and the domain specific enabler "Gateway for Secondary Substations using S3C GE" will additionally introduce redundancy management. The experiment for that domain specific enabler was done in the Institute for Automation of Complex Power Systems at RWTH Aachen University and studied the impact of communication disturbances on the load management of electric vehicles in conjunction with the power grid frequency control. In addition, the experimentation results from Grenoble INP Lab were also used to study the impact of the communication network performance and thus the viability of different communication channels for the "Gateway for Secondary Substations using S3C GE" domain specific enabler.

The "IEC 61850 Protocol Adapter" DSE is also related to communications requirements and was experimented at RWTH Aachen University. The experiments shows the impact of computing time delay, sampling time delay and transporting time delay as major disturbances in communication systems.

The "Supervisory Controller as Service" DSE was experimented in two approaches: With a simulator to validate the DSE in different layers and in a physical infrastructure. The infrastructure for the physical experiment was provided through Energy@home and real data from 30 private houses were analyzed.

Electric vehicles are an important component in the future smart grid. The electric vehicles can be used for instance to stabilize the grid frequency by contributing to the primary frequency control. This and the impact of a huge amount of simultaneously charging electric vehicles were experimented in the Institute for Automation of Complex Power Systems at RWTH Aachen University. The "Electric Vehicle Supply Equipment" domain specific enabler is necessary to utilize the electric vehicles in an intelligent way, for instance as an effective contributor to grid stability, because this DSE is the connection component between the smart grid and the electric vehicles.

The flattening of the demand curve of the energy consumed is another important item in the future smart grid. This will be addressed by the "Demand Side Manager" domain specific enabler. This enabler was experimented in two different facilities, BeyWatch and Energy@home. The purpose of the two conducted experimentations was to verify demand response using market mechanisms in different markets. BeyWatch focuses more on full neighborhoods and Energy@home on single homes.

By considering the results of the conducted experiments the initial specification of the selected domain specific enablers must possibly be updated. The final specification of the domain specific enablers at the end of this document consider any potential impacts resulted by the experimentations.

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1. List of Abbreviations

This document uses the list of abbreviations and terms defined in the general FINSENY glossary and terms [1] and additional the following list:

3G	3. Generation
ACS	Automation of Complex Power Systems
ACSI	Abstract Communication Service Interface
ADA	Advanced Distribution Automation
ADSL	Asymmetric Digital Subscriber Line
BAL	Building Abstraction Layer
B2B	Business to Business
B2C	Business to Consumer
BEMS	Home/Building Energy Management System
CFE	Communication Front-end
CPS	Combined Photovoltaic System
CT	Communication Technology
CTD	Computing Time Delay
DAC	Data Acquisition and Control
DCS	Distributed Control System
DER	Distributed Energy Resources
DLMS/COSEM	Device Language Message Specification / Companion Specification for Energy Metering
DS	Distribution System
DSE	Domain Specific Enabler
DSM	Demand Side Management
DSMgr	Demand Side Manager
DSO	Distribution System Operator
EECS	Energy Efficiency Control System
eMarket4DSM	Electronic Marketplace for Demand Side Management
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCR	Frequency Containment Reserve
FI	Future Internet
FPGA	Field Programmable Gate Array
FTTH	Fiber to the Home
GB	Gigabyte
GE	Generic Enabler
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GTA I/O	Giga-Transceiver Analog Input and Output
GUI	Graphical User Interface

HAL	Home Abstraction Layer
HAN	Home Area Network
HSPA	High Speed Packet Access
HTTP	Hypertext Transfer Protocol
ICT	Information Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IPSEC	Internet Protocol Security
kW	Kilowatts
LAN	Local Area Network
LTE	Long Term Evolution
LV	Low Voltage
MGCC	Microgrid Control Centre
MiLeSEnS	Multi-Level Smart Environment Simulator
MMS	Multimedia Messaging Service
MV	Middle Voltage
MVDAC	Middle Voltage Data Acquisition and Control
MW	Megawatts
OPC	OLE for Process Control
OSC	Permissible Frequency Oscillation
OSGi	Open Service Gateway initiative
OSI	Open Systems Interconnection
OVS	Permissible Frequency Overshoot
PAC	Programmable Automation Controller
PCIe	Peripheral Component Interconnect Express
PLC	Powerline Communication
PTOC	Protection Time Overcurrent
PWM	Pulse Width Modulation
QoS	Quality of Service
REST	Representational State Transfer
RTDS	Real-Time Digital Simulator
RTU	Remote Terminal Unit
S3C	Service, Capability, Connectivity and Control
SCADA	Supervisory Control and Data Acquisition
SCL	Substation Configuration description Language
SGAM	Smart Grid Architecture Model
SIM	Subscriber Identity Module
STD	Sampling Time Delay

TCP/IP	Transmission Control Protocol / Internet Protocol
TSO	Transmission Service Operator
TTD	Transporting Time Delay
UDP	User Datagram Protocol
V2G	Vehicle to Grid
VDC	Volts Direct Current
VLAN	Virtual Local Area Network
VPP	Virtual Power Plant
WAN	Wide Area Network
WANem	Wide Area Network emulator
WCDMA	Wideband Code Division Multiple Access
WP	Work Package
WSAN	Wireless Sensors and Actuators
XCBR	Circuit Breaker
xDSL	Digital Subscriber Line

2. Introduction

2.1 FINSENY Work Package 8 Overview

The main objective of FINSENY Work Package (WP) 8 is the identification, collection and investigation of the most prominent Domain Specific Enablers (DSE) supported by experiments. To achieve this, the work packed is divided in the following tasks [3]:

- Task T8.1: Provides the list of experimental labs and intended experiments that will be executed.
- Task T8.2: Provides the list of DSEs that will be experimented together with the list of Information Communication Technology (ICT) specific requirements covered by these DSEs.
- Task T8.3: Specifies the details on how the selected DSEs are going to be evaluated in each of the identified capabilities, defining an experimentation plan.
- Task T8.4: Will execute the experimentation and will outcome the experimentation results.

The relationship between different tasks in WP8 is shown in the following figure:

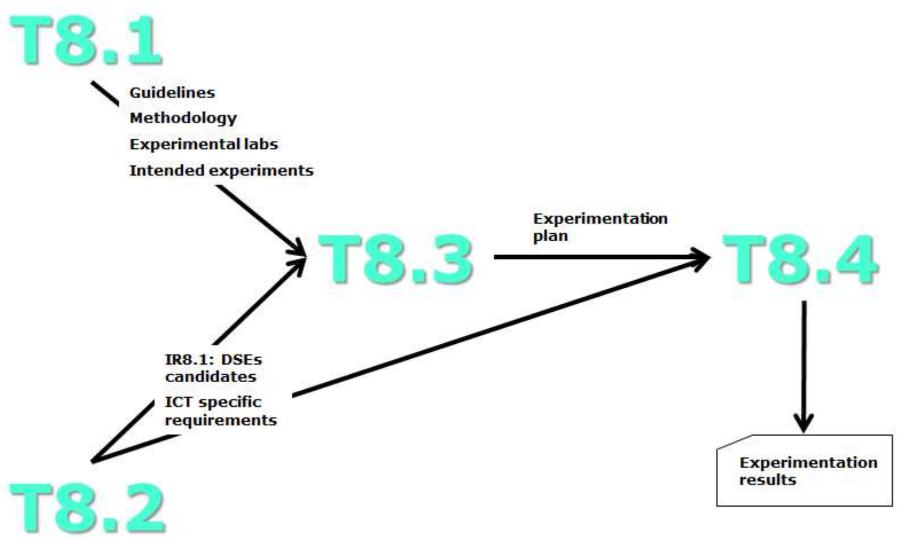


Figure 1: Work package 8 overview

2.2 Scope of the Deliverable

Experimentation is the last step in work package 8 to select the most prominent domain specific enablers. The selections process should be supported by experiments to guarantee the practicability, the technical feasibility and usability. For that experimentation facilities were selected (deliverable 8.1 [2]) and experimentation plans were described (deliverable 8.2 [3]). This deliverable finalizes the selected DSEs by using the experimentation facilities and experimentation plans. The selected DSE were experimented in different facilities. The experiments and the facilities are partly closely connected with the selected DSEs or show the need for the selected DSE. The initial DSE specification will be compared with the experiment results. The specification will be updated according the results. New parameters will be considered just as unnecessary parameters will be removed. Thus the scope of the deliverable is:

- Summary of the selected DSEs
- Experiments with the selected DSEs
- Finalization of the selected DSEs

The following table summarizes beforehand the selected and in this deliverable processed most prominent DSEs:

Work package	Domain specific enabler
WP2	Gateway for Secondary Substations using S3C GE
WP3	IEC 61850 Protocol Adapter
WP4	Supervisory Controller as Service
WP5	Electric Vehicle Supply Equipment
WP6	Demand Side Manager

Table 1: Initial selected domain specific enablers

2.3 Structure of the Deliverable

The document is structured in the following chapters:

- Chapter 1: List of Abbreviations
- Chapter 2: Introduction
- Chapter 3: Selected Domain Specific Enablers
- Chapter 4: Experimentations
- Chapter 5: Final Specification
- Chapter 6: Conclusion
- Chapter 7: References

3. Selected Domain Specific Enablers

3.1 DSE WP2: Gateway for Secondary Substations using S3C GE

The domain specific enabler of WP2, "Gateway for Secondary Substations using Service, Capability, Connectivity and Control (S3C) Generic Enabler (GE)", has been described in [3]. That DSE is briefly described in the following.

In order to tackle the future challenges of integration of the distributed and intermittent energy generation sources, the Distribution System (DS) has to support the functionalities such as: DS-wide monitoring of the grid status; automation of grid operations; automatic detection of fault conditions and restoration, etc. This requires managing and controlling many connected devices in the DS, and automation of processes. A variety of communication technologies will be applied in electricity networks, and in addition, participants and their devices need to be interconnected in a distributed way.

To define the Future Internet (FI) ICT architecture for the smart grid distribution systems, five use cases were developed in the FINSENY WP2. They go beyond addressing the traditional functionality by expanding the views to the field of Advanced Distribution Automation (ADA) and novel load and generation control e.g. for Distributed Energy Resources (DER). Based on the Smart Grid Architecture Model (SGAM) analysis the use cases were examined for all interfaces from the following perspectives: # devices, payload, latency, time stamp resolution, transmission internal, redundancy and response confidence. That analysis resulted in the ICT requirements for the smart grid DSs. The list of requirements was then the basis for identifying the generic and domain-specific enablers, which together build the functional DS ICT architecture.

In the selected use case for experimentation, Middle Voltage (MV) Data Acquisition and Control (DAC), covers data acquisition and control of different elements of the MV network (including DERs) from the utility control centre. Thus it covers the distribution and the DER domains. In the operation zone, a grid operator is in charge of network monitoring and control using a grid control application. The Supervisory Control and Data Acquisition (SCADA) front-end is responsible for the collection of the time critical information from the Remote Terminal Units (RTUs), which are in charge of interfacing with sensors and actuators in remote locations. In the field zone, the complementary SCADA protocol termination takes place in the RTUs.

For communication between the SCADA and RTUs different protocols can be used. International Electrotechnical Commission (IEC) 60870 series defines point to point or point to multipoint communication for retrieving or updating electrical time critical information from the terminal locations. The substandard IEC 60870-5-104 defines the communication using Transmission Control Protocol / Internet Protocol (TCP/IP). IEC 61850 is reference architecture for electric power systems. The abstract data models defined in IEC 61850 can be mapped to a number of protocols. By using standardized protocols, equipment from many different suppliers can be made to interoperate.

At the RTU level, a generic enabler S3C was proposed to be used. One of the examples in which the GE S3C can provide a clear advantage for MVDAC is the redundancy management of the connectivity of one or more operators or technologies. For this experimentation the GE S3C was not available. The following table summarizes the WP2 DSE [3].

Title	GATEWAY for Secondary Substations using S3C GE
Lead partner	Timo Kyntäjä (WP2), Jukka Salo (WP8)
Domain	Distribution / DER
Zone	Station / Field
Interoperability layer	Communication
Entity (S/C) and references	S (Single)

Description	Secondary substations can be identified as aggregation points for all sensors and actuators in the Low Voltage (LV) and MV network (sensor/actuator network based on Powerline Communication (PLC)). Digital Subscriber Line (xDSL) or General Packet Radio Service (GPRS) routers have been deployed in several secondary substations for communication with the central operation centre. This domain specific enabler will develop a gateway fulfilling all xDSL/GPRS routers' current requirements, and adapting it for Fibre to the Home (FTTH)/ Long Term Evolution (LTE) interfaces and for the use of S3C GE. The gateway consists of existing standard solutions (TCP/ User Datagram Protocol (UDP)/IP stack), GEs (S3C), and DSE's (IEC 60870-104)
Detailed description	This gateway should use the S3C GE for an improved use of the public network. It may fulfil ICT requirements identified in WP2, and in concrete those for the MVDAC scenario. This equipment will be installed in all electrical locations, and special environmental conditions and dimensions shall be taken into account. In particular, it should be fed in Volts Direct Current (VDC) taking advantage of the already available batteries. The secondary substation is a kind of aggregator element of different services (Telecontrol, PLC smart metering aggregation, safety, other measures), so this router should manage different virtual networks. This router will also encrypt the communication using Internet Protocol Security (IPSEC) or a similar method. This router should make it possible for the applications to use a static IP address even if the operator network would deliver only dynamic IP addresses. This kind of gateway could also be installed in a DER element, and the distribution company should access to this router through a specific virtual network even if the Subscriber Identity Module (SIM) card or the access has been contracted by a third party.
Expected inputs	Data to be transferred between a grid control application and the RTUs, which interfaces with the actuators and sensors.
Expected outputs	Data transferred between a grid control application and the RTUs.
Interface to other functional entities or GEs	S3C
Standards, encodings, data model	LTE, FTTH, IEC 60870-5-104, Device Language Message Specification / Companion Specification for Energy Metering (DLMS/COSEM), PLC
ICT requirement name	Connectivity infrastructure Interoperability on Communications Technology (CT) layer Connectivity Services Reliability and availability on CT layer Quality of Service (QoS) for Connectivity Packet loss Connectivity Communication services Dedicated or shared transport infrastructure Latency Reliable data transport over heterogeneous networks

Table 2: WP2 DSE specification before experiments

3.2 DSE WP3: IEC 61850 Protocol Adapter

3.2.1 General Description

The “IEC 61850 Protocol Adapter” DSE refers to an IEC 61850 stack implementation (client and server). This stack will be used on smart energy gateways for DERs, secondary substations or home energy management systems as well as in the communication front-end (CFE) of the microgrid control centre (MGCC).

In the current functional architecture of the MGCC following communication components are distinguished (see deliverable D3.3):

Component	Description
Communication front-end for network devices	This component realizes the communication to the network smart devices, i.e. an intelligent electrical device in the microgrid that can be supervised and controlled (e.g. sensors, circuit-breakers or switches). In this component different communication protocol adapters might be supported to ensure flexibility and compatibility with respect to different standards (e.g. IEC 61850, IEC 60870-5-101/104).
Communication front-end for prosumer Devices	This component realizes the communication to the devices owned and operated by a third party, e.g. a prosumer. These devices include DER and storage units as well as Home/Building Energy Management Systems (BEMS). Also in this component different communication protocol adapters are realized and supporting the same or similar standards as for energy network devices. Because these devices are not owned and operated by the microgrid operator communication is managed in a separate component.

Table 3: Communication components for WP3 DSE

The following table summarizes the WP3 DSE [3].

Title	IEC 61850 Protocol Adapter
Lead partner	WP3
Domain	Distribution / DER / Customer
Zone	Operation / Station / Field
Interoperability layer	Communication / Information
Entity (S/C) and references	S(Single)
Description	IEC 61850 stack implementation (client and server). This stack will be used on smart energy gateways for DERs, secondary substations or BEMS as well as in the communication front-end of the MGCC.

Detailed description	To guarantee the efficient information exchange throughout a distributed control system common standards are a must. The complexity of the control task requires standardized information models, support for simple and complex data types, meta data and well-designed data repositories and processing units. For these conditions there are only a few standard solutions ready to be used in the near future, especially for devices of "classical" and renewable power generation in the electrical smart grid. One of the most prominent future-oriented solutions for electrical grids is the IEC 61850 protocol family. The main advantages of IEC 61850 are: • It uses the strengths of the Open Systems Interconnection (OSI) 7 layer communication model, • It standardizes data models for electrical applications, • It defines Data Types and Communication Services, • It models devices, functions, processes and architectures, • It describes the engineering and configuration Process, • It provides examples of typical applications in electrical substations, • The data is organized in devices in a standardized way, • The devices are "self-descriptive", either online (e.g. Multimedia Messaging Service (MMS) protocol) or offline (Substation Configuration description Language (SCL), IEC 61850-6), • IEDs not only provide the data itself but also the information about data types used, its structure and complete naming, • IEC 61850 supports application-oriented architectures by introducing meaningful semantics, • IEC 61850 defines application specific data like Protection Time Overcurrent (PTOC) logical node or Circuit Breaker (XCBR) logical node, etc.
Expected inputs	IEC61850 information translated into internal data format, internal data translated into IEC61850 information
Expected outputs	IEC61850 information translated into internal data format, internal data translated into IEC61850 information
Interface to other functional entities or GEs	Internet of Things (IoT)
Standards, encodings, data model	IEC 61850, TCP/IP
ICT requirement name	Communication Services: • Request / Response • Publish / Subscribe Monitoring and Control Services: • Creation of data set • Request / Response for data set • Publish / Subscribe for data set • Set Configuration • Create control set • Operate • Select before operate

Table 4: WP3 DSE specification before experiments

3.3 DSE WP4: Supervisory Controller as Service

3.3.1 Discrete Supervisory Control DSE

Supervisory control as addressed here corresponds to an automatic control of sets of entities modeled as discrete event systems and is distinct from supervisory control in the SCADA acceptation. It is a formal approach based on specific tools from the discrete events dynamical systems domain. It operates in a closed loop by: observing the generated events by the process, and sending controls in accordance with specifications corresponding to the control strategies. This control is loosely coupled to the plant system and drives the discrete event dynamics of the system in a way that may override control of the set points of a local control or may in turn be overridden by a higher-level control application.

As detailed in FINSENY D8.2 [3], section 5.2 - "DSE WP4: Supervisory Controller as Service", at first this DSE is parsed in a sophisticated simulation framework, using an environment to validate it in any layer and, afterwards, it is tested through the Energy@home, a physical infrastructure for conduct experimentations within private homes with the goal to monitor, control and optimize the electrical power consumption. These two steps are described separately in section 4.3.1and 4.3.2 in order to avoid confusion between real and simulated parameters.

3.3.1.1 DSE Utilization

The supervisory control can be used to setup a system for controlling and monitoring all kinds of infrastructure-based systems or processes, including homes, buildings and cities and physical goods distribution networks, water/gas distribution systems, smart grids, especially (at microgrid at virtual power plant scales, i.e. excluding transmission networks), transportation networks. In each of these environments, the applications targeted could be in e.g. the following domains (not all of them are relevant for all environments):

- Safety,
- Security,
- Energy efficiency,
- Care,
- Comfort.

This DSE differentiates itself from application-level control by not being dedicated to one particular type and instance of building/home, or to one environment. It integrates capabilities of self-adaptation to the variations of a given target environment and potentially to different applications in this environment within a single generic framework.

Though efforts have been expended to achieve the home/building automation goal, most of them require custom manual adaptation to every aspect in the context from the hardware, such as physical entities, sensors and actuators, to the software, such as the control logic application. A generic framework with a middleware, that insulates applications from the specifics of the plant, is still missing. Supervisory control could be the upper layer of such a middleware. This kind of generic framework will reduce the costs of development of such a control system and the applications that use it, compared to customize it manually every time, which will thus promote the deployment of smart environment in everyday life. This DSE does not aim to address the most critical environments such as nuclear power plants, airplanes or battlefield systems, which require an absolute reliability with little tolerance and warrant the design of a 100% dedicated custom-designed control system.

3.3.1.2 Aim of the DSE

The supervisory control we propose is intended to effect a maximally permissive joint control of several individual controlled entities. These entities are self-contained subsystems of the target overall system. Its main role is to coordinate all the controlled entities in order to reach or avoid a prescribed joint state of the overall system comprising these entities. It is designed to be able to adapt itself to changing context and make decisions based on specific inputs and the current states of each controlled entity.

3.3.1.3 Entity Abstraction Layer

Entity abstraction layer is a solution which enables auto-integration of non-ICT entities into an intelligent management system and their auto-configuration after the integration. This abstraction layer relies on a set of sensors and actuators which are part of a network of Wireless Sensors and Actuators (WSANs). There are several variations of the entity abstraction layer for different scale of usage, such as Home Abstraction Layer (HAL), Building Abstraction Layer (BAL), etc. Its principles of operation are described below:

- **Dynamical creation of proxy for non-ICT entities:** The approach is to dynamically create a proxy or representation ICT component for each individual target physical entity which connects to the physical subsystem through a dynamically configured set of potentially shared sensors and actuators, chosen among those available in the relevant environment. This ontology subsumes several relevant categorizations of the target entities and it is possible that an entity belongs to several of them. It can be useful for finding a model as specific as it can to a detected entity. The following example is about the identification of a washing machine. At the root is the main class entity, as explained above, according to the data received from sensors and the determination criteria, we may find out that the target entity belongs to several categories and their intersection indicates that this is a washing machine as illustrated in the following figure.

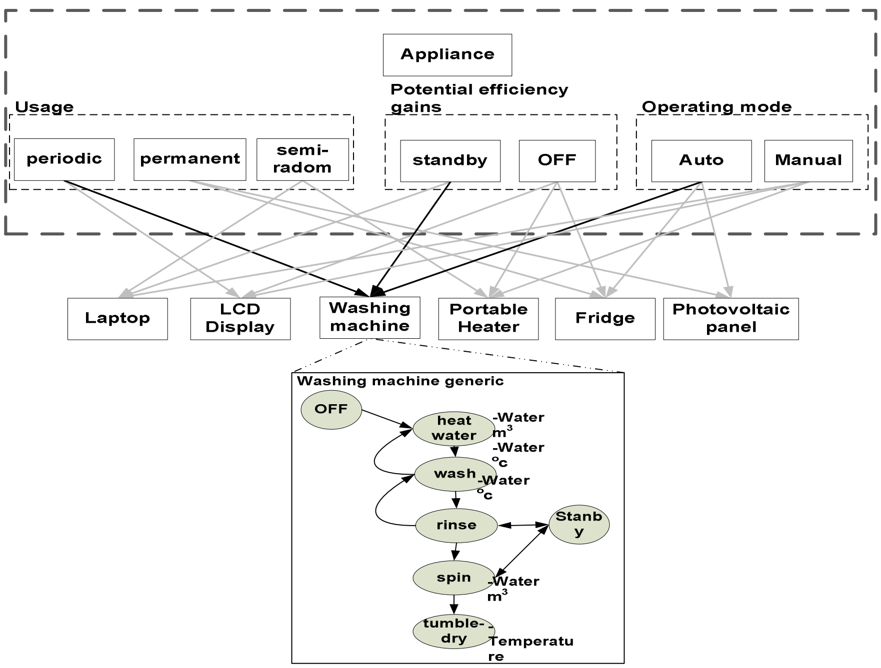


Figure 2: Home entity ontology and corresponding discrete state model example for home appliances

- **Finite state machine Automata models:** The automata (finite state machines) used to model target entities represent a trade-off between expressivity and ease of identification. The full description of a physical system such as the target appliance would normally require a continuous-state and continuous-time model, but the automatic identification of the parameters of such models would be impossible.

3.3.1.4 Target System

In our days, supervisory controllers are most known under the concept of SCADA for large scale control system, or of Distributed Control System (DCS) for smaller range of application. Both of the mentioned systems exist since decades and were designed for hardwired industrial control, which implies that they are not able to benefit from the auto-integration and auto-configuration functionalities provided by the entity abstraction layer which lies on the sensor and actuator device layer as well. A supervisory controller is still missing for monitoring and controlling behaviors of the system “shadowed” by the xAL (x for H, B, C, etc).

The global architecture of the whole system adopts the concept of multi-level ICT systems such as the TCP/IP stack for reasons of decentralization and separation of concerns. The supervisory controller is considered as component of the service layer which is just above the abstraction layer where all the entities to be controlled exist, and just below the application layer to which it provides interfaces of common control functions.

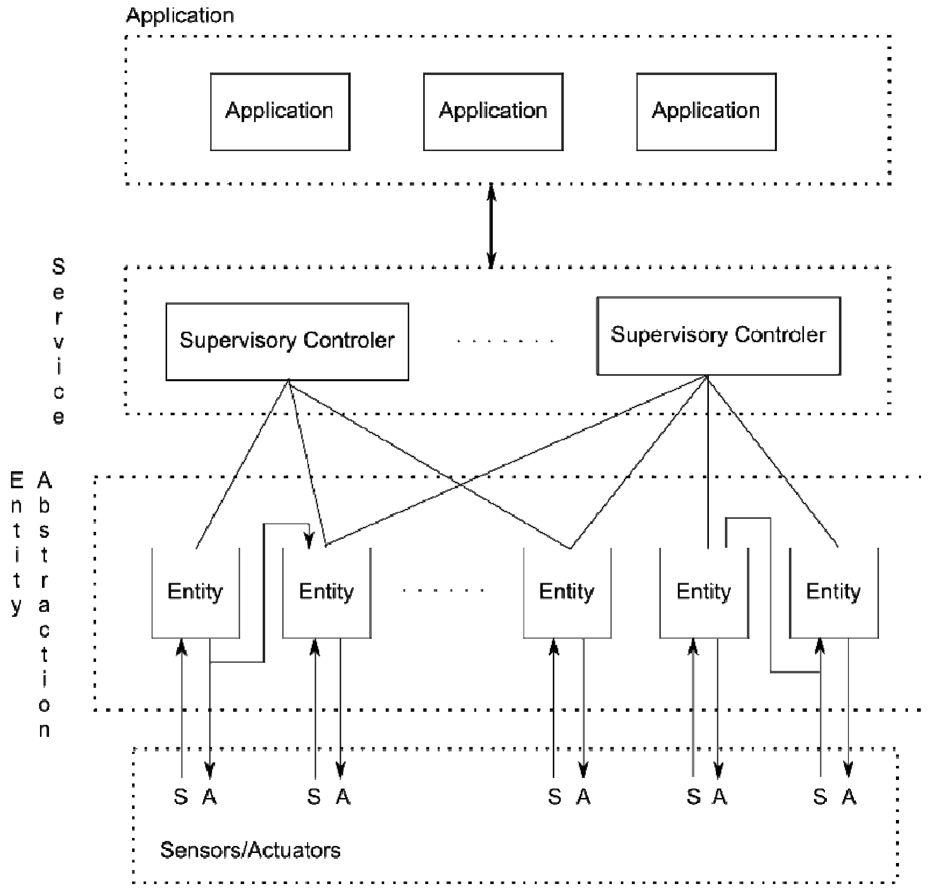


Figure 3: Global architecture with supervisory control in service layer

Just like other normal services, there can be several supervisory controllers for different purposes. The mapping between the supervisory controllers and the entities in the abstraction level (xAL) is n-to-n, which means one entity can be associated with several supervisory controllers and one supervisory controller could control several entities as shown in the figure above.

Supervisory control in the service level will not replace the more comprehensive and complex dedicated application-specific control being affected by applications in the upper application layer. They are for different purposes and designed in different ways. Supervisory control service is designed in a bottom-up approach, which means it starts from the entity models in the lower level and ends in providing lightweight control functions based on exclusion or sequence criteria, such as general safety and energy-saving constraints. By contrast, application-layer control adopts rather a top-down approach, which means it aims at some specific goal, such as energy optimization, and should achieve it by taking into account many different criteria between which it seeks to find an optimal tradeoff (such as e.g. carbon footprint, cost, demand-response constraints, etc). Supervisory control service will provide a basic minimal system control to ensure safety and basic energy-saving that should not conflict with this comprehensive optimization.

3.3.1.5 Entity Groups

In smart environment domain, or even in other application domains, we concern more about the whole environment rather than the individual entities. For example, if the end user wants to heat his room where several radiators are available, he would like either to turn on all the radiators to heat very quickly, or some of the radiators if he wants to consume less electricity, but what he doesn't concern about is which exactly the radiator(s) to be turned on. That's where the concept of "entity group" begins to be useful.

Entity groups refer to abstract grouping of discrete state machine models according to shared environment impacting properties or other interesting properties to the controllers. By analogy to the domain ontology's used in the entity layer to integrate and configure non-networked objects and spaces, an entity group is also ontology in the same domain which follows other classification rules than those for recognizing entities. Also, by analogy to the domain ontology's in the entity layer where various paths passing through different hierarchical intermediate entities can reach the same target entity, different intermediate groups can be created by different grouping strategies with the same end entities, which means more than one control rules coming from different controllers can apply on the same target entity group at one time which will furthermore transfer the rules to associated entity instances.

In order to manage collective behaviors at the level of group, a group will have an interface that all its sub-entities should be consistent with, and it will have quantifiers to treat a range of variables of its sub-entities without worrying about the specific ones among them.

The most outstanding advantage of the concept of the entity group is that the control specifications of one system are stay always valid at the level of entity group without worrying about the lower level variations. Suppose that there are 2 rooms that have 3 lamps and 2 TVs respectively and TV and lamp are both member of the group "Light". Thought the number or the nature of the entities are different in the 2 rooms, the specification at the entity group level "all entities belonging to 'Light' group are turned off if the room is empty" is still valid without any adaptation to the entity-level difference.

We will detail the use of entity groups via a scenario in the experimentation chapter which will serves as validation method of the DSE.

An example of entity group is given in the experimentation section 4.3.1.

3.3.2 Continuous Supervisory Control

As detailed in FINSENY D8.2 [3], section 5.2 – "DSE WP4: Supervisory Controller as Service", at first this DSE is parsed in a sophisticated simulation framework, using an environment to validate it in any layer and, afterwards, it is tested through the Energy@home, a physical infrastructure for conduct experimentations within private homes with the goal to monitor, control and optimize the electrical power consumption. These two steps are described separately in section 4.3.1 and 4.3.2 in order to avoid confusion between real and simulated parameters.

NOTE: The field trials carried out with the Energy@home system, which are described in the next chapter, contribute to the validation of some services based on this WP4 DSE and they make use of standard communication protocols (e.g. ZigBee, Wi-Fi, 3G etc.). Therefore the relative WP4 DSE I/O specifications are here not intended as "Technical specifications" but as "Service specifications" before and after the tests.

That said, Table 5 shows the WP4 DSE template (for the Energy@home part) before the tests, while Table 31 shows the WP4 DSE results after the test and the DSE final specifications.

<table>
<tr><th>WP4 service tests with Energy@home</th><th>I/O DSE specifications before the Energy@home service tests</th></tr>
<tr><td>Tests on detailed energy data collection and its historicization</td><td>Input
<u>Power data collection coming from</u>:
Smart Info
Smart plugs with a local meter, a switch, and ZigBee radio communication
Smart appliance with embedded ZigBee radio communication
Energy box: This is the Home Area Network (HAN) controller. It is an Asymmetric Digital Subscriber Line (ADSL) home gateway with Open Service Gateway initiative (OSGi) framework and HAN wireless communication capability.
Output
<u>Data mining and data historicization obtained from</u>:
Remote service platform: It manages the data mining algorithm and the data historicization.</td></tr>
<tr><td>Test to keep under control and manage (at home and outside) the household electrical devices avoiding power-off for excess of load.</td><td>Input
The information coming from the data mining algorithm (managed by the remote service platform) are sent to a Graphical User Interface (GUI) allowing at the final user, both in home and outdoors, to monitor and control the loads through a notebook, net book, tablet, smart-phone etc.
Wi-Fi and ZigBee protocol communication infrastructure is supported from the indoor operations, while Global System for Mobile Communications (GSM)/GPRS/3G communication infrastructure is supported for outdoor nomadic operations.
Output
Aggregate info and graphic on the user interface.
Control actions from the user interface toward the household appliances.</td></tr>
<tr><td>Test to check the functionality of the management of priorities among all the smart appliances and the traditional ones.</td><td>Input
The power consumption data coming from the smart info, smart plugs and smart appliances are collected by the home gateway.
Output
If the total power consumption exceeded the total available one, the home gateway sends a “pause” command to the smart appliances.
If the “pause” command is not accepted by the smart appliance then another load is paused by consulting a predefined priority-list.</td></tr>
</table>

Table 5: WP4 I/O DSE specifications before experiments

3.4 DSE WP5: Electric Vehicle Supply Equipment

The DSE of WP5, “Electric Vehicle Supply Equipment (EVSE)”, was described in [3]. In a nutshell this DSE should support the stabilization of the power grid. For that, the EVSE should be especially remotely manageable (turn on/ turn off, scheduled charging, adjustable charging) and should support smart metering functionalities.

From these major requirements follows the WP5 DSE template [3].

Title	Electric Vehicle Supply Equipment
Lead partner	Jesse Kielthy (WP5), Thomas Loewel (WP8)
Domain	Electric Mobility / Customer
Zone	Customer
Interoperability layer	Communication
Entity (S/C) and references	S (Single)
Description	Metering and charging information is concerned with all metered information of charging processes. This includes the metered data at the EVSE, in particular in relation to the time. Significantly, a smart EVSE utilises intelligent technology to allow remote monitoring and control. In this instance, the smart EVSE will enable grid operators to stop, start or limit the charge to an Electric Vehicle (EV) as part of an overall demand side management solution. End-users will also be able to remotely communicate with the EVSE to schedule a charge or receive information updates. Overall the EVSE supports actively the load balancing process and thus the optimal use of renewable energy.
Detailed description	Deployment requirements: • Charging Points • Mobility Data Management Functional Requirements: • Technological: All this information is of technical nature and is needed as an input for (planning) (dis)charging processes. However, this information is typically derived from the respective systems. • Economic: The domain is set to the customer as electric vehicles consume energy triggered by the consumers, and they can be used as a DER in the Vehicle to Grid (V2G) scenario. Besides the information available in the EVSE and the supporting systems, also respective messages sent to electric vehicles and their users (e.g., information regarding the current or scheduled (dis)charging processes, connection messages inside the electric vehicles) represent information on charging process and equipment. • Legal: As cars are used by humans, status information of cars might be mapped to individuals. This requires the same privacy protection as with user information • Operational: Information on the EVSE can be of static nature (e.g., supported charging modes and payment methods) or dynamic nature (e.g., current and planned availability and reservation). • Schedule: In the SGAM framework, electric-vehicle information is located in the customer and DER domain and in the operation zone. • Cultural: Privacy protection for user information
Expected inputs	Communication interface (from EV and from Back-end) to exchange meter data with EV, to get price signals, to support the authorization, etc.

Expected outputs	Pulse Width Modulation (PWM) signal (to set the charging mode); Communication-Interface (to EV and to Back-end) to exchange meter data with the Back-end, to support the authorization, etc.
Interface to other functional entities or GEs	I2ND.CDI, I2ND.NetIC
Standards, encodings, data model	3GPP, Charging points and devices, information exchange, communications
ICT requirement name	Monitoring of EVSE Aggregate EVs to virtual power plants Control of EV (charging signals)

Table 6: WP5 DSE specification before experiments

3.5 DSE WP6: Demand Side Manager

The DSE of WP6, “Demand Side Manager”, has been described in [3]. That DSE is briefly described in the following.

The DSE assumes dwellers having an Energy-Efficiency Control System (EECS) at home for controlling and managing the consumption of electricity in their houses. The system allows receiving Demand Side Management (DSM) signals from the DSM manager (DSMgr) based on subscribed conditions and user preferences.

The users have access to the Business to Consumer (B2C) marketplace on the Internet where they can see different offerings for demand side management programs from demand side managers. These offerings could be based on real time tariff schemes that users can choose to contract one of these services with the aim of reducing the monthly bills. The offers might be coupled with energy contracts and vary in the incentives how much money is paid (or reduced from the bill) when a user actually reacts to load-shifting requests. By contracting such a service, the user allows the grid operator to send demand-response signals to her/his energy-efficiency control system. The signals are used to initiate actions in the appliances connected to the energy-efficiency control system, in order to schedule operations (e.g. electric vehicle charging, starting a washing machine) or lower/increase the temperature of the customers building by some degrees (within a certain range). It must be noted that the contract need to reflect the possibility for the user to not accept DSM signals at any time in order to allow user's manual decisions on how and when to use the contracted energy.

When consumers have contracted with demand side managers and an infrastructure is available that can execute demand-response measures, the Business to Business (B2B) marketplace described in the following uses market mechanisms for trading flexible loads for demand-response purposes. Energy retailers considering a demand-response measure can send their request to the electronic B2B marketplace. The demand side managers then send priority signals to energy-efficiency control systems of their contracted consumers. These systems then take the best decision based on DSM signals, incentives, and user preferences to send the signal to intelligent devices in the consumer's premises as well as charging infrastructure of electric vehicles.

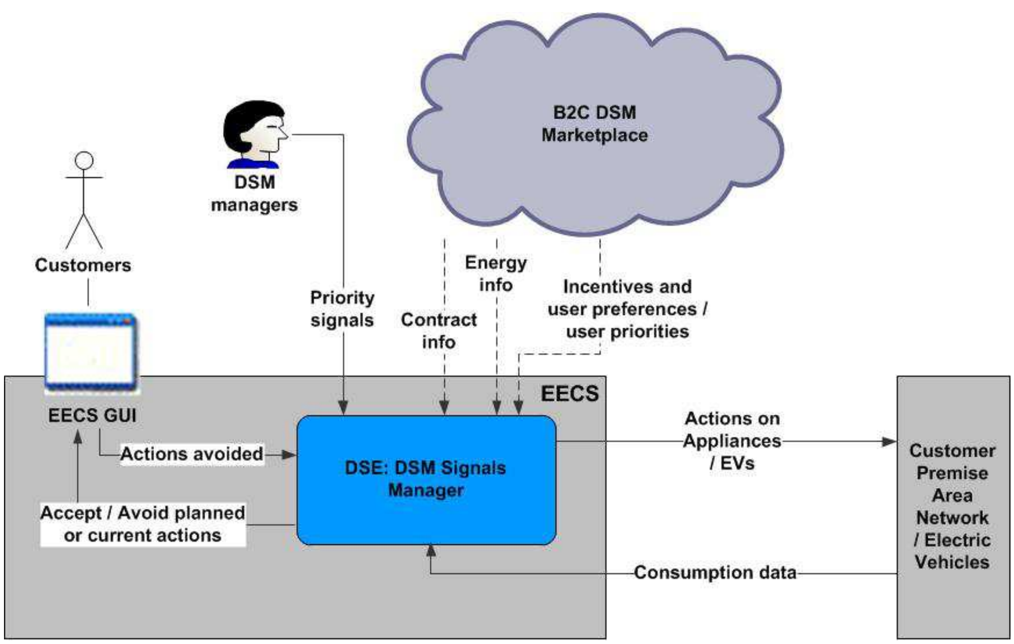


Figure 4: DSE architecture

The following table summarizes the WP6 DSE [3].

Title	Demand Side Manager
Lead partner	Engineering S.p.A.
Domain	Market and Enterprise

Zone	Distribution / DER / Customer
Interoperability layer	Information / Communication
Entity (S/C) and references	S (Single)
Description	The domain specific enabler "Demand Side Manager" is a software module included in an energy management system in charge of the management of DSM signals intended to flatten the electrical demand curve in a specific area. A B2C marketplace (eMarket4DSM) assumes the availability of an infrastructure (hardware and software on board / bundled) where consumers have installed an EECS at home that monitors and controls the energy consumption of appliances, by changing their programming parameters. An EECS equipped with a DSMgr will be able to be activated by DSM signals from the demand side operator (typically the DSO) based on the subscribed conditions and user preferences.
Detailed description	The core idea of the domain specific enabler is to manage the DSM signals from the operator side to the home area network (via a device control system) in order to influence the flattening of the demand curve of the energy consumed in some areas. This is only possible with an entity (normally software) in each electrical installation (buildings, houses etc.) that can ensure security and effective programming of the appliances to avoid any inconvenience. The approach is that the DSM operator can effect some "changes" in the default contract values / parameters of the various contract classes with the aim of incentivizing / dis-incentivizing consumers / residential agents to exhibit the expected or hoped for consumer behaviour (with regard to electricity consumption during critical hours). For that intent, the DSM operator sends signals to the installations affected in the target area. These signals should be managed for a re-scheduling in the operation of the electric appliances (consumer appliance control actions) depending on some conditions as the incentives, contra-incentives, power cap, penalized power, sell/buy price (of electricity) and the preferences of the final user. Anyway, the final user has always the option to cancel the response of the DSM signals at any moment or any period of time no matter the DSM conditions subscribed in the contracts.
Expected inputs	DSM signals from the demand side managers (from the smart grid); incentives / disincentives; user preferences (e.g. type of energy such as nuclear or solar) / priorities (time range in a day when automatic actions are allowed); price information; contract information (from the eMarket4DSM); rough power consumption data (coming from the energy monitoring systems provided by the EECS); (eventually) rejection of the forthcoming actions on the controlled appliances activated by the DSMgr
Expected outputs	Consumer's appliance control actions; Notification (to the consumer) of forthcoming actions on the controlled appliances activated by the DSMgr and the incentives/contra-incentives for attending DSM signals
Interface to other functional entities or GEs	IoT - Gateway Data Handling, IoT - Device Management, I2ND - Connected Devices Interfacing, SECURITY- Identity and Privacy Management, DATA - Publish/Subscribe Broker and APPS - Marketplace
Standards, encodings, data model	Communication protocol among GEs and DSE: Representational State Transfer (REST), Hypertext Transfer Protocol (HTTP(S))
ICT requirement name	User software agent system Power limits information Contract information Tariffing signals and profile Energy source information hourly-daily

Table 7: WP6 DSE specification before experiments

4. Experimentations

4.1 DSE WP2: Gateway for Secondary Substations using S3C GE

A smart grid DS has to support several functionalities in order to tackle the future challenges of integration of the different energy generation sources, including:

- DS-wide monitoring of the grid status,
- Automation of grid operations,
- Automatic detection of fault conditions and restoration,
- Balancing of load / generation including reactive power,
- Efficient and reliable workforce management,
- Improved forecasting for the efficient alignment of the consumption to the generation.

This requires managing and controlling many connected devices in the smart grid DS, and automation of processes, and a variety of communication technologies will be applied in electricity networks.

The experimentation (RWTH Aachen University, institute for Automation of Complex Power Systems (ACS)) consisted of simulated devices and emulated connections, e.g. parameters according to an LTE network. Those experiments were complemented with the tests carried out in the Grenoble INP Experiment Laboratory, PREDIS, in the context of the EU FP6 funded project called INTEGRAL [4].

4.1.1 Experiments in the ACS Laboratory

From the frequency control point of view, the ever-increasing share of renewable energy resources in electricity generation has one immediate consequence: decrease in the equivalent inertia of the system which will in turn affect frequency control. With a smaller share of synchronous generators in system operation and control, there will be less kinetic energy stored in the system[1]. This means that the rotating masses can have an ever smaller contribution to frequency support following large disturbances. Therefore, faster response to such unbalances will be essential. However, this is not very easy to achieve by adjusting the generator outputs as it takes some time until they can increase their output. One idea to tackle this problem is to utilize flexible load and storage systems. Decrease or increase in the power consumption, from the frequency control point of view, is equivalent to generation increase or decrease, respectively. Considering their relatively large charging power and flexibility, electric vehicles have been suggested for the purpose of primary frequency control in recent years [7], [8].

The efforts in the ACS experiment started with the development of aggregated models for electric vehicles and building up a simulation model for a typical power system in a real-time simulation environment as will be explained in the next sections. After having the system modeled, the work was structured to investigate the following two FINSENY work package (WP) cases:

- WP2
  - Investigate the impact of communication disturbances on the contribution of EVs in frequency control of future smart grids, and by this show the benefits of specific QoS levels in power grid communication.
- WP5
  - Study the impact of sudden increase in EV charging load on system frequency,
  - Investigate benefits of smart chargers by possible contribution of EVs to frequency control in future smart grids following the occurrence of a sudden unbalance between load and generation in the system, assuming that ideal communication exists in the system.

For the purpose of simulation, one standard test case systems has been considered. This and the next steps are discussed in the next sections.

[1] The equivalent inertia of the system is the sum of the inertia of all rotating masses in the system. On the other hand, the kinetic energy stored in the power system components, which is proportional to the equivalent inertia of the system, is the means to maintain the frequency immediately following large unbalances between generation and load before primary control can activate.

4.1.1.1 Experimentation Setup

The experimentation facilities at the RWTH Aachen University, institute for Automation of Complex Power Systems lab are shown in Figure 5. This setup is composed of the RTDS® which can communicate through a Local Area Network (LAN) to a real-time PC on which a LabVIEW program representing the control center runs. The analogue I/O signals of RTDS, which are provided by its Giga-Transceiver Analog Input and Output (GTA I/O) cards, are exchanged with a National Instruments (NI) Peripheral Component Interconnect Express (PCIe) Field Programmable Gate Array (FPGA) chip. The FPGA chip is embedded in a LabVIEW real-time target PC which prepares and exchanges signals with the network. The control center decides the necessary control actions based on the measurements performed in the system. These decisions are then sent to the power system through the communication network. As shown in the figure, a Wide Area Network emulator (WANem) emulates the communication disturbances that may occur.

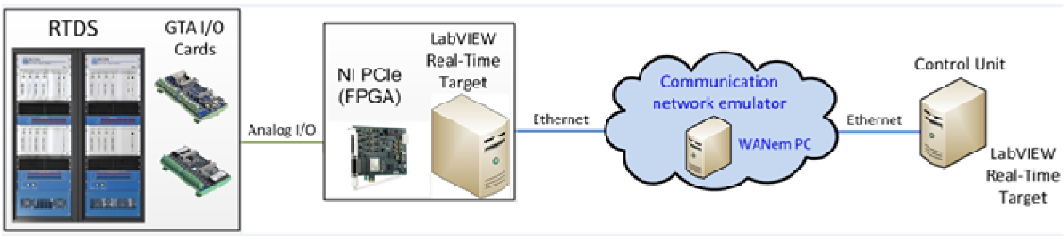


Figure 5: Experiment setup schematic

This experiment requires modeling of two major systems, namely power system and communication system. The modeled systems then need to interact with each other. RTDS® and WANem are used for modeling of the power and communications systems respectively.

RTDS® is a fully digital electromagnetic transient power system simulator which works in continuous, sustained real time. That means that it can solve the power system equations fast enough to continuously produce output conditions that realistically represent conditions in the real power system. This is a significant advantage over traditional simulation platforms such as Matrix laboratory (MATLAB) and Power Simulation Program with Integrated Circuit Emphasis (PSPICE) and Power System Analysis Software Package (PSASP), in which the simulation is done in a time rate depending on the computational capabilities of the machine. Using RTDS® for real-time simulation provides the basis for a further step which includes real communication interfaces [9].

In order to study the impact of communication system disturbances on the control loop performance, a network emulator called WANem is used. WANem is a Wide Area Network (WAN) emulator which is designed to emulate WAN characteristics such as delay, packet loss, packet corruption, disconnections, packet re-ordering, jitter, etc.

The characteristics of the communication network to be emulated in WANem [10] are either obtained from statistics or via simulation of the communication network using simulations tools like OPNET [11].

4.1.1.2 Test Case Description

Institute of Electrical and Electronics Engineers (IEEE) 39 bus system is selected as a typical and standard system with multiple generators. The system is slightly modified by dividing bus 39 to bus 39 with load and bus 40 with a generator.

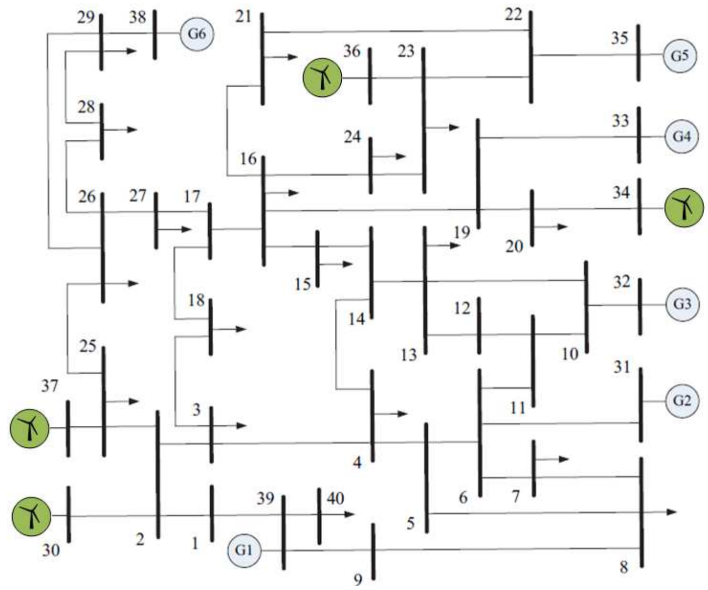


Figure 6: Modified IEEE 39 bus system [7]

A summary of the above system data is given in Table 8:

Number of buses	40	Number of loads	18
Number of conventional generators	6	Number of lines	35
Number of wind generators	4	Number of transformers	12

Table 8: Brief summary of the modified IEEE 39 bus system

Ireland has set the initial target of 10% of the car fleet or roughly 230,000 to be electrified by 2020 [12]. For 2050, the passenger car fleet is expected to increase to about 2.9 million with about 60% being electric vehicles. This translates into about 1,740,000 electric vehicles [12], [13].

The peak load of the Irish network was 4,589MW in 2012 and this is expected to rise up to about 5,800MW in 2020 [14], [15]. Therefore, the 39 bus system as used in this experimentation with a total load of about 6,000MW has a similar load level as the Irish network in about 10 years from now. It is also assumed that a considerable share of the total generation comes from wind turbines. This is in order to have the scenarios match with Irish government targets of 40% electricity consumption from renewable energy resources by 2020 [16].

Based on the above information, the following base scenario of load and generation and EV number is considered:

Total generation of conventional generators	Total generation of wind generators	System load (before connection of EV loads)
5550MW	650MW	6150MW

Table 9: Description of the base scenario

It is also assumed that a total number of 230,000 electric vehicles exist, but they are not charging in the base case scenario and therefore have no impact on the system.

The algorithm used in this experimentation for the demand side management control is developed at the Institute for Automation of Complex Power Systems at RWTH Aachen University [17]. This algorithm uses a centralized adaptive load shedding approach which considers both active and reactive power. As a result, it can address the combined voltage and frequency stability issues more effectively compared to conventional methods in which under frequency load shedding and under voltage load shedding are usually performed separately.

4.1.1.3 Conduct of Experiment

In order to tackle the future challenges of integration of the distributed energy resources, and the challenges of the smart consumption of energy, the communication technology has to support various smart grid functionalities in different environmental conditions. Therefore, the target in this experiment was to better understand how the disturbances in the communication system may affect the EV load management contribution to the primary frequency control. In order to best reflect a real environment, we assumed that the communication link is not ideal and has some variations in terms of latency, jitter and packet loss.

The test scenarios included the transfer of data across different emulated communication links. The parameters of the WANem emulator were changed in order to show the impact of the different communication characteristics on the distribution system and control loop.

4.1.1.4 Experimentation Results

As mentioned previously, the WP2 experiment aims at investigating the impact of communication system disturbances on the contribution of EV load management on primary frequency control. It is assumed that 200,000 EVs with an average charging power of 3kW are already connected to the system at t = 0 and a major part of the system generation is suddenly disconnected at t = 3s. In this experiment, the communication link is considered to have some disturbances. The following scenarios of network disturbances are considered:

Scenario number	Network	Bandwidth (Mbps)	Latency (round-trip) (ms)	Jitter (Packet delay variation) (ms)	Packet loss (%)
1	xDSL	5	11	4	0
2	xDSL	5	19	6	0
3	LTE	15	19	6	0.025
4	LTE	15	55	20	0.5
5	GPRS	0.5	500	100	0
6	GPRS	0.5	500	100	15

Table 10: Communication disturbance scenarios

These parameters are applied to the system using WANem web interface, as mentioned in the previous section. A snapshot of the web interfaces is shown in Figure 7:

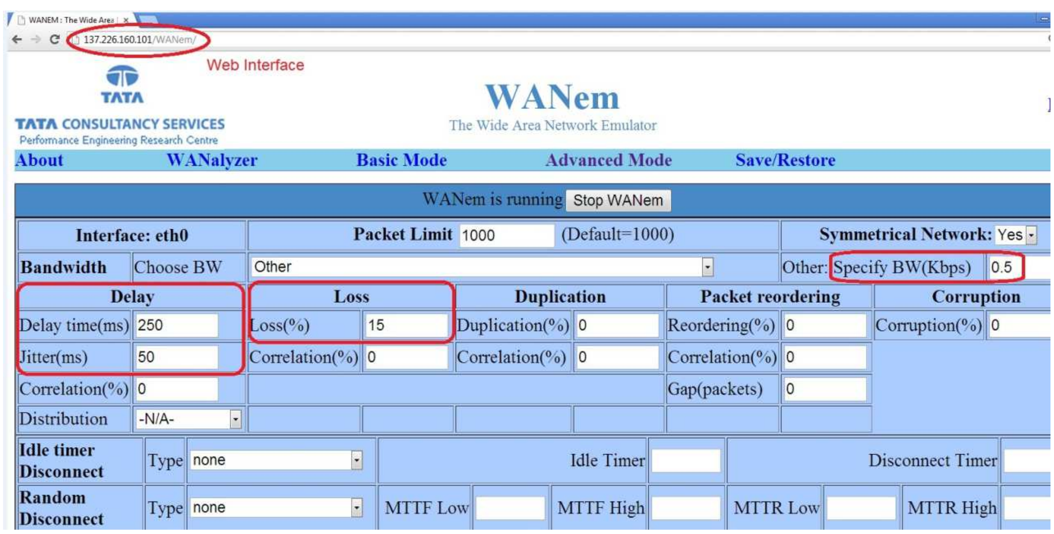


Figure 7: WANem web interface for applying communication interfaces

The following figures show the frequency response of the system in presence of the above disturbances:

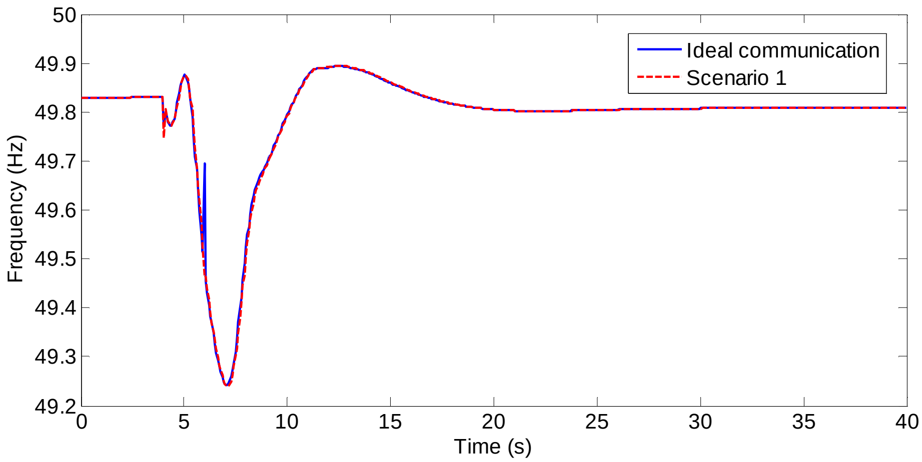


Figure 8: Scenario 1 with 15ms of delay compared to the case with no delay

Comparison of scenario 1 with the case of ideal communication depicted in Figure 8 shows that a delay of 15ms does not have any considerable impact on the system frequency response.

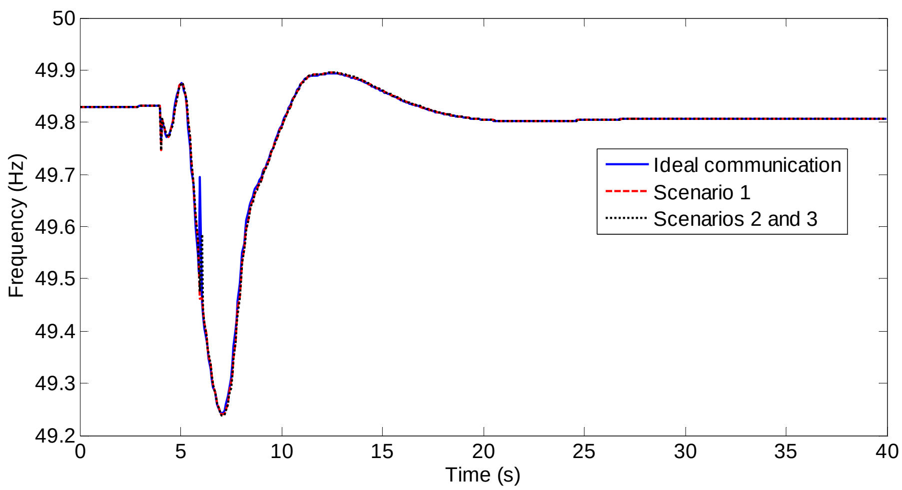


Figure 9: Scenarios 2 and 3 compared with scenario 1 and the test case of ideal communication

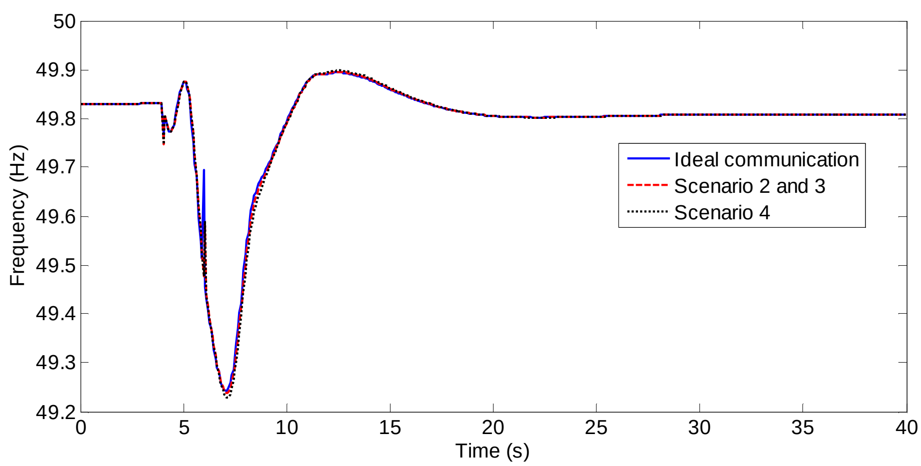


Figure 10: Scenario 4 compared with scenarios 2 and 3 and the case of ideal communication

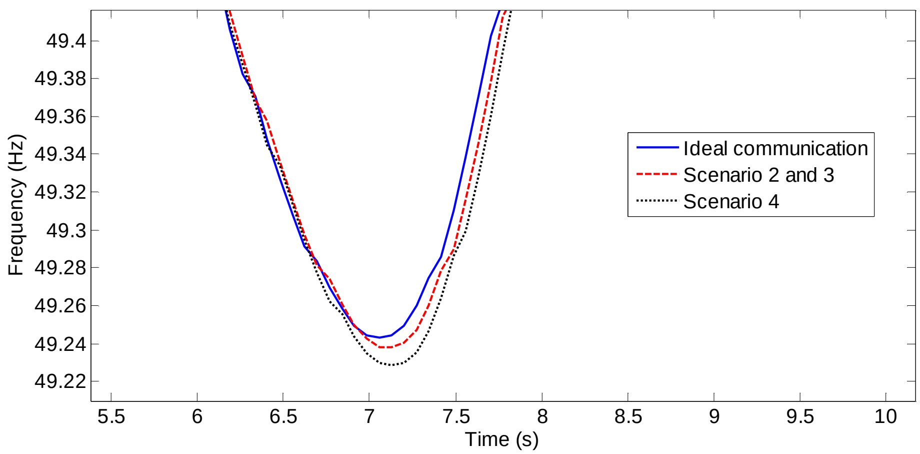


Figure 11: Closer view of the frequency response in scenario 4 compared with scenarios 2 and 3 and the ideal communication

The plots shown in Figure 9 to Figure 11 suggest that the communication disturbances defined in scenarios 1-4 do not have significant impact on the system behavior.

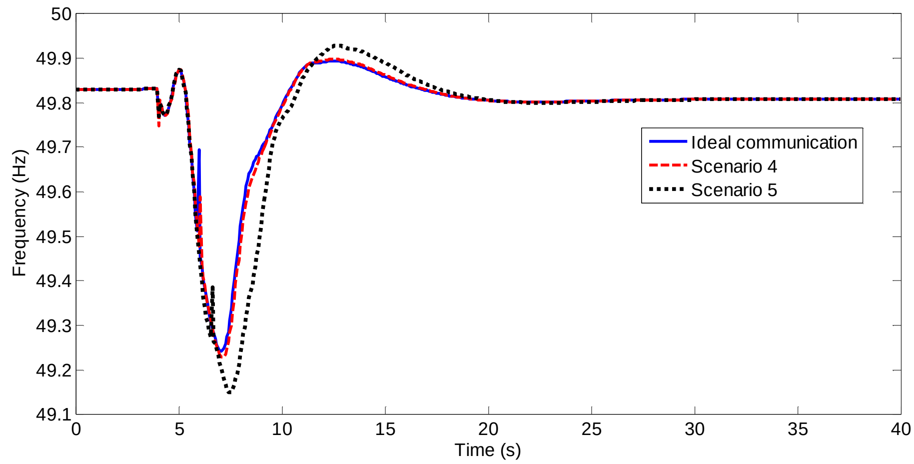


Figure 12: Scenario 5 compared with scenario 4 and the case of ideal communication

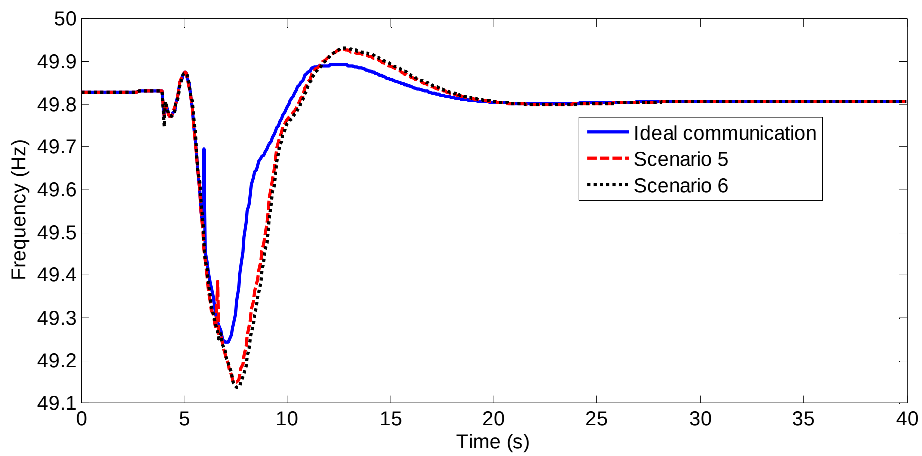


Figure 13: Scenario 6 compared with scenario 5 and the case of ideal communication

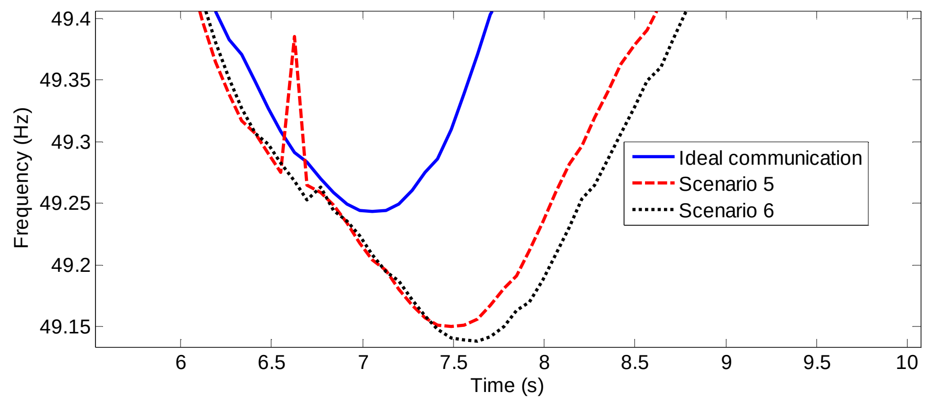


Figure 14: Closer view of the frequency response in scenario 6 compared with scenario 4 and the ideal communication.

As can be seen from Figure 12 to Figure 14, the communication disturbances defined by scenarios 5 and 6, namely communication delays of about 500ms (and packet loss) have visible impact on the system response.

4.1.1.5 Assessment

The different sets of communication characteristics lead to different frequency response behavior. It can be seen that with increase of the delay and packet loss in the communication system, the power system frequency may drop to lower values following sudden decrease in the power generation.

Although the delay and packet loss did not cause any serious problem for the system stability and control in the above tests, this cannot lead to the conclusion that communication disturbances such as delay and packet loss may not endanger the secure operation of the power system in a general case. To support this point, it should be mentioned that today's power systems are supplied by predominantly conventional generation units, which have large rotating masses and help the system avoid large frequency variations right after large disturbances. In the future systems, which will be fed by a higher share of renewable energy resources, these masses will not be present and this makes the frequency drop for a certain mismatch of power generation and consumption considerably bigger. As a result, some communication disturbances that may have minimal effects in today's systems may result in severe problems in future power systems. In addition, it should be emphasized that an advanced method for load shedding [17] is used which allows larger delays than traditional methods.

The use of public telecommunication infrastructure is in many cases the evident choice due to economic and availability reasons. For comparison, the key characteristics of the different radio technologies have been presented in Figure 15 below. As can be seen by this experiment, the selected network characteristics have different impact on the control of the power system. A gateway providing guaranteed communication characteristics can help to allow the use of public communication infrastructure for control actions in the power system such as load shedding by electric vehicles.

	EDGE-E	WCDMA	HSPA	LTE
Peak data rate DL/UL	1.3 Mbps/ 653 kbps **	384/384 kbps **	14/5 Mbps **	299/75 Mbps **
Latency	70-80ms *	180-200 ms *	80-100ms *	10-20ms *
Bandwidth	200 kHz	5MHz	5MHz	1.25 - 20MHz

Sources:
* HSPA to LTE-Advanced, Rysavy Research / 3G Americas, September 2009
** FINSENY Deliverable D3.2

Figure 15: The key parameters of the cellular radio technologies

4.1.2 Experiments in the Grenoble INP Laboratory

The Infrastructures in Grenoble INP premises are focused on emergency operating conditions, and on showing the self-healing capabilities of the DER/RES aggregations. The aim of the experimentations in the INTEGRAL project was to provide solutions for reducing the outage time and operation costs due to a fault occurrence within the network. The results of the experimentations, where the focus was on the analysis of the impact of the communication network performance (latency, error and bandwidth) on detecting, localizing and isolating the fault within the grid, were made available to the FINSENY project. The test procedures and the evaluation of the results in the INTEGRAL project have been presented in INTEGRAL deliverables D8.1 (Definition of test and evaluation procedures) [5] and D8.2 (Evaluation of the Results and Guidelines for EU Research) [6].

To be able to evaluate the ICT performances requested by the self-healing agent, different independent (Virtual Local Area Network (VLAN)) sub communication networks (area) including homogenous devices (VLAN 210 FPI-Fault Passage Indicator, VLAN 211 Substation Fault recorders and FPI database, VLAN 212 agent, VLAN 213 SCADA) and associated monitoring have been developed, see Figure 16. The communications needed for the self-healing process are completely controlled by an emulated ICT system. This network (Level 1 in Figure 16) is able to control bandwidth, latency and error rates but also to analyze all the protocols used between RTUs, agent and SCADA during a fault. The level 2 presents the different RTUs (real communicating fault passage indicator, fault recorders), a distributed database, the agent and the SCADA server. The level 3 presents the Programmable Automation Controllers (PACs) and other controllers of the test bench.

In the experiment carried out in the INTEGRAL project the self-healing function was tested. In that test, the Distribution System Operator (DSO) used the high-level functionality to detect and isolate the faulty section of the network. Several options of bandwidth, error and latency were applied in the communication network between the RTUs and the agents.

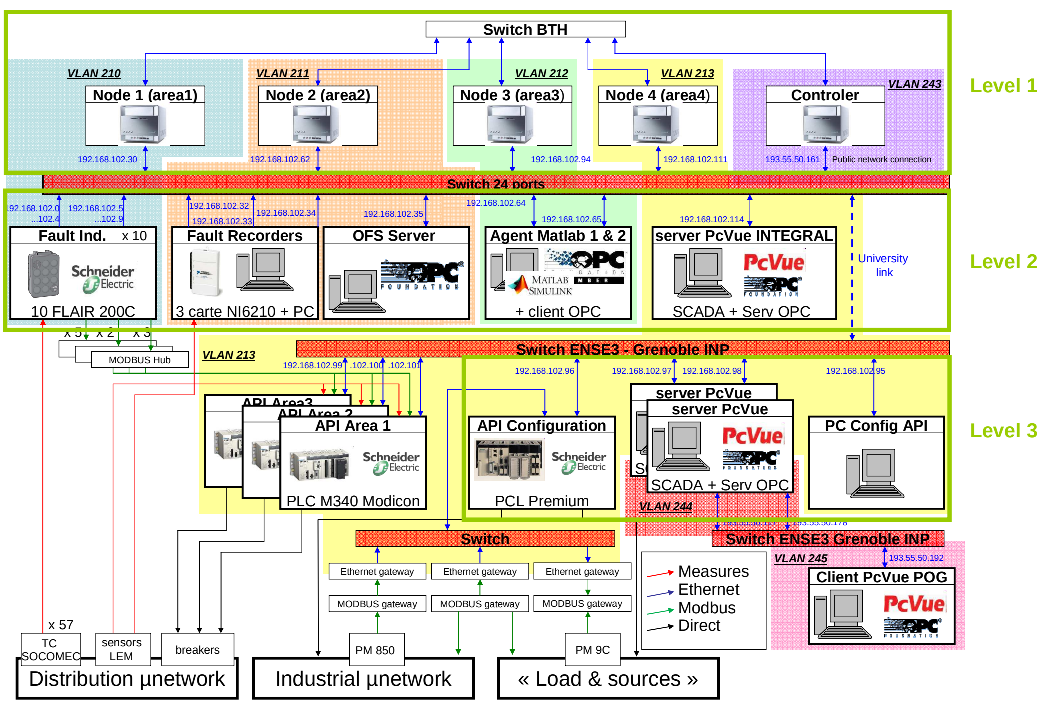


Figure 16: The ICT infrastructure of the system used in the INTEGRAL project

4.1.2.1 Conduct of Experiment

In the INTEGRAL project several test scenarios were run, including:

- Fault location (seven lines can handle overloads in the distribution network),
- Grounding of the substation (both resistive and impedance grounding are available),
- Type of the fault (single phase, two phases, two phases to ground and three phase faults),
- **Communication network performances (latency, error rate and bandwidth)**,
- Power flow inside the network (loads and sources),
- Topology of the network before the fault (normally open point location in loop able structures).

The use of the self-healing approach is one of the emerging ideas to protect the electric power system against the catastrophic failures. In the test scenario communication network performance, which is relevant also for the FINSENY project, the self-healing function was tested. In that test, the DSO used the high-level functionality associated with the ADA devices to detect and isolate the faulty section of the network.

Several options of bandwidth, error and latency were applied in the communication network between the RTUs and the agents in the INTEGRAL project. For FINSENY, however, the results were made available from the experiments, where different latencies but only unlimited data rates were used.

4.1.2.2 Experimentation Results

Table 11 presents the different tests done to assess the influence of the developed self-healing solution in respect with the telecommunication infrastructure performance. It presents the dependency of the complete self-healing ADA function duration (fault location-isolation-restoration) compared to the evolution of the delay in area 3 which represents the agent units.

Faulty line 11; fault type: two phases to ground fault type, communication performances at node 3 with a unlimited bandwidth on every area (VLAN 21x)			
Test label	Latency (obtained by a ping: round trip)	Duration of the complete self-healing process (sec.)	Success @ statistical confidence in faulty section identification
A14	1ms	8,7s	OK @ 59,1%
A15	40ms	14,97s	OK @ 59,1%
A16	80ms	22,72s	OK @ 59,1%
A17	120ms	32,11s	OK @ 59,1%
A18	160ms	40,63s	OK @ 59,1%
A19	200ms	49,17s	OK @ 59,1%
A20	240ms	57,92s	OK @ 59,1%

Table 11: Results for latency variation (all are successful, the percentage shown is the confidence of the agent within the first statistically proposed area to locate the fault)

The tests show clearly the dependency between the self-healing function and the communication infrastructure performance. Communication standards such as IEC 61850 are already pointing out the needs of low latency communication for the very specific communications related to network protection. These conclusions can thus be extended to the developed self-healing function which needs to transfer a large amount of data as the electrical distance is not computed inside the fault recorder, this mean data of more than 250 kb to transfer through OLE for Process Control (OPC) protocols.

4.1.2.3 Assessment

If a typical latency from the Internet (typical long latency 160ms) is used in a smart grid application with the self-healing ADA function implementation, the performance can be as bad as 40 seconds for the complete detection, isolation and restoration process in our specific case.

The self-healing process is not linked with the protective relay coordination and does not need real time communication performance related with the protection systems (down to few ms for usual differential protections). Nevertheless, if a near real time communication performance is achieved for the agent, the customers will be re-energized quickly. The goal of the agent is to reach a service restoration faster than the service restoration with a human (operator) in the loop. This means that the overall performance (sensor + communication + agent computerization + communication to switches + execution + feeder breaker action) is around 30 seconds (compare to an average of 240 seconds today).

Based on the results from the experimentation in the INTEGRAL project, the final assessment on the viability of using a cellular network as a communication channel beneath the DSE “Gateway for Secondary Substations using S3C GE” is difficult, since the experiment covered only the case where the data rate was unlimited. However, since the latencies of the cellular radio technologies (see Figure 15) are far below the typical long latency of the Internet, and since their data rates are much higher than the data rates of the old media used in the power systems (see Table 12), one may conclude that these technologies would be viable as the communication channel beneath the DSE in question in the self-healing function.

Transmission media	Data Rate
Frame Relay	280kbps
ISDN	140kbps
T1 fractional	62.5kbps
56k leased line	565kbps (effective bandwidth lower than this)
Radio frequency	9.6kbps
Power line carrier	1.2kbps

Table 12: Data rate of usual media used in the power systems

4.2 DSE WP3: IEC 61850 Protocol Adapter

4.2.1 Experiment Availability

IEC 61850 is a key standard for Smart Grids and the WP3 DSE "IEC 61850 protocol adapter" will ensure interoperability between systems and devices in a microgrid and beyond. In several other activities also the applicability of IEC 61850 outside of a substation was demonstrated successfully. On the information layer extensions for DERs were defined in IEC61850-7-420 and are currently improved by several technical reports in the IEC 61850-90 series. On the communication layer new mappings like Web services are discussed in IEC TC57 for Abstract Communication Service Interface (ACSI) as defined in IEC61850-7-2 to develop IEC61850-8-2. Other research projects have shown successfully for the information layer as well as the communication layer that IEC61850 can be used for smart energy aggregation platforms like microgrids, Virtual Power Plants (VPPs) or aggregator systems. Examples are the E-Energy projects RegModHarz and E-DeMa.

For the microgrid scenario sensible tests on for instance the QoS of microgrid control communications would go beyond the current state-of-the-art but need the full microgrid control logic. Due to the complexity of the microgrid scenario this could not be shown in FINSENY for the whole scenario but only for selected use cases. Hence, we focused on the experimentation of communication disturbances.

4.2.2 Experimentation Setup

The experimentation model at the "Institut für Hochspannungstechnik der RWTH" is shown in Figure 17. This setup is composed of the grid itself, which reacts to power deviations and calculates the resulting frequency deviation. The grid failure block is adding a frequency noise, caused by switching loads and can simulate any size of incident to the grid. The frequency load control is shown by the VPP coordinator and the VPP. The latter contains the DER. The coordinator meters the current frequency at any time of simulation and decides the necessary control actions, due to a frequency deviation of ±20mHz. This new type of control is not required by toady's prequalification. After a failure in the grid has been accounted, the coordinator calculates the power output due to the frequency deviation and sends signals to every single unit of the VPP. Before those signals reach the single power plant unit, several communication disturbances can be emulated. After the VPP received the signal it will activate the Frequency Containment Reserve (FCR) (primary reserve).

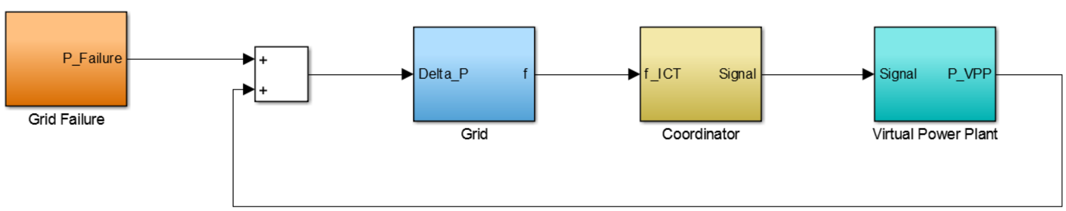


Figure 17: Experiment simulation model

4.2.3 Test Case Description

This system is based on the recommended practice of ENTSO-E technical characteristics to the synchronous area of the Continental Europe. The other synchronous areas (Great Britain, Irland, Nordic and Cyprus), will not be considered. The model works with an ideal one-bus-network. If all impedances are neglected, the whole transmission grid is reduced to one bus. The impedances have only a slide influence on the frequency, that's why the assumption was made, that the frequency at any point in the network is equal.

The following assumptions have been applied for the definition of marginal conditions for the operation of FCR, according to ENTSO-E guidelines. The European synchronous area has a system off-peak load of 150GW and a peak-load of 300GW and the self-regulation effect of load is 1.5%/Hz. To analyze the marginal operating conditions of the network, the off peak load of 150GW is selected.

Self-regulation of loads	System load	Additional reserve of self-regulation effect (200mHz)	Additional reserve of self-regulation effect (800mHz)
1.5%/Hz	150GW	450MW	1800MW
1.5%/Hz	300GW	900MW	3600MW

Table 13: Addition reserve of the self-regulation of loads

Table 13 shows the self-regulation effect due to the minimum and maximum instantaneous frequency, which is defined to be 49.2Hz and 50.8Hz (corresponds to ±800mHz as maximum permissible dynamic frequency deviation from the nominal frequency f_0) in response to a shortfall in generation capacity, a loss of load or interruption of power exchanges equal to or less than the reference incident of ±3000MW. The maximum permissible quasi-steady-state frequency deviation is ±200mHz.

4.2.4 Conduct of Experiment

In this analysis the requirements for information and communication technologies will be defined by comparing different power gradients of VVPs and its parameter variation. Those requirements for ICT are a tradeoff between the prequalification of FCR and the grid stability. Therefore, Computing Time Delay (CTD), Sampling Time Delay (STD) and Transporting Time Delay (TTD) are the major disturbances in the IT and communication system. In order to show their impact on the system stability, different communication characteristics and incidents in the synchronous area are emulated.

4.2.5 Benchmarks of Experiment

1. Physical deployment time
   - 15 seconds to disturbances ΔP of less than 1500MW
   - 30 seconds to disturbances ΔP greater than 1500MW,
2. Maximum permissible frequency deviation quasi-steady-state: ±200mHz,
3. Maximum permissible frequency deviation dynamic-state: ±800mHz,
4. Maximum permissible frequency overshoot (OVS) per frequency deviation of the ideal system to f_0: 20%,
5. Maximum permissible frequency oscillation (OSC) in quasi-steady-state per frequency deviation of the ideal system to 50Hz: 10%.

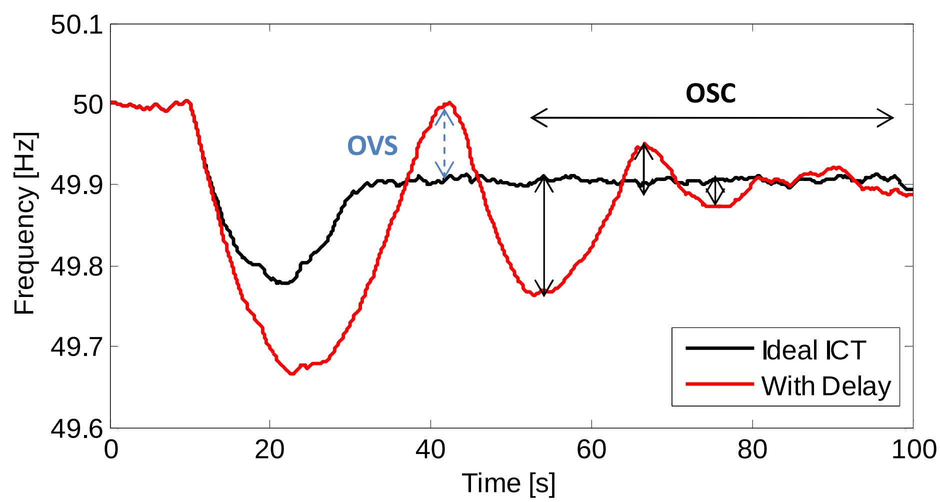


Figure 18: Experimentation benchmarks

$$OVS = \frac{|f_{ideal_{qss}} - fovs|}{|f0 - f_{ideal_{qss}}|}$$ **Equation 1**

$$OSC = \frac{|f_{ideal_{qss}} - fosc|}{|f0 - f_{ideal_{qss}}|}$$ **Equation 2**

4.2.6 Experimentation Results

The latency of information and communication technologies always affects the performance of real-time systems when digital control or signal processing is involved. This chapter demonstrates the impact of different ICT delays on the system stability. Relevant influence coefficients are computing delays, sampling delays and transporting delays. Table 14 shows the following scenarios, with its benchmarks.

Scenarios	Variation of delays	Benchmarks
Computing Time Delay	0 - 30s 0 - 5s	Frequency deviation
Sampling Time Delay	0 - 5s 0 - 2s	Frequency overshoot Frequency oscillation
Transporting Time Delay	0 - 5s 0 - 1s	Frequency overshoot Frequency oscillation

Table 14: Scenarios and benchmarks

4.2.6.1 Computing Time Delay

The computing time delay is the time between the detection of a grid failure and the first dispatch of signals to a single unit in the VPP. The implementation can be such that the distribution system controller output is directed to the plant immediately when the actual computations are finished. After the first signal has been send the computing time is less than the constant sampling interval. Loss of packages may occur when the time-varying CTD is greater than the sampling interval. This, however, will not be discussed in this experiment.

Benchmark

The minimum and maximum deviation of frequency from the nominal frequency (the difference "$f\text{-}f_0$" of the actual system frequency f from the scheduled frequency f_0) will be taken as a benchmark for the impact of different CTD.

Benchmark	Permitted range	Prohibited range
Physical deployment time	$t \leq 30s$	> 30s
Instantaneous frequency	$f \geq -800mHz$ $f \leq 800mHz$	$f < -800mHz$ $f > 800mHz$

Table 15: Benchmark

The CTD is determinate by two parameters, the min-/maximum instantaneous frequency and the physical deployment. A VPP with an overall power gradient of 100%/30s will not be prequalified by Transmission Service Operator (TSO), because the communication latency between the coordinator and the VVP will increase the physical deployment time.

Figure 19 and Figure 20 are two examples for different power gradients, virtual power plant 100 (100%/30s), which implies a physical deployment time of 30s. Simultaneously, virtual power plant 600 (600%/30s) has a physical deployment time of 5s. The negative power gradient is in all scenarios 600%/30s, which can be seen in Figure 20, where the result is symmetrically to a 0MW incident or the 50Hz axis.

Simulation results - computing time delays - frequency deviation [Hz]

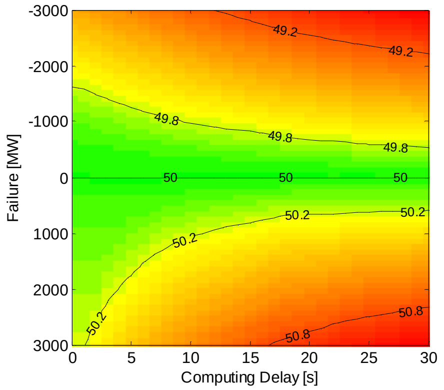


Figure 19: Power gradient 100% - 30s

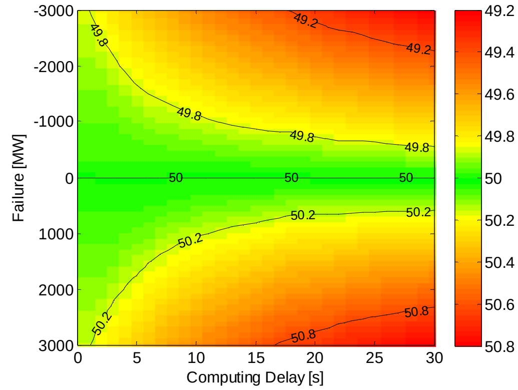


Figure 20: Power gradient 600% - 30s

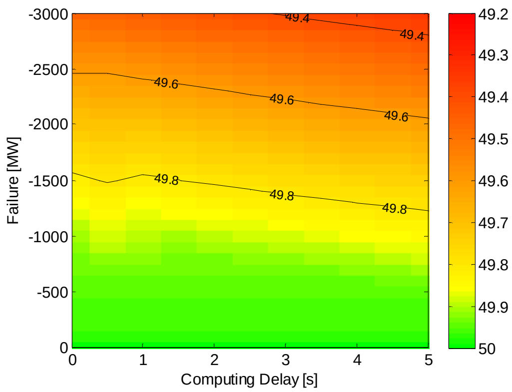


Figure 21: Power gradient 100% - 5s

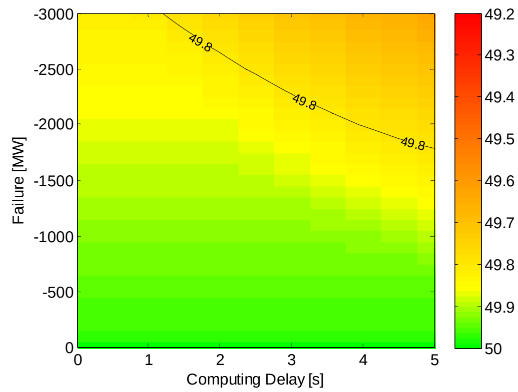


Figure 22: Power gradient 600% - 5s

The green colored area between 49.8Hz and 50.2Hz illustrates the “best case” scenario. The more time the computing takes, the more the frequency deviation increases. At the same time, the quasi-steady-state frequency deviation borders converge to related primary control reserve activation. A detailed enquires can be seen in Figure 21 and Figure 22, in which a CTD of 5 seconds and a shortfall in generation capacity is considered. No violations of prequalification standards are committed. Therefore, a CTD of 5s is a permitted value.

Comparing the different VPP on the basis of the power gradients, it appears that the dynamic frequency deviation of ±800mHz is reached later by faster working systems. Computing time delay has greatly degrading effects on control system performance.

To point out the effect of the latency between the incidents and the activation of the frequency containment control system, the reaction of a VPP with a power gradient of 150%/30s caused by a frequency deviation is shown in Figure 23. For the following, a reference negative incident of 3000MW for the synchronous area is considered.

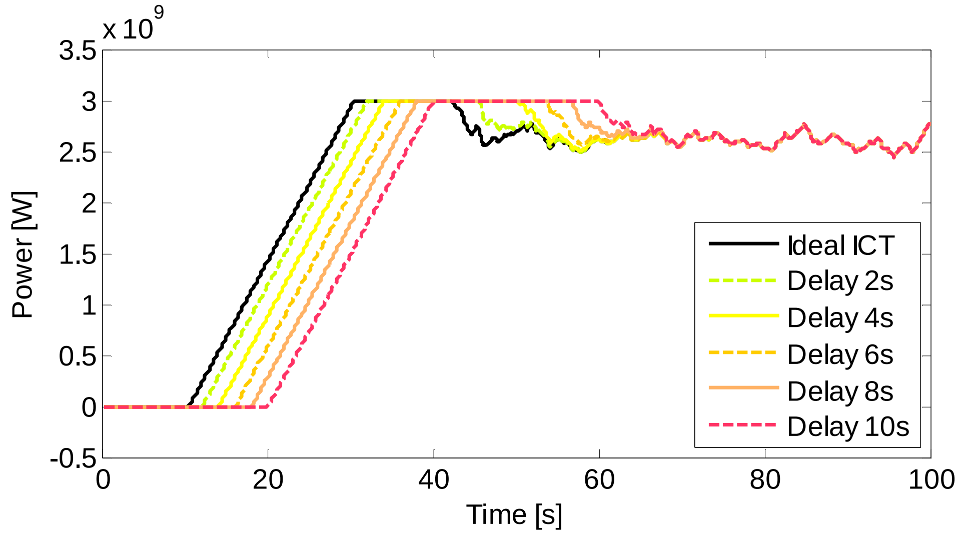


Figure 23: Computing time delay - primary control reserve

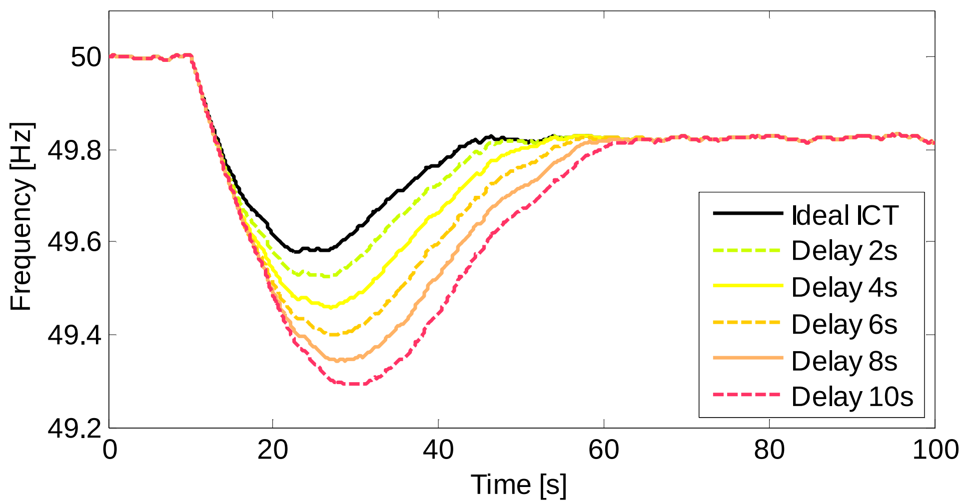


Figure 24: Computing time delay - frequency deviation

An array of activated power curves as a function of delays has been plotted. After 10s seconds the failure prevails and the maximum primary power control is activated. It can be seen, that the CTD lags the feedback. Moreover Figure 24 presents the frequency drop to 49.3Hz caused by the CTD (10s) and stabilization on higher level around 49.8Hz. Eventually, the quasi-steady-state frequency deviation is reached for all cases after 60s. This scenario shows a VPP with a computing delay up to 10s and does not exceed prequalification boundaries.

	Power Gradient [%/30s]						
Benchmark	100	120	150	200	300	600	Inf
Physical deployment time (30s)	0	5	10	15	20	25	30
Instantaneous frequency (±800mHz)	12	13	14	16	18	18	19
Computing delay	0	5	10	15	18	18	19

Table 16: Maximal permissible computing delay [sec]

The different CTDs lead to various frequency response behaviors. The delay did not cause any problems to the system stability, because all arrays converge after 60s. In Table 3 there are the maximal permitted computing delays for different virtual power plants. Those times are calculated without the upcoming delays, which will be discussed in the next chapter.

E.g. the maximal permitted CTD for a VVP with a power gradient of 200%/30s is 15 seconds. To obtain the result by comparing the two benchmarks, physical deployment time and instantaneous frequency and taking the less allowed CTD. Until a power gradient of 200%/30s, the physical deployment time limits the CTD and after that the instantaneous frequency limits it. Until now, we have no overall CTD, because of the variation of different power gradients of VPPs.

4.2.6.2 Sampling Time Delay

Until now the signals are sent continuously by the coordinator to the VPP. With the broad applications of digital communication, it is of great significance to study the consensus of sampled data. High communication traffic can be reduced by sampling intervals and effectively save the bandwidth of networks and communication costs.

In engineering application, communication delay might cause systems to oscillate or diverge, thus the disturbance of delay might effects the frequency stability. As being said before, the CTD has to be less than a sampling delay. Concluding, the sampling time delay is a determining factor for the CTD

The STD is the time in which each signal is being sent to a single power plant. Therefore, the implementation can be such that the distribution system controller output is directed to the power plant until the new sampling trigger has been reached.

Benchmark

As being said above, the disturbance of sampling a signal might have negative effects on the frequency stability, this will be tested on the mean oscillation in the quasi-steady-state frequency in comparison to an ideal communication system between the periods of 60s - 100s. The oscillation is divided by the mean quasi-steady-state frequency deviation of the ideal communication related to the nominal frequency 50Hz (see Equation 1). The lower the mean oscillation, the better is the frequency stability and therefore the operating power system.

The second benchmark is the overshooting of the frequency after the instantaneous frequency point has been passed and tries to stabilize into the permitted quasi-steady-state frequency deviation borders (49.8 and 50.2Hz). The overshoot is the maximum frequency deviation to an ideal communication system. To have comparable results, the overshoot is divided by the mean quasi-steady-state frequency deviation of the ideal communication related to the nominal frequency 50Hz (see Equation 2). Consequently, the lower the overshoot, the better is the system stability.

Benchmark	Permitted range	Prohibited range
Frequency oscillation	0-10%	above 10%
Frequency overshoot	0-20%	above 20%

Table 17: Benchmark

Simulation results - sampling time delay - oscillation [%]

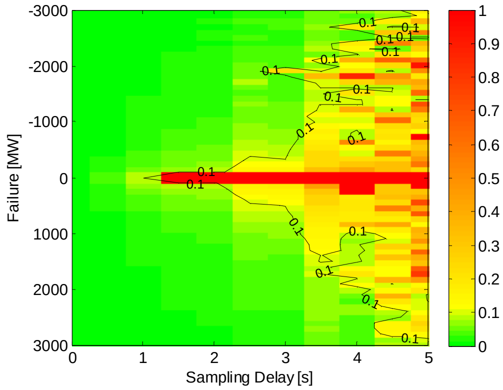


Figure 25: Power gradient 100% - 5s

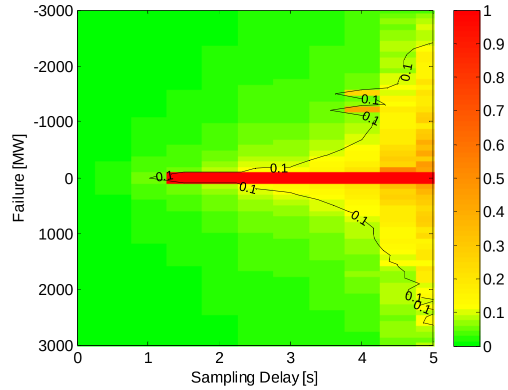


Figure 26: Power gradient 600% - 5s

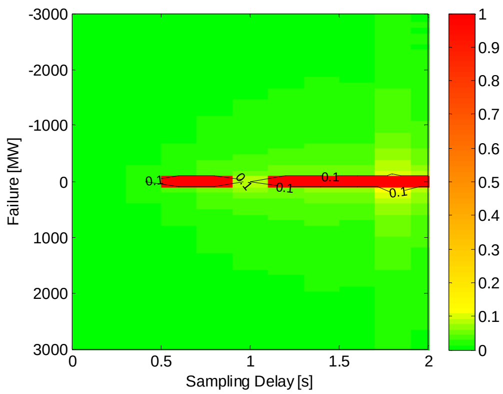


Figure 27: Power gradient 100% - 2s

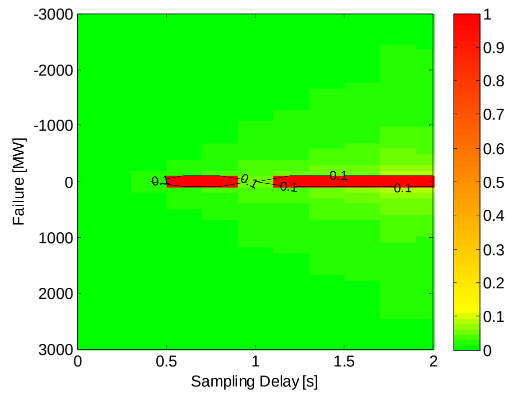


Figure 28: Power gradient 600% - 2s

The green colored area from 0 to 10% is set as the permitted area of oscillation. The longer the sampling delay, the more the frequency oscillates around the ideal quasi-steady-state frequency deviation (Figure 25, Figure 26, Figure 34. An oscillation about 100% (red area) indicates a frequency oscillation of the mean quasi-steady-state frequency deviation of the ideal system to the nominal frequency. The worst case scenario, is a deviation into the dead band (49.98Hz - 50.02Hz), which is prohibited. If the frequency enters the dead band before secondary control is activated, it may result in an unacceptable level of performance. The coordinator will not be allowed to switch off the FCR, because the frequency will drop simultaneously (Figure 33).

Besides, the power gradient has an impact on the oscillation as well. The major oscillation arises around 0MW. This strong oscillation is accountable to the modulation of the dead band and the frequency noise. Not taking this problem into consideration, the maximal permitted STD is 2 seconds.

Simulation results - sampling time delay - overshooting [%]

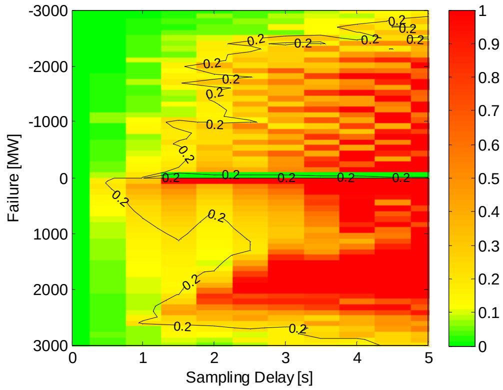


Figure 29: Power gradient 100% - 5s

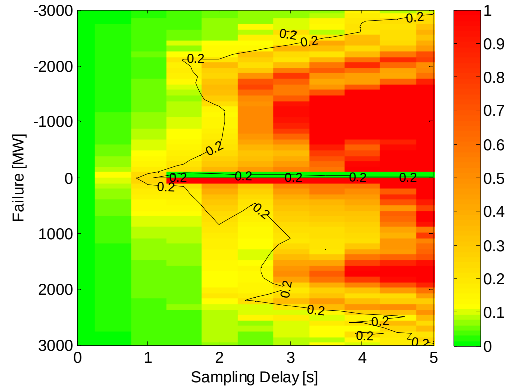


Figure 30: Power gradient 600% - 5s

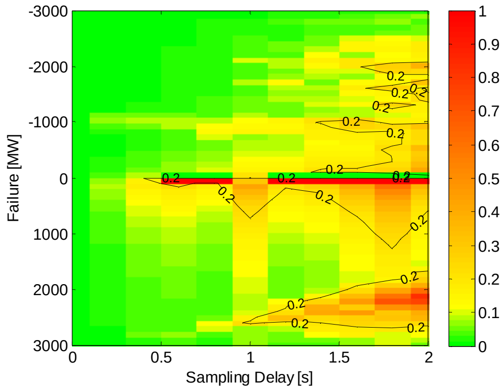


Figure 31: Power gradient 100% - 2s

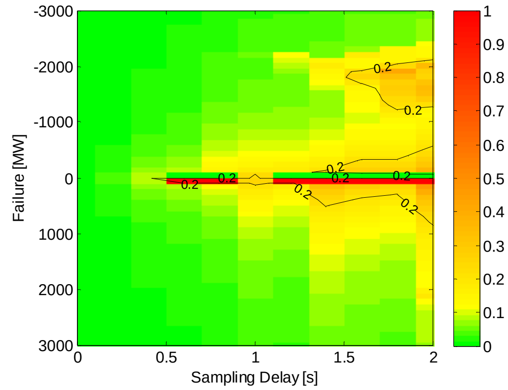


Figure 32: Power gradient 600% - 2s

The second benchmark, the overshoot, shows a different behavior. The permitted overshooting is the green colored area from 0 to 20%. The overshoot is an import indicator for the frequency stability, but incidences just once upon the period of review and always exceeds the oscillation. Therefore, the permitted area is double the size of the permitted range of oscillation.

While a longer sampling delay causes a stronger frequency deviation, a loss of load or interruption of power exchanges are not similar to a shortfall of generation. The negative power gradient of 600%/30s has an amplified reaction on the frequency deviation (Figure 31), while the slower positive power gradient of 100%/30s cannot compensate fast enough. This causes an overshoot of 20% around 1 second of STD. If both power gradients converge, the overshoot will be damped. Therefore, the overshoot is 20% around 2 seconds.

Overall, the sampling delay affects the frequency stability. To plot this effect between a continuous (ideal system) and a sampled signal, the reaction of a virtual power plant with a power gradient of 150%/30s caused by a frequency deviation is shown in Figure 34. In the following, a reference incident of 2000MW for the synchronous area is considered.

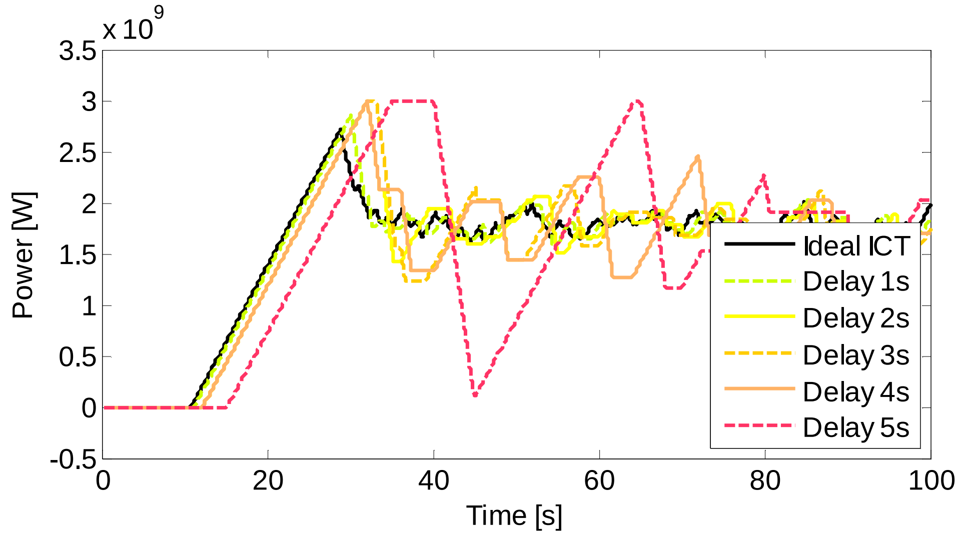


Figure 33: Sampling time delay - primary control reserve activation

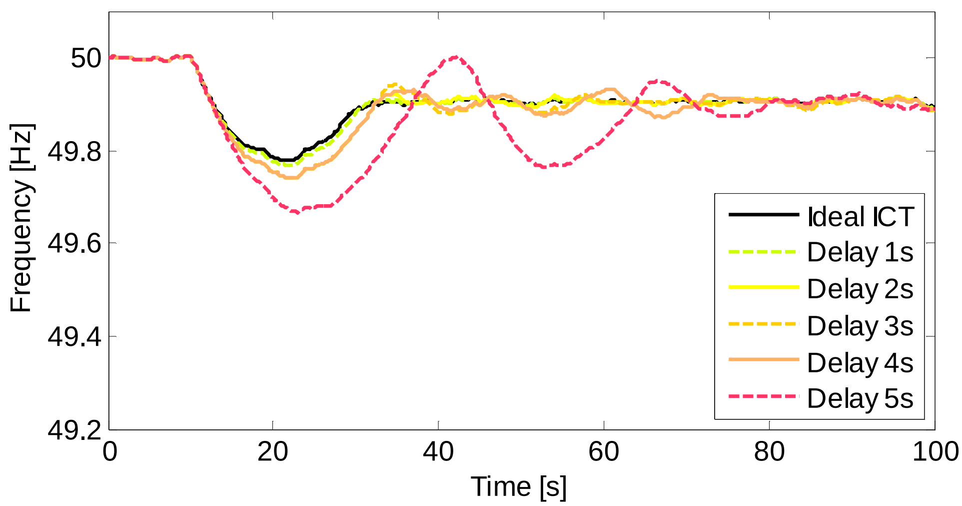


Figure 34: Sampling time delay - frequency deviation

An array of activated power curves Figure 33 as a function of delays has been plotted. After 10 seconds the failure prevails and the maximum FCR is activated. As can be seen in Figure 34, the frequency drops to 49.67Hz caused by the STD (5s) and overshoots between 30s - 40s into the dead band. This not permitted overshoot of over 100% causes a shutdown of the activated FCR. Eventually, the quasi-steady-state frequency deviation has been reached for all cases after 80s, but the sampling delay causes various overshoots and oscillations. A sampling delay below 2 seconds causes no mentionable overshoot or oscillation and therefore maintains a stable system.

4.2.6.3 Transporting Time Delay

The transporting time delay is the length of time it takes the signal to be sent by the coordinator to the VPP. This time delay therefore consists of the transmission times between the two points of a signal.

TTD might have similar effects as the STD. The latency may cause an oscillation or divagation of the ideal communication, thus the disturbance of delay might have effects on the frequency stability. The TTD has to be less than the CTD and the STD.

Benchmark

As well as the STD it will be tested on the mean oscillation in the quasi-steady-state frequency in comparison to an ideal communication system between the periods of 60s - 100s. Consequently, the lower the mean oscillation, the better the frequency stability and therefore the operating power system.

The second benchmark is the overshooting of the frequency after the instantaneous frequency point has been passed and tries to stabilize into the permitted quasi-steady-state frequency deviation borders (49.8 and 50.2Hz). Consequently, the overshoot is the maximum frequency deviation to an ideal communication system. The lower the overshoot, the better is the system stability.

Benchmark	Permitted range	Prohibited range
Frequency oscillation	0-10%	above 10%
Frequency overshoot	0-20%	above 20%

Table 18: Benchmark

Simulation results - transporting time delay - oscillation [%]

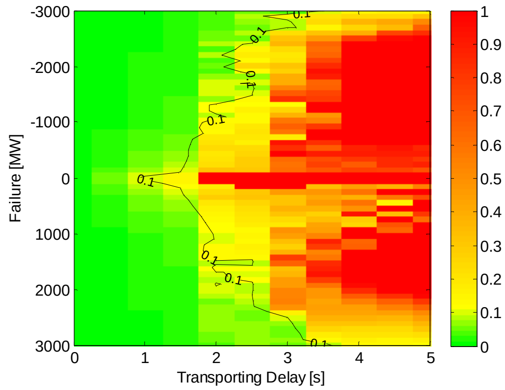


Figure 35: Power gradient 100% - 5s

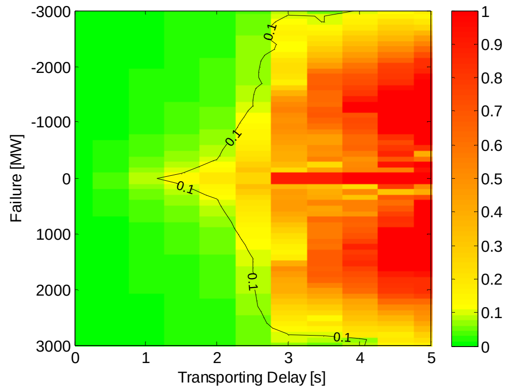


Figure 36: Power gradient 600% - 5s

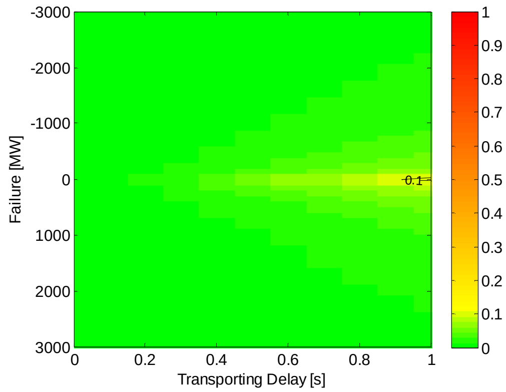


Figure 37: Power gradient 100% - 1s

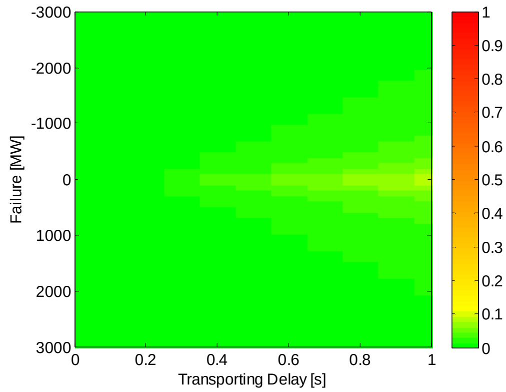


Figure 38: Power gradient 600% - 1s

Again, the green colored area from 0 to 10% is the permitted area of oscillation. The longer the transporting time delay, the more the frequency oscillates around the ideal quasi-steady-state frequency deviation Figure 44. An oscillation about 100% indicates a frequency oscillation of the mean quasi-steady-state frequency deviation of the ideal system to the nominal frequency. The worst case scenario, is a deviation into the dead band (49.98Hz - 50.02Hz), which is prohibited, as we have seen in the chapter before. Figure 35, Figure 36 (red colored area) and Figure 43 encourages this interdiction. The overshoot percolates the deadbaned and a switch of primary reserve power is displayed, although there is a negative failure. Besides, the power gradient has an impact on the oscillation as well. The major oscillation arises between failures of 500 to 2000MW. A proportional behavior of oscillation and TTD is displayed. Below a TTD of 2 seconds no amplified oscillation can be seen.

Simulation results - transporting time delay - overshoot [%]

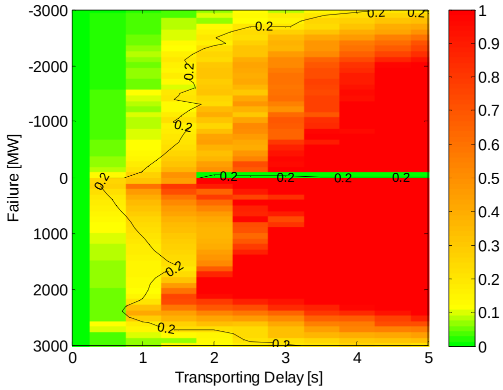


Figure 39: Power gradient 100% - 5s

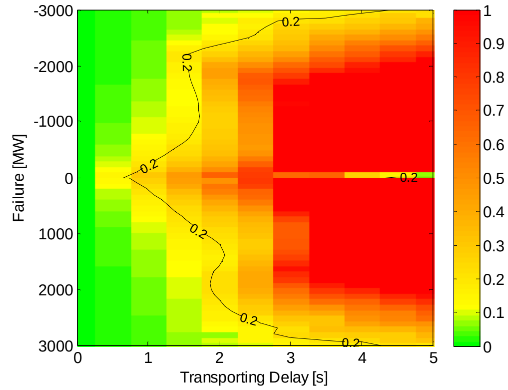


Figure 40: Power gradient 600% - 5s

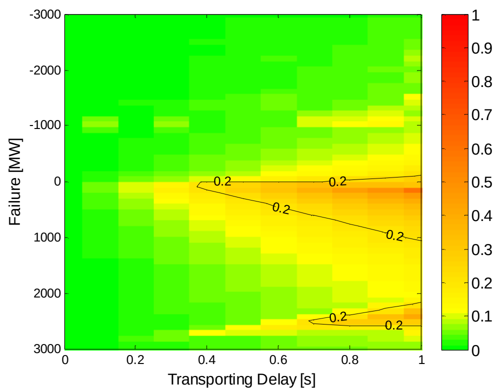


Figure 41: Power gradient 100% - 1s

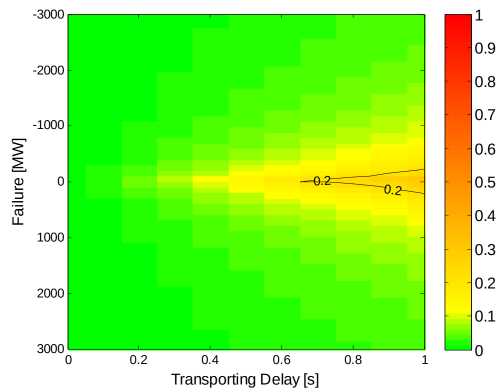


Figure 42: Power gradient 600% - 1s

The second benchmark, the overshoot, shows a different behavior. While a longer TTD causes a stronger frequency deviation, a loss of load or interruption of power exchanges are not similar to a shortfall of generation. The negative power gradient of 600%/30s has an amplified reaction on the frequency deviation, while the slower positive power gradient of 100%/30s cannot compensate fast enough Figure 41. If both power gradients converge, the overshoot will be damped Figure 42. As the oscillation, the overshoot reacts proportional to the time delay. But a TTD of 2s let the frequency overshoot too much (over 50%) Figure 39.

Overall, the TTD affects the frequency stability, from 3s upwards. To plot this effect between a continuous (ideal ICT) and a signal with a TTD, the reaction of a VPP with a power gradient of 150%/30s caused by a frequency deviation is shown in Figure 44. In the following, a reference incident of 2000MW is considered.

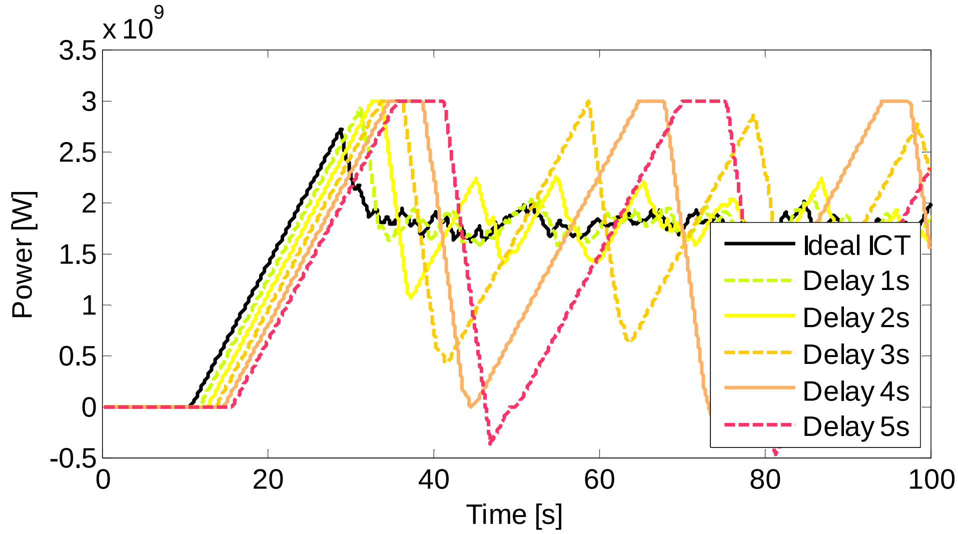


Figure 43: Transporting time delay - primary control reserve activation

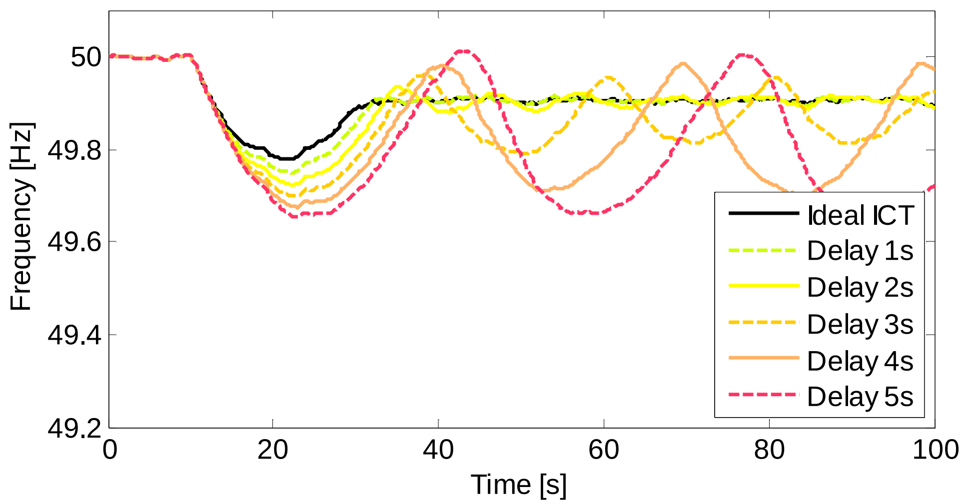


Figure 44: Transporting time delay - frequency deviation

An array of activated power curves, as a function of delays, has been plotted. After 10 seconds, the failure prevails and the maximum primary control reserve is activated. The frequency drops to 49.65Hz caused by the STD (10s) and overshoots to 40s. Eventually, the quasi-steady-state frequency deviation has been reached the first three cases. Above a TTD of 2s, it causes various overshoots and oscillations. A transporting time delay below 2s causes no mentionable overshoot or oscillation and therefore maintains a stable system.

4.2.6.4 Final ICT Requirements

Due to the predetermination of requirements in the last three chapters the following information and communication technologies requirements are set.

Delay type	Maximum permitted time delays
Computing time delay	< 2 seconds
Sampling time delay	≤ 2 seconds
Transporting time delay	≤ 1 second

Table 19: ICT requirements

The CTD only lags the activation of FCR, while the STD and TTD have a significant impact on frequency oscillation and overshoot. A CTD of less than 2 seconds is negligible, if the problem to solve is simple. Even an algorithm, which might exceed the 2 seconds, a faster computing cluster, may solve it faster. Aside, the STD is not strictly limited to the computing time, but has to be longer. Reducing the STD decreases the permitted CTD, but increases the computing time at the same time, because of the enhancement more data traffic and therefore has to be selected carefully. The TTD is limited to the used broadcast, which has been discussed in ICT. GPRS has RTT of 500ms and represents the slowest communication technic of the state of the art.

In the following two variations of time delays and their impact on a 3000MW failures and different power gradients are presented. The first simulation shows the frequency deviation and FCR activation with the maximum permitted time delay (Table 19). The second simulation is an indicator for the most realistic combination of communication disturbances, which has been set to [CTD:1s, STD:1.5s, TTD:0.5s].

Requirements results - 3000MW failure - CTD 2s, STD 2s, TTD 1s

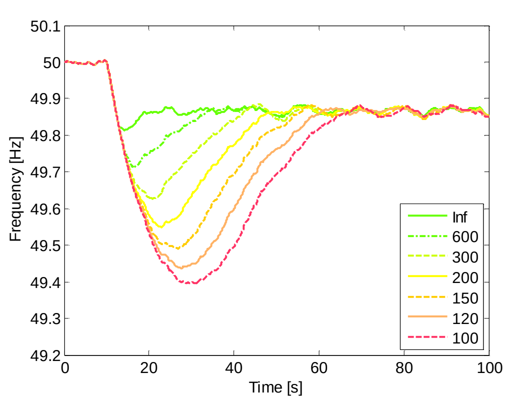


Figure 45: Frequency - C2S2T1

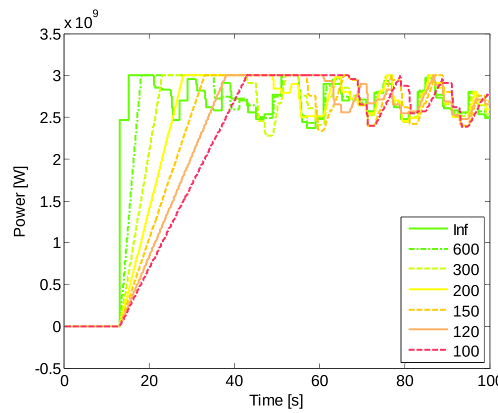


Figure 46: Power - C2S2T1

Requirements results - 3000MW failure - CTD 1s, STD 1.5s, TTD 0.5s

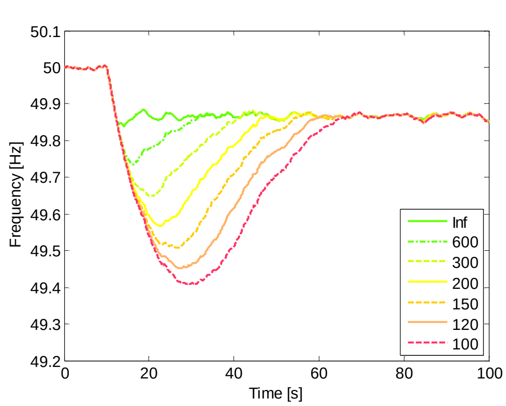


Figure 47: Frequency - C1S1 T0.5

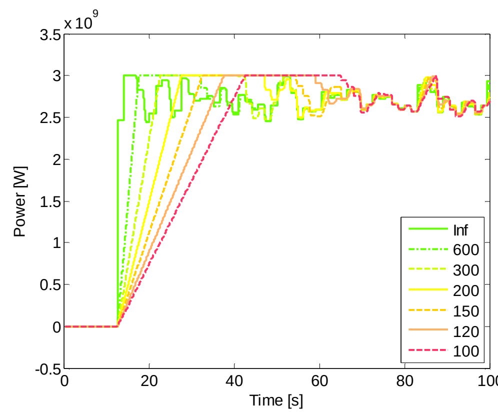


Figure 48: Power - C1S1 T0.5

The final simulation for ICT requirements displays the impact of the maximum permitted and the most realistic time delays. It can be seen, that the faster working ICT system leads to a better solution in oscillation and overshoot. The Frequency deviation is nearly the same. Comparing the FCR activation in Figure 46 with Figure 48 until 60 seconds, no serious deviation between the power deliveries can be mentioned. Beyond this point of time, the output of different power plants converge to the same output in Figure 48, which results in a somewhat more stable system.

4.2.7 Assessment

The different sets of communication delays lead to a various frequency response behaviors. It can be seen that the increase of the communication disturbances results in a stronger variation of frequency deviations. The computing time delay mainly affects the maximal frequency drop, while the sampling time delay and transporting time delay effect is mostly seen in the overshoot and oscillation of the frequency in comparison to an ideal communication system.

At the end the interaction of all effects is important to evaluate the requirements and therefore the ranges of ICT delay times. A CTD of less than 2 seconds, a STD less than 2 seconds and a TTD less than 1 second have the best results for a VVP with an average power gradient of 120%/30s and cause no serious problems for the system stability and control.

4.3 DSE WP4: Supervisory Controller as Service

In this section the "Supervisory Controller" DSE is analyzed with the two following approaches:

- At first this DSE is parsed in a sophisticated simulation framework, using an environment to validate it in any layer.
- The second approach consists in experimenting this DSE through the Energy@home, a physical infrastructure for conduct experimentations within private homes with the goal to monitor, control and optimize the electrical power consumption.

These two approaches are here described in separate paragraphs in order to avoid confusion between real and simulated parameters.

Anyway their contributions are very synergistic to cover the complete testing of this DSE: while Energy@home is mainly focusing on the development of a communication infrastructure that enables provision of value added energy services in the HAN, the simulation framework extends the scope from single homes to full neighborhoods.

4.3.1 Discrete Supervisory Control validation with Multilevel Multiscale Simulation

4.3.1.1 MileSEnS Context Simulator

In this section, the DSE is running in a simulation framework to be validated with a variety of environmental conditions that would be difficult to obtain in a real environment.

A DSE is supposed to be situated in either the entity, service or application layers in the general architecture of a system. The validation of a DSE depends on its execution results based on an environment where all the lower layers compared to the one it stays in, simulated or not, are complete and ready to use.

The simulator we propose to use here to validate the DSE is designed to be multi-layer where each layer is independent from others to be able to validate DSEs in any layer independently. However, the priority is given to the service layer because there are already other simulation environments for the lower layers. This simulator offers above all the framework containing the physic, device and entity layers with available models in corresponding layer.

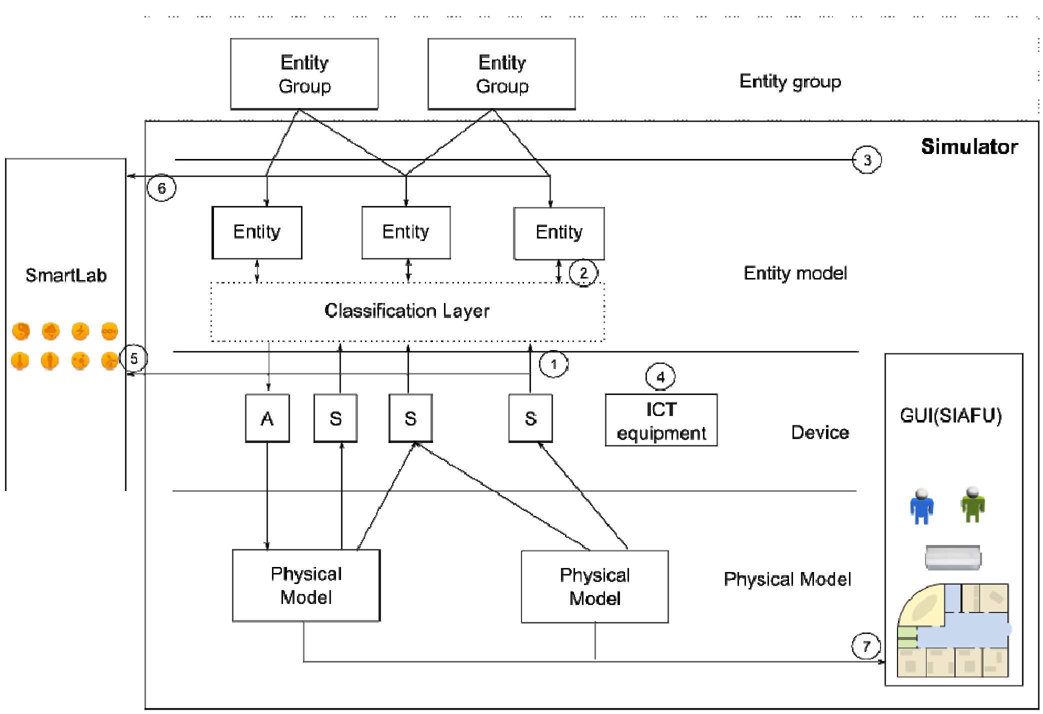


Figure 49: Simulator architecture

In this simulator, called MiLeSEnS (Multi-Level Smart Environment Simulator), the different layers and models used as an interface to the programs (such as the DSE) is being tested with the simulator) refer to:

- **Physical layer and models:** This layer is where the software representations of physical entities in the real world are located. These models have the modeled entities' physical properties such as the thermal behavior.
- **Device Layer and models:** They refer to sensors, actuators and ICT equipments which have network interface.
- **Entity layer and models:** Entity models are discrete state machines with abstract state properties more relevant to control purpose than real physical aspects. For example, an electrical radiator is modeled as an automaton with states "ON" and "OFF" and transition events between them. Classification layer refers to the mechanism of integration and auto-configuration of non-networked objects into a control system.
- **Entity group layer and models:** Entity groups are more abstract grouping of models in the entity layer based on environment impacting properties shared by several entity models or other criteria interesting the controllers, such as location of the entities. More details on the entity group will be described in the next paragraph.

Inter-layer communication will be ensured by different kinds of interface. The inter-layer relationship between models will be dynamic and affected by different level integration and configuration algorithms.

GUI offered by this simulation environment is based on an open source java context simulator SIAFU which provide animation of physical entities and their interactions. For more information refer to SIAFU website[2].

4.3.1.1.1 Physical Models in the Scenario

At the lowest layer of the simulator, there are physical models of the simulation environment which represent the behavior and properties of the equipments in the real world.

- Person: This is the only mobile agent in the simulation environment of this scenario, yet there would be other types of mobile agent in other circumstances such as cars in a city. Its path can be planned or aleatory. It can trigger the event to turn on some equipment.
- Door: It can be opened or closed. People can go through it.
- Window: It can be opened or closed.
- Lamp: When it is on, the whole room is lightened up.
- Radiator: The radiator changes color to indicate whether it is on or off.
- TV: A TV set displays an image when it is on.

These physical models are monitored and controlled by sensors and actuators in the device layer. Available sensors now are:

- Sensor of presence: Several presence sensors may be installed in one room in order to cover the whole surface of the room.
- Sensor of door/window: It detects if the door or window is well closed or not.

Actuators are for the moment attached to the controller, which means the actions for the equipments are directly triggered by the super level controller in the simulation environment.

[2] http://siafusimulator.org/

4.3.1.1.2 Map of the Simulation Environment

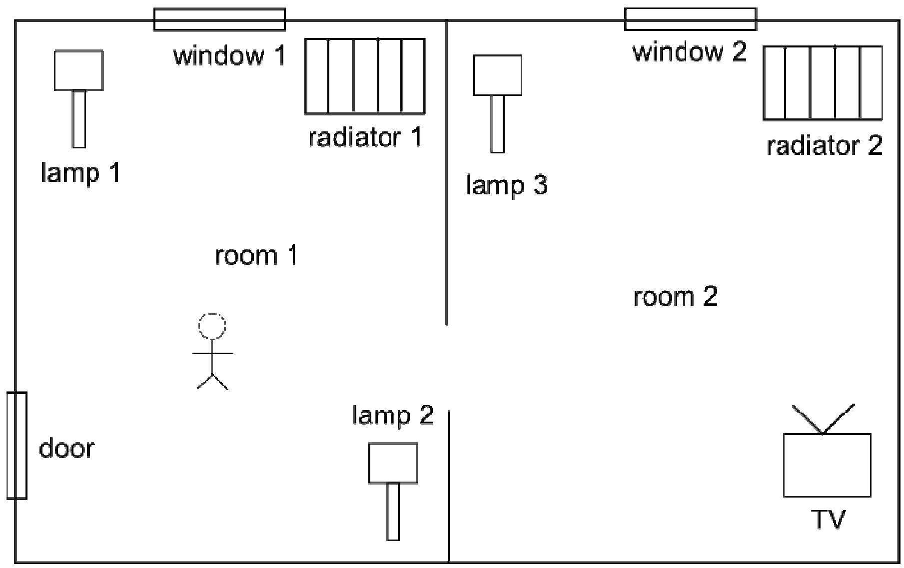


Figure 50: Simulation environment map

The simulation scenario takes place in an apartment that follows the above map where the entire space is divided into two individual rooms. The door between the two sub spaces is not considered having impact during the whole conduct of the scenario, thus the supervisory controller does not control it.

People move freely in two rooms and between the two rooms. Their presence is detected by sensors placed in the room and will cause the state change of the current room.

4.3.1.1.3 Entity Models used by the Controller

Controlled equipments are modeled as entities (automata) identified already completely in the abstraction layer (HAL) which the supervisory controller has a very good knowledge of. In the following model schemas, the subscript i indicates that some equipments are instances of the same model and they are independent from each other in terms of received order and emitted action.

N.B. The notation used in the following schemas of entity model is after the convention of BZR[3] language which is very close to the one used in the very general automata diagrams [20]:

- Door. This is the entry to the considered space. It receives the "open" action from a human (open_di) which is uncontrollable, and the controllable variable from the supervisory controller (c_di). Its output is the value of a boolean variable (d_openi) which takes "true" when the entity is in the state "OPEN" and "false" when it is in the state "CLOSED". The transition from the state "CLOSED" to "OPEN" is possible only when someone pushes the door and the controller allows it (imagine that the door would not be opened if someone pushes it from the outside without a key). On the other hand, the transition from "OPEN" to "CLOSED" is possible if one of the input values is false.

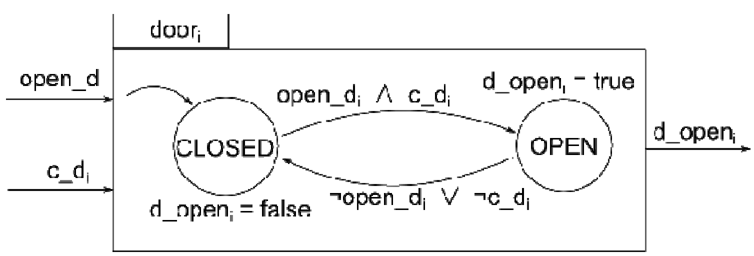


Figure 51: Entity model: Door

[3] http://bzr.inria.fr

- Window 1 and window 2. Like the door, they allow the considered simulation space having exchange of heat or light with the outside world. It is very similar to the model of door with a small change that the names of the variables are adapted to window.

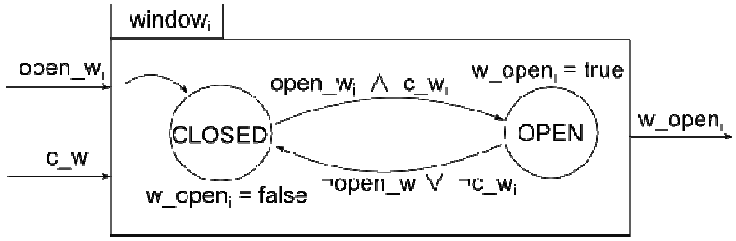


Figure 52: Entity model: Window

- Room 1 and Room 2. People can move freely in both of the rooms and pass from one to the other. However, the two rooms are considered isolated one from the other in terms of light source and heat exchange. The room model is not controllable and more like an observer of the occupancy of the space. It takes the value of people's presence in the space ($presence_i$) detected by presence sensor(s) and output the value representing the room's occupancy ($room\_oc_i$) which takes "true" in the state "OCCUPIED" and "false" in the state "EMPTY".

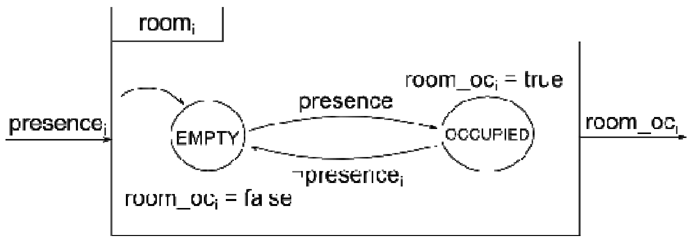


Figure 53: Entity model: Room

There are two variants of room in the scenario: living room and bedroom. They both keeps the basic states (empty and occupied) and have one more state according to their nature. They are considered as derived models of the basic model.

- Bedroom: one state "sleeping" is added with transition from the state "occupied". If the person is not moving in the room during more than 5 minutes, the transition is triggered.

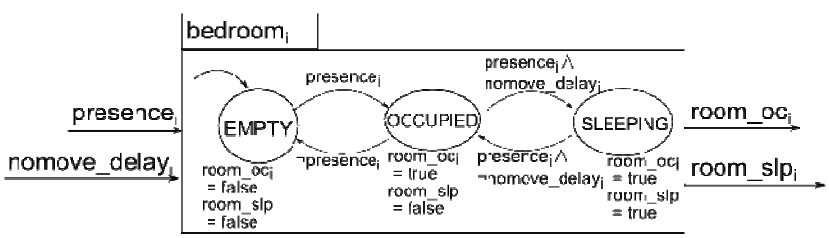


Figure 54: Entity model: Bedroom

- Living room: one state "transitory" is added between "empty" and "occupied". This in fact introduces a delay to switch between "empty" and "occupied". If a temporary (no) presence which is less than 3 minutes in the living room, no transition will be triggered.

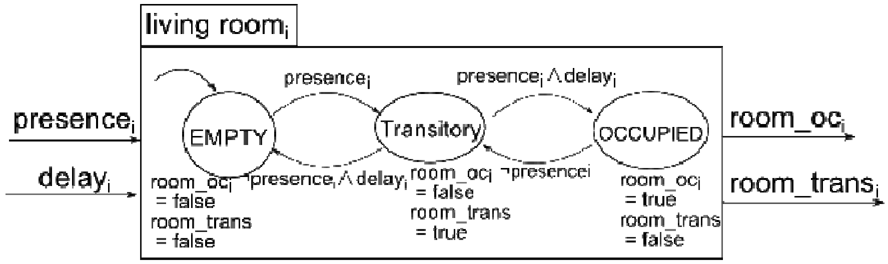


Figure 55: Entity model: Living room

- Lamp 1, lamp 2. They are light source in the room 1. The “lamp” model receives the signal from the switch (on_lamp$_i$), which is uncontrollable, and the value of controllable variable from the supervisory controller. On output, it sends the value of a Boolean variable (lamp_on$_i$) which takes the value “true” in the state “ON” and the value “false” in the state “OFF”. The transition from the state “OFF” to “ON” is triggered by the “true” value of any of the two inputs, and the transition from the state “ON” to “OFF” is triggered when any of the two inputs is false.

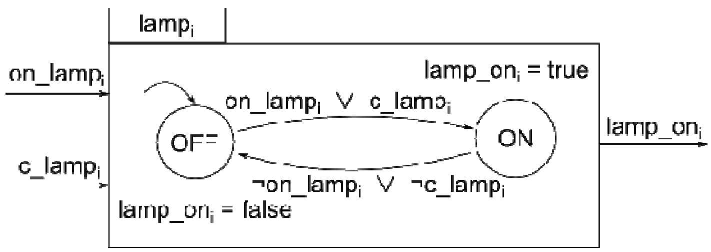


Figure 56: Entity model: Lamp

- Lamp 3. It is a light source in room 2. It is instance of the lamp model as lamp 1 and lamp 2.
- TV. It is a light source as well. This model is very similar compared to the lamp model only with changes on the variable names.

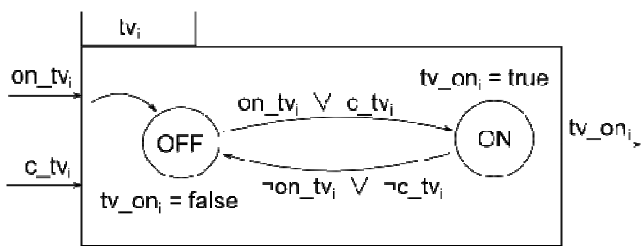


Figure 57: Entity model: TV

- Radiator 1, radiator 2. They are heat source respectively of room 1 and room 2. The radiator model has 3 states: “OFF” where the radiator is completely turned off, “LOW” where the radiator is at a “frost protection” mode, and “HIGH” where the radiator works at higher power level. In order to make transitions between 3 states, 2 input signals and 1 control variable are needed. The input signals “up_rad$_i$” and “down_rad$_i$” are uncontrollable from the switch, while the “c_rad$_i$” is from the supervisory controller to prevent the radiator from being turned on illegally. The 2 outputs are indicators of current state of the radiator. The transition from left to right which attempts to reach a higher level of power is only possible when the “up_rad$_i$” signal is received and the controller allows it, while the transition in the opposite direction is triggered when either the “down_rad$_i$” is received or the control variable is false.

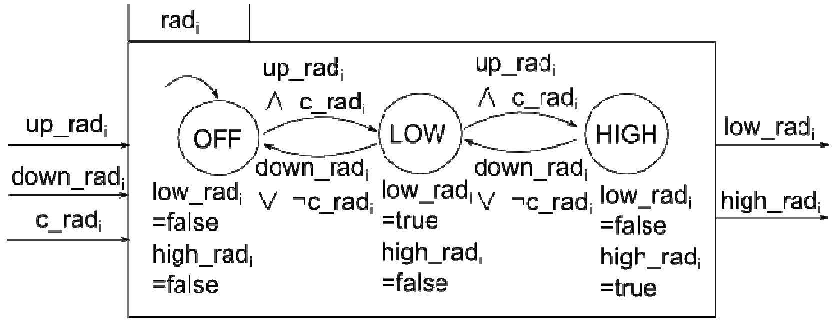


Figure 58: Entity model: Radiator

4.3.1.2 Tested Supervisory controller

4.3.1.2.1 Objectives of the Controller

The generic primary objective of the controller being tested here by simulation is to adapt the controllable entities of a room to the occupancy of rooms. Entities and rooms are all managed as entities and interfaced through the entity abstraction layer. The controller may be designed to meet security, safety or energy efficiency objectives. Tradeoffs and possibly arbitrations between these complementary but possibly contradictory objectives will also be tested by simulation.

- For the security objective, the control system will force the closing of all opening equipment (windows and doors to the outside) and possibly simulate presence of people by turning on the lighting or opening window blinds at regular but randomly staggered intervals if there is no presence of people in any of the two rooms.
- For the safety objective, the control system will force the lighting of at least one source of light in each room in order to avoid accident if people had to move in the dark.
- For the energy efficiency objective, the control system will force to turn off all the light sources of a room which is not occupied, on the basis of occupancy evaluated as a non-transitory state. And it will also turn off of heating equipment if some opening equipment (windows and doors to the outside) is open.

4.3.1.2.2 Expression of Scenario Description into Specification

- Rule 1: If the room is dark and the presence of a person is detected, the supervisory controller will ensure that at least one source of light is on (excpet if the people are sleeping) to avoid corporal accident
- Rule 2: If no presence is detected in the whole space, the supervisory controller should lock the whole space by closing all the opening equipment to the outside, and turn off all the light sources and put the heating equipment in “frost protection” mode.
- Rule 3: If one of the opening equipment is open to the outside, the supervisory controller should turn off the heating of the room in order to not waste energy.
- Rule 4: If there is no presence in a room, turn off all the light sources.

4.3.1.2.3 Entity Group

In this experiment, we will not be implicated by the aspect of dynamic classification of entities into different groups for different control purposes. What we try to show by this experiment is the aspect of using control groups as mediate between the supervisory controller and the concrete entities to be controlled in order to achieve control goals which concern some environmental properties influenced by several entities. According to the scope mentioned above, the groups are made static and there is only one level of entity groups for this scenario.

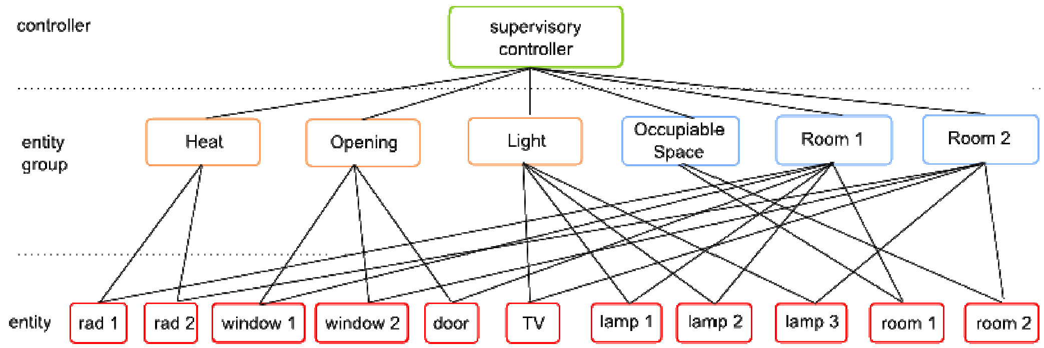


Figure 59: Entity groups

The above figure shows that the entities are classified by their main property to the environment and their localization that will facilitate the supervisory controller to make up the relation between the entity and their place.

N.B.: The naming convention we use here is that all the group names begin with a capital letter while the entity names begin with a lowercase letter.

- Heat: All its members heat the environment by their main feature.
- Opening: All its members are entry to the outside and allow heat exchange with the outside.
- Light: All its members can light one piece of room.
- Occupiable Space: All its members can be occupied by people's presence.
- Room 1: It contains all the entities which locate in the room 1, including the space entity "room 1" itself.
- Room 2: Similar to "Room 1" with all the entities locating in the room 2.

By making such groups, the 4 rules mentioned in the previous section can be expressed as the following:

- Rule 1: For safety concern, if the room is dark and the room X is occupied, the supervisory controller will ensure that at least one entity which belongs to the group "Room X" and to the group "Light" is on to avoid corporal accident.
- Rule 2: For security concern, if all the entities in the group "Occupiable Space" is in the state "empty", the supervisory controller should lock the whole space by closing all the entities of the "Opening" group, and put the entities in "Heat" group to "frost protection" mode for those which have it and turn off those which have only "ON" and "OFF" states.
- Rule 3: For energy purpose, if one of the entities of the "Opening" group and of the "Room X" group is in state "OPEN", the supervisory controller should turn off the entities that belongs to group "Room X" and group "Heat" in order to avoid energy wasting.
- Rule 4: For energy purpose, if room X is in the "empty" state, the supervisory controller should turn off all the entities belonging to group "Light" and group "Room X".

4.3.1.3 Conduct of Experiment

After having got the auto generated C/JAVA code of the desired supervisory controller, it is time to bind it to the simulator to validate the simulation scenario.

4.3.1.3.1 Configuration of the Simulation Environment

We should remember that the one of the most remarkable interest to run a simulation in smart home domain is that the test time can be compressed to test a whole scenario which takes several hours or days in the real world. This advantage can help to save a lot of time and resource especially during the first stage of software validation.

Therefore the time acceleration ratio in this simulation that we have chosen is 60x in order to compress an an-hour-and-a-half real-life scenario into 1 minute and 30 seconds, which is appropriate for showing the controller's features.

The stage of the scenario is set at evening to show the effect by rules on the entities in the lighting group. And in order to accentuate the role of the supervisory controller in the simulation, we will run the same scenario twice with and without the controller, and the situations which would have been eliminated if the supervisory controller were present will be warned with a sign of danger. The two modes "with" and "without" controller can be switched easily in the config file accompanying the simulation program.

4.3.1.3.2 Timeline of the Simulation

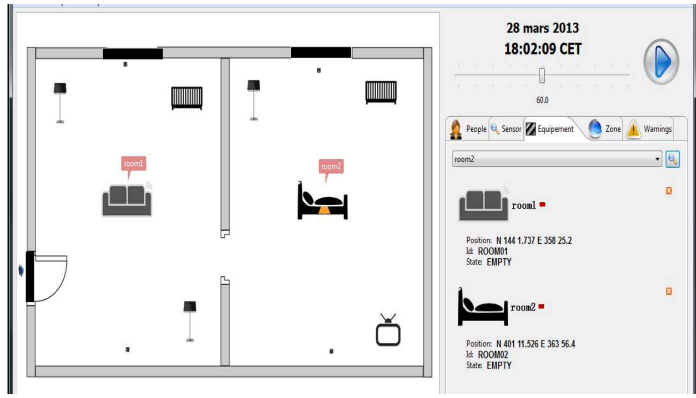
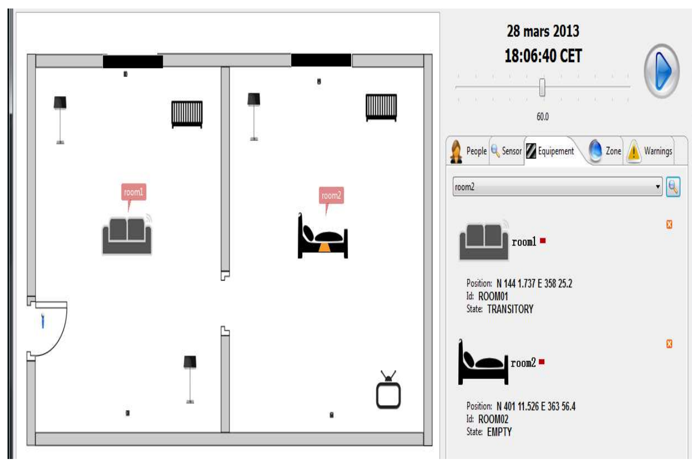
The conduct of the scenario with its controller is described in detail as following:

Time/period	Events/actions	Status of environment after actions
18:00		The person is outside the door, windows and door closed appliances off including radiators. Rooms are empty.
18:00-18:30	1. The person opens the door and enters 2. He closes the door behind 3. He goes to turn on the radiator in room 1 and puts it in high level 4. He goes to the radiator in room 2 and turn it to high	The person is in room 2. Door and windows closed. Radiators are in high level.
18:30-18:45 (it's getting dark)	1. He goes to open the window in room 1 2. He goes to open the window in room 2	Different with/without the controller. Refer to the experimentation results section.
18:45-19:15 (it's dark)	1. He goes to close the window in room 1 2. He goes to close the window in room 2 3. He goes to turn the radiator in room 1 to low level 4. He goes to turn the radiator in room 2 to low level 5. He stays in room 2	〃 〃 〃 〃
19:15-19:30	He goes to turn the radiator in room 1 to high level	〃 〃 〃 〃
19:30-19:45	1. He opens the door and goes outside	〃 〃 〃 〃

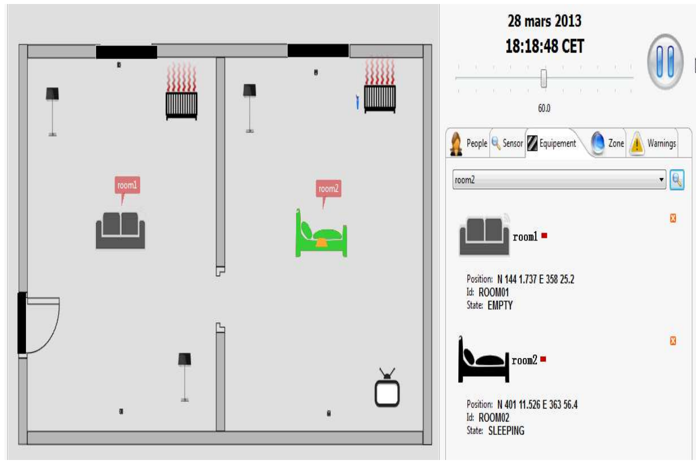
Table 20: Timeline of simulation

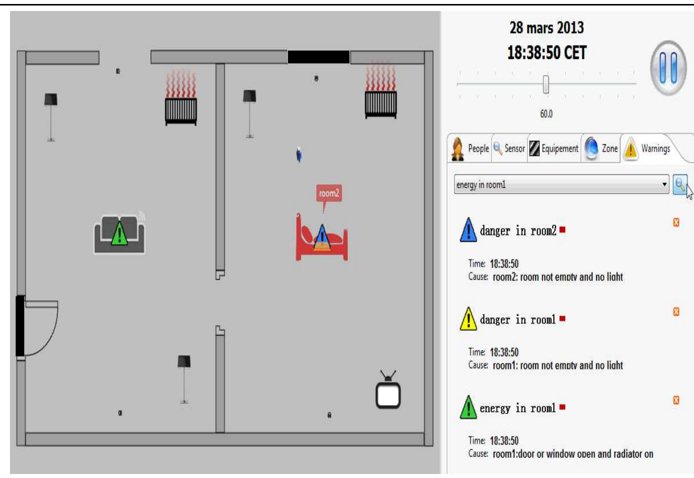
4.3.1.4 Experimentation Results

4.3.1.4.1 Simulation without Controller

<table>
<tr><th>Events/actions</th><th>Status of environment after actions</th></tr>
<tr><td>Initial configuration, no action</td><td>
</td></tr>
<tr><td>The person opens the door and enters</td><td>

Door is open.
Room 1 (living room) is in state "TRANSITORY" for the short (up to now) presence of the person.</td></tr>
</table>

<table>
<tr>
<td>He closes the door, goes to radiator in room 1 to turn it high, and goes to the radiator in room 2 to turn it high. Then he stays in room 2.</td>
<td>


Room 1 is in “Empty” state as the person left the room some time ago.
The two radiators are in high level as the red radiation shows.
Room 2 (bedroom) is in “Sleeping” state as the person doesn’t move since some time.
</td>
</tr>
<tr>
<td>He goes to room 1 to open the window.</td>
<td>


Not satisfied mutual exclusions of states:
(Rule 1) After 18:30 it’s dark, the room is not empty and all lights are off.
(Rule 3) While there is window open, the radiator is still on.
</td>
</tr>
</table>

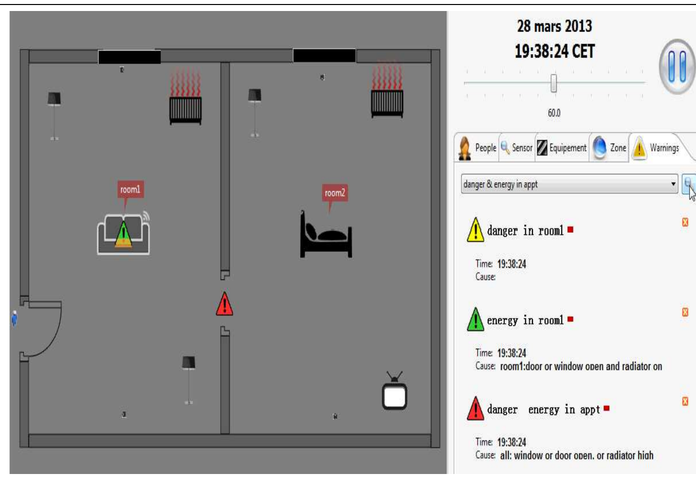
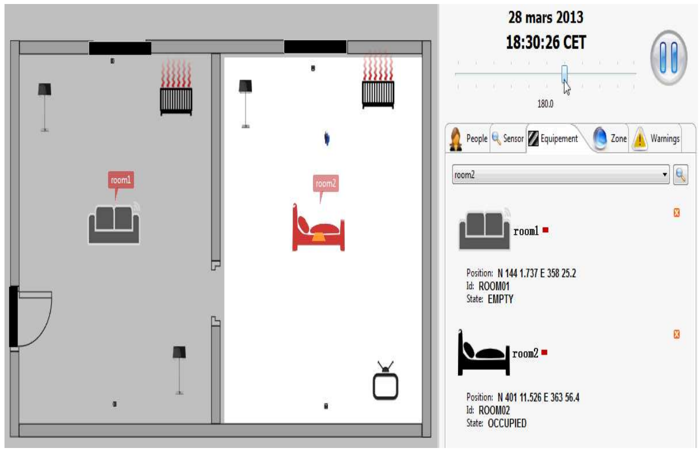
He closes both windows.	 After having closed both windows, the only not satisfied mutual exclusion of states is that in room 2, no light is on with someone inside.
He opens the door and goes outside	 Not satisfied mutual exclusions of states: (Rule 2) The whole space is empty while the radiators are still in high level and the door is not closed. (Rule 3) While the door is open, the radiator is still on.

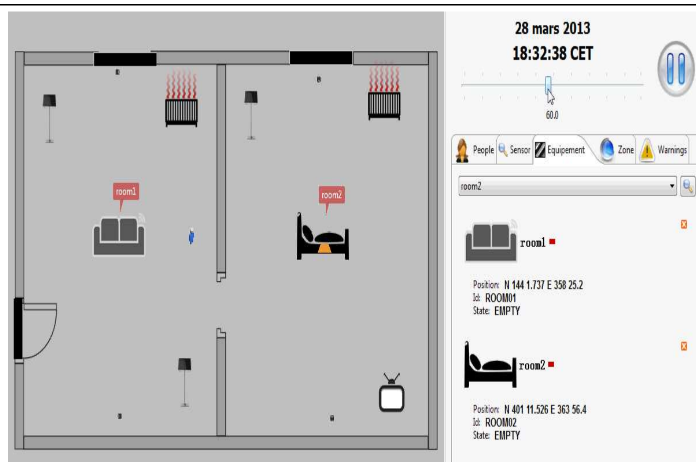
Table 21: Simulation without controller

4.3.1.4.2 Simulation with Controller

<table>
<tr><th>Events/actions</th><th>Status of environment after actions</th></tr>
<tr><td colspan="2">Before 18:30, the results with the controller is the same without controller because:
1. It is still bright enough that the rules about lighting are not activated yet.
2. The actions about energy saving haven't taken place.</td></tr>
<tr><td>Control action:
Controller turns one of the lights in room 2.</td><td>

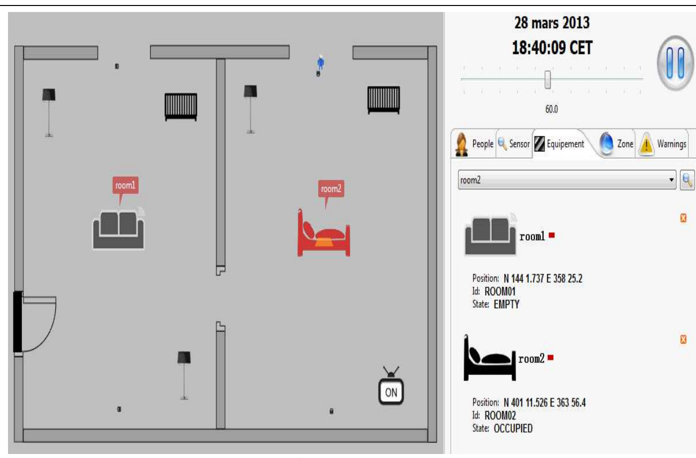


Rule 1: It's dark and room not empty, one light is turned on by the controller.</td></tr>
<tr><td>Control action:
Controller turns off the light in room 2 which is empty.</td><td>



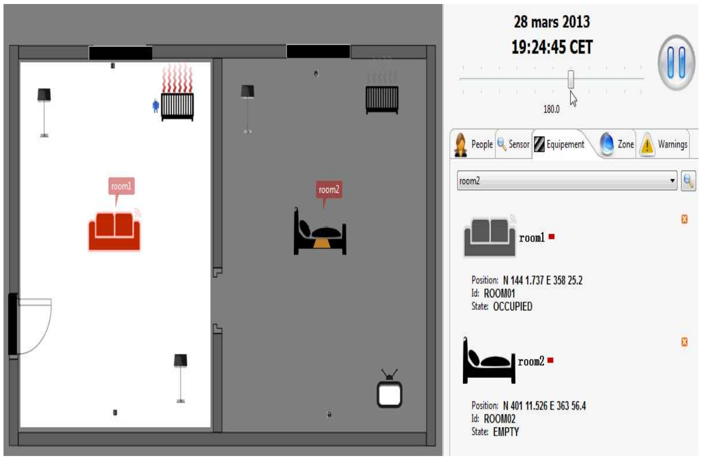
No light is on in an "empty" room.</td></tr>
<tr><td>Human action:
He opens the two windows.

Controller action:
It turns off the two radiators and turns on the TV which is considered as a light source.</td><td>



Rule 1: In room 2, because of the human's presence, the TV is turned on to provide light.
Rule 3: In each room, the radiator is off when the window is open.</td></tr>
</table>

<table>
<tr>
<td>Human action:
He goes to turn on respectively the two radiators.

Controller action:
It turns on one light in room 1.</td>
<td>

The two radiators are turned on because none of the windows are open.
Rule 1: One of the lights in room 1 is turned on.</td>
</tr>
<tr>
<td>Human action:
He opens the door and goes outside.

Controller action:
It closes the door as both rooms are empty. It turns off the radiator when the door is open.</td>
<td>

Rule 2: The radiators are none in the high level. The windows and the door are closed.
Rule 3: Once the door is open, the radiator is turned off in this room.
Rule 4: Lights are turned off when no presence.</td>
</tr>
</table>

Table 22: Simulation with controller

4.3.1.4.3 Comparison of the Results from two Variations of the Same Scenario for Determination of the Room's State

We can clearly see the effect of the present supervisory controller by comparing the results. All the system's specifications are respected in the variation with the supervisory controller.

With the simple supervisory controller which works on the states of abstracted automata by the Abstraction Layer, we are able to ensure the system would never go to undesired mutual states. And the introduction of entity groups in the controller makes the supervisory controller more generic and adaptable in more situations. Without worrying about exactly which equipment to control, the specifications of the system's properties to be ensured are written at the group level and leave the entity groups to do the work that dispatch the group-level specifications to the concerned entities.

The simulation shows also the interest of using a simulator for the validation stage. It runs more quickly than real time test by compressing running time, and it's easy to vary the scenario to test with only some changes of parameters.

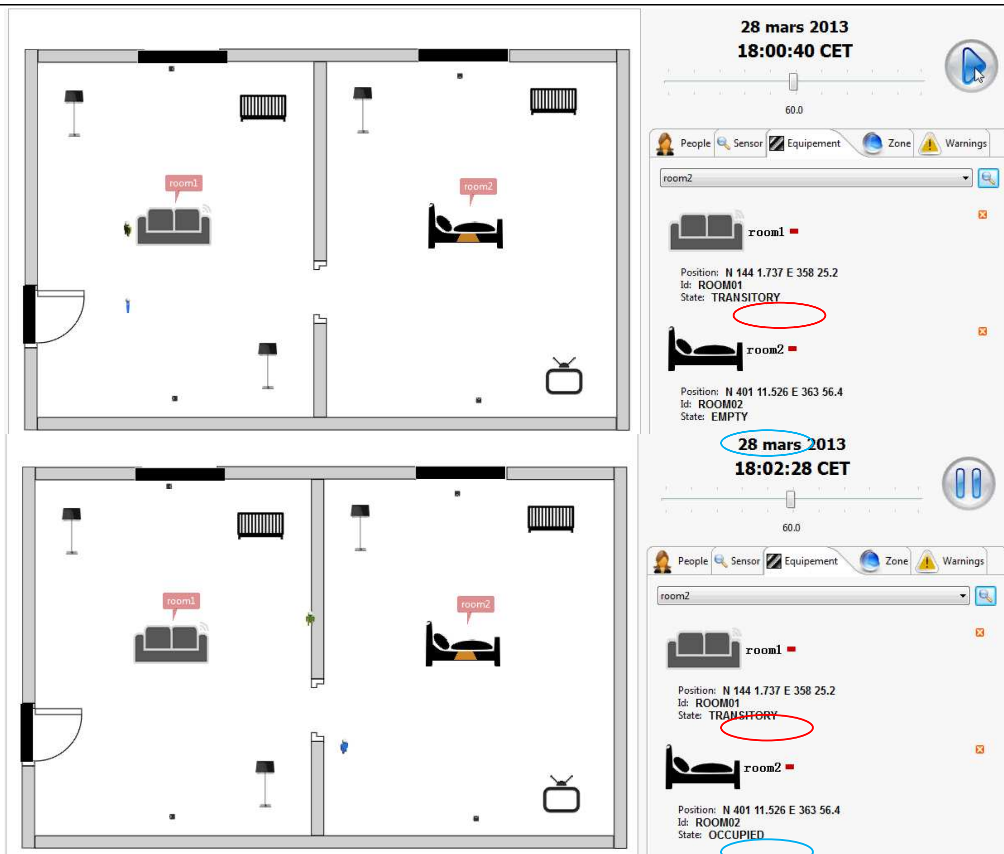
As we mentioned in the simulation structure graph, there is a classification layer implemented by HAL (Home Abstraction Layer) between the entity layer and the sensor/actuator layer. In the tested scenario, we can clearly observe the effect of the presence of this intermediate layer which consolidates the lower level data to give a state-transition-trigger event more meaningful.

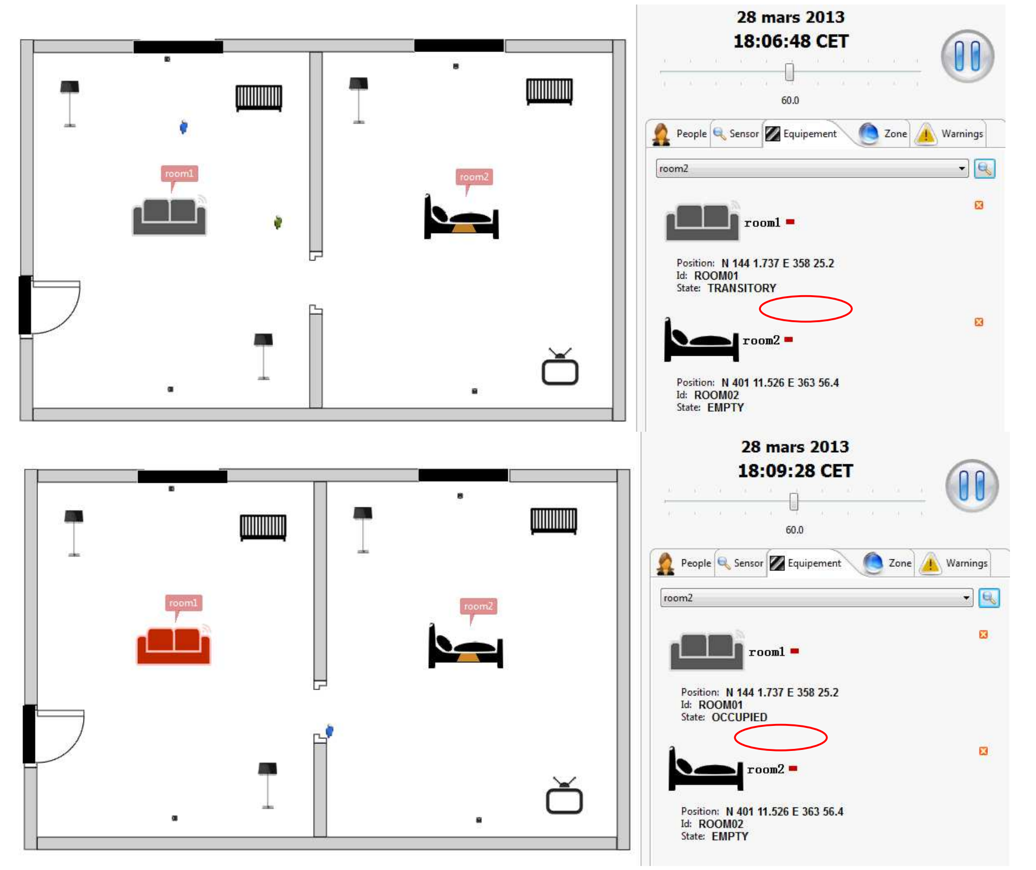
N.B. The consolidation of lower level data is just one of the features of the classification layer (implemented by HAL).

In this specific simulation scenario, we configure the classification layer in the way that the entity “living room” would not change its state immediately when a presence or a no presence is detected by one of the sensors. In fact, the presence or the no presence for a very short time will be filtered by the classification layer and will not cause state change. A simple initial configuration parameter change of people’s speed will cause different time of stay in the same room for the same activity, thus the effect on state change. For demonstration reason, we add a “TRANSITORY” state between the “empty” and “occupied” state to make the data consolidation more visible.

The following table will show two running of the same scenario with different speed of people.

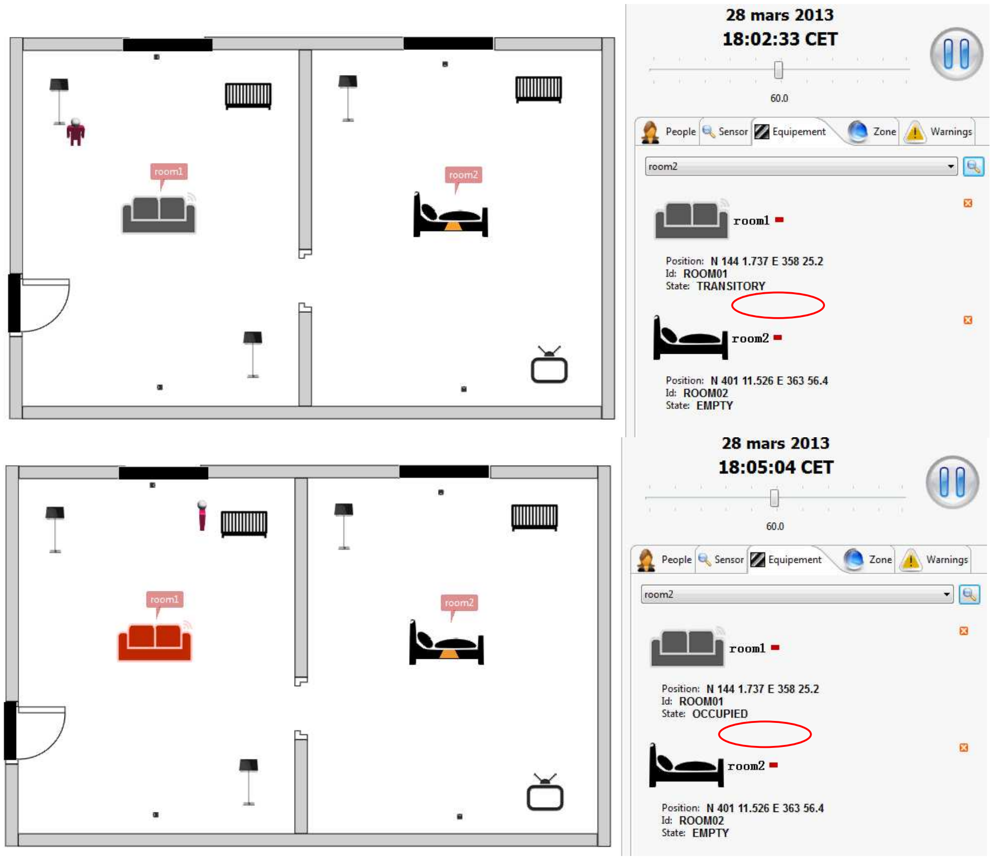
N.B. To illustrate the effect by comparison: The bedroom beside the living room has no transitory state, which means it changes state immediately when a person shows up or leaves.

Running 1: Two children in the space who move very quickly and everywhere (relative speed: 6)
 As shown in the two pictures, the two children have done some activity in the living room and are leaving for the bedroom. As it is a short stay, the state of the living room is always “transitory” while the bedroom changes its state once the person enters.



If they stay longer in the living room, it changes to “occupied” at the end.

Running 2 : An old man moves slowly in the space (relative speed: 3)



As the person moves more slowly than in the previous running, when he has done the same activity, he has already stayed long enough that the living room changes to “occupied” state.

Table 23: Scenario with different speed of people

4.3.2 Continuous supervisory control validation with Real Experimentation

In this section, the "Supervisory Controller" DSE is tested through the Energy@home system, a physical infrastructure for conduct experimentations within private homes with the goal to monitor, control and optimize the electrical power consumption.

As described in the FINSENY D8.2 deliverable [3], chapter "5.2.2 - Real experimentation for the DSE", at the time of writing, Energy@home test infrastructure is installed in 30 private houses. By the first quarter of 2013 it is planned to extend this to 100 houses.

This test infrastructure envisions a protocol that shall be used to build an integrated platform to allow cooperation between the main devices involved in residential energy management.

With reference to Figure 60 from the final customer side, these devices are:

- **Electronic Meter:** Responsible for providing certified metering data. The meter shall be interfaced via a new-generation device called Smart Info to enable communication with the telecommunication infrastructure and the household appliances.
- **Smart Appliances:** Able to cooperate in order to adjust power consumption by modifying their behaviour, while preserving the quality of service and user experience.
- **Smart Plugs:** Able to collect metering data and to implement a simple on/off control on the plugged energy loads other than smart appliances.
- **Energy Box:** This is also the HAN controller. It is an Alice home gateway (a device of Telecom Italia) with OSGi framework and HAN wireless communication capability.
- **Customer Interfaces:** I.e. all the devices used by the customer to monitor and configure his/her energy behaviour.

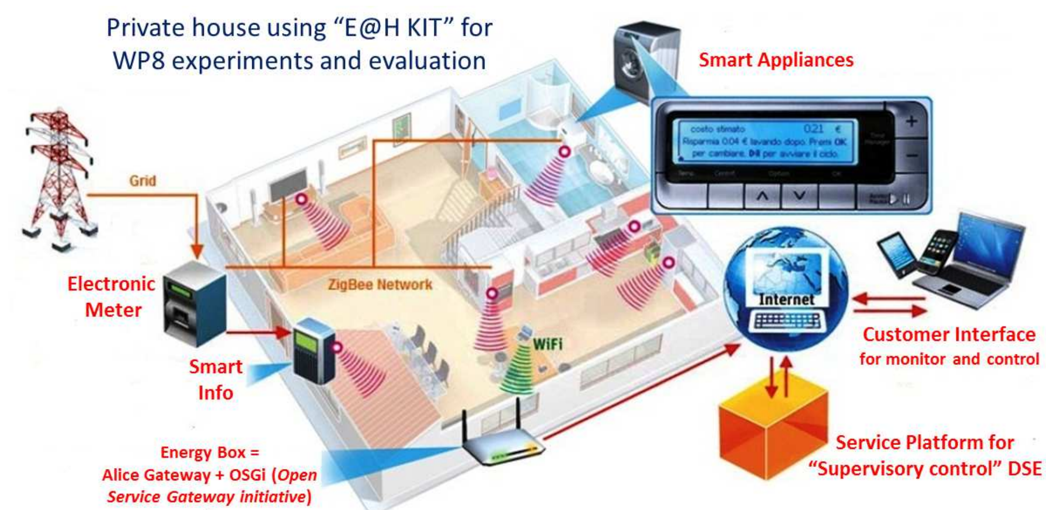


Figure 60: Test architecture for the "Supervisory Controller" DSE

From the remote demand side manager there is the:

- **Remote Service Platform:** It manages, together with any home gateway, the HAN devices and provides service oriented interfaces for the development of third-party applications. It monitors and controls a plurality of individual entities and it includes de-facto the "Supervisory control" DSE. This platform is unique for the entire experimentation involved house and it includes the DSE FINSENY "Supervisory Control". In fact, the "Supervisory control" DSE refers to a lightweight joint control of several individual controlled entities. In other words, this DSE acts not only for a smart home but also for one or more smart buildings. This remote service platform actually runs on servers in Innovation Lab and it is planned to be moved on Telecom Italia Cloud Computing Services.

4.3.2.1 Conduct of Experiment

The “Phase 1” Energy@home experimentation for the “Supervisory control” DSE has begun on December 2011 and it has been analysed a period of one year, that means that have been collected the real data coming from 30 private houses till November 30th, 2012.

All these clients have an ENEL electricity supply contract with a power limit of 3kW or 4.5kW. ENEL is the first utility in the world to replace the traditional electromechanical meters of its 33 million Italian retail customers with smart meters that make it possible to measure consumption in real time and manage contractual relationships remotely. This innovative tool is the key to the development of smart grids, smart cities and electric mobility.

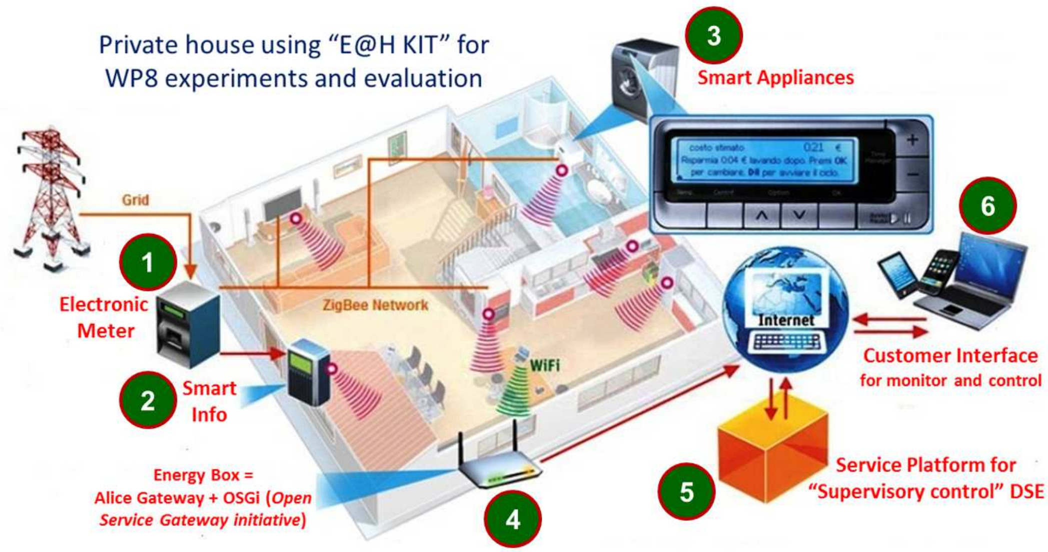


Figure 61: Data flow for the planned “Supervisory Controller” DSE experiments

With reference to the test architecture shown in Figure 61, the data flow for the planned tests follows this path:

Step 1: Information from the ENEL electronic meter is distributed through the smart info to the smart appliances that will adjust their cycles according to the available power and the energy tariff in order to optimize the consumption and to reduce the energy bill to the customer.

Step 2: The smart info gathers the data sent via powerline from the electronic meter and distribute them wirelessly inside the house.

Step 3: The smart appliance receives the data from the smart info and manages their processes according the power availability and in agreement with the user preferences.

Step 4: The energy box, which is also the HAN controller, is an Alice gateway with OSGi framework and HAN wireless communication capability. It collects all the data sent from the domestic wireless network and forwards them outside thanks to a broadband always-on connection giving the possibility to display the info about energy on the Web portal or a smart-phone.

Step 5: The remote service platform manages, together with any home gateway, the HAN devices and provides service oriented interfaces for the development of third-party applications. It monitors and controls a plurality of individual entities and, together with the energy box, it represents de-facto the “Supervisory control” DSE.

Step 6: The customer interface (that can be a notebook, a tablet or a smart-phone) receives information about power consumption, its prices and overload alarms; it can also resume the automatic and remote control at any time, allowing to the end customer to manage directly its desired consumption. Moreover, the home gateway provides a Web customer interface for these functionalities in case that the customer moves from indoor operations to the outdoor ones.

How it is easy to imagine, this experimentation means GB (Gigabyte) of raw data collection, that have to be submitted to an action of data mining, namely the set of techniques and methods that relate to the extraction of knowledge from large amounts of data. Certainly in this section will presented below the results of the analysis after the data mining, which then is the real information of interest.

For privacy-related reasons, the identities of end customers have been replaced by numerical identity; in particular the seven users have been selected here deemed to be more significant for the test of the DSE in question.

The adopted format for the user identities follows the rule shown in the following example:

"User #114", where **#1** means *"Phase 1" Energy@home experimentations*" and **14** means that it is the final user number 14. So here following it will be reported the analysis results from the seven end users identified from the number #**114** to the number **#120**.

With the obvious exception of the smart meter, which is already installed in all the houses, and the Remote Service Platform, which is centralized, the tests have been executed within the private houses hosting the "Energy@home KIT" that is containing:

- 1 smart info device of ENEL that bridges the Smart Meter communication with the Home Area Network.
- 1 energy box which is also the HAN controller. It is an Alice gateway with OSGi framework and HAN ZigBee wireless communication capability.
- 5 smart plugs with a local meter, a switch, and ZigBee radio communication.
- 1 smart appliance with embedded ZigBee radio communication.

The experiments for the "Supervisory Controller" DSE consist into:

1. <u>Smart metering and control</u>:
   a. Involving smart plugs and smart meters, metering data will be collected and on/off control is implemented on simple plugged energy loads.
   b. For the smart appliances the above remote load control will be subject to its control in order to assure the correct execution of its working procedure, its results and performance. For example, a smart washing machine, when requested to modify its consumption behaviour, shall assure the result of the washing cycle.
2. <u>Communication and data protocol</u>:
   a. It interfaces smart appliances and other user's devices and provide a broadband connection to internet.
   b. It collects energy data from the Smart Info and additional information from smart appliances, publish them in the HAN and use all collected data to control smart appliances and optimize their behaviour.
   c. It offers a web user interface and provides an execution environment (e.g. Java OSGi framework) to host third-party application (e.g. a software component implementing the algorithm to calculate the energy price at a given time, provided by the energy retailer).

Last but not least, for each of the seven end users there is available the power consumption and related costs of the year preceding the trial, that is, when in their homes the Energy@home KIT had not yet installed. This information is essential to understand how it has changed the awareness of the end user against its management.

In the next "Experimentation results" section, the obtained results of these tests will be detailed.

4.3.2.2 Experimentation Results

From these experiments of the "Supervisory Controller" DSE, the following macro-results have been obtained:

- To have a consistent data-history, collected at a set time, in order to obtain important information about the contractual choice of energy retailers and to optimize the use of energy available.
- To keep under control and manage (at home and outside) the household electrical devices avoiding power-off for excess of load.
- To check the functionality of the management of priorities among all the smart appliances and the traditional ones.

All the tests performed with the Energy@home system, described in this document, relate to the following household appliances:

- Washing machine (smart appliance),
- Dishwasher,
- Boiler,
- TV,
- Oven,
- Lighting,
- Conditioning.

The refrigerator is excluded from this household appliances list because:

- It represents a virtually constant load and is therefore predictable (as shown in Figure 62). Small variations are due to the more or less frequent opening of the door of the refrigerator.
- It may not be managed because it is not possible to interrupt the cycle of food preservation.

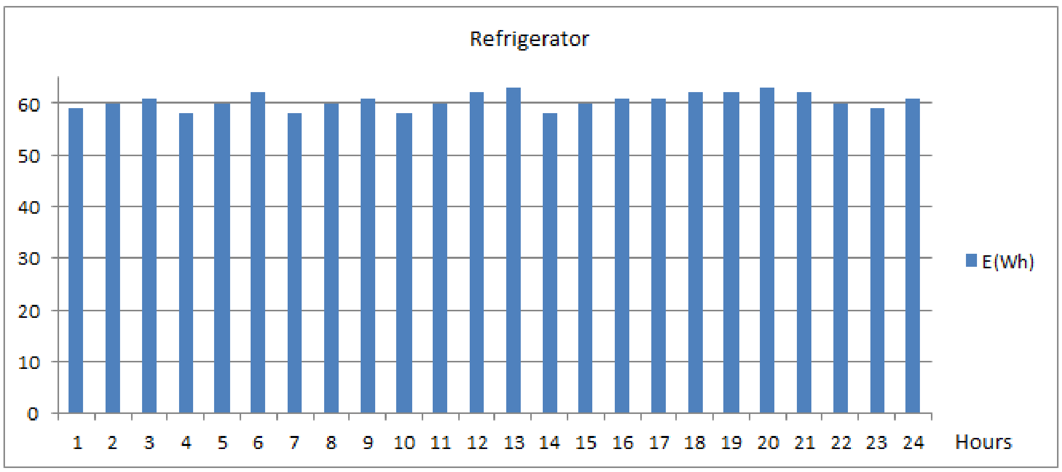


Figure 62: The refrigerator is a load almost constant and non-interruptible

In the next paragraphs the obtained results of these tests will be detailed.

4.3.2.2.1 Tests on Detailed Energy Data Collection and its Historicization

In this paragraph the tests are treated on the aggregated and disaggregated data collection in terms of energy (Wh). This historicizing data allows knowing the habits of the end users along the 24 hours, throughout the week and also for the entire year. Also visible are the variations in consumption between winter and summer and, more in general along the whole year.

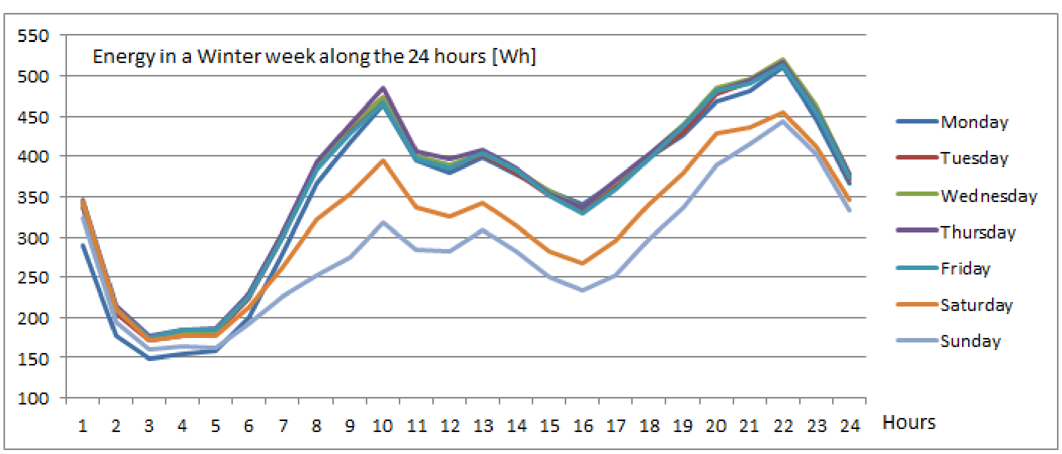


Figure 63: Average load curve in a winter week (2012 - users #114÷120)

The knowledge of these profiles allows Energy@home to better manage the distribution of loads involving the end user through its graphical interface which will be described later in this document. These collected data are also useful to the creation of models for the forecast services about the future energy consumption.

In Figure 63 and Figure 64 the average load curves are shown respectively in winter and summer season. The reason for the difference between these curves will be detailed in the next graphs where the total collected data will be disaggregated for each household appliance.

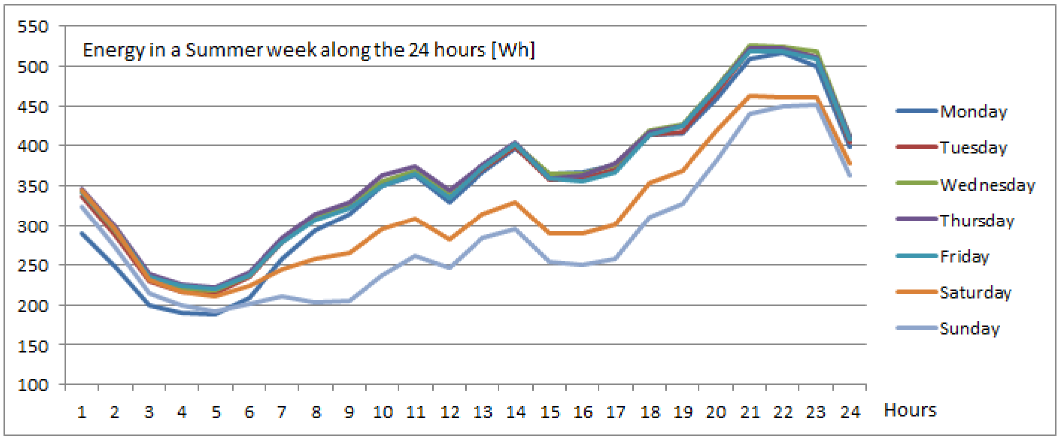


Figure 64: Average load curve in a summer week (2012 - users #114÷120)

Ideally by plotting a straight line of mean value in these two graphs, shows an energy spread over a period of 24 hours of about 330Wh; this means that in one year, the average energy consumption for an Italian family with three persons (the above case) is:

330Wh * 24hours * 365 days = **2890kWh** (see also section 4.5).

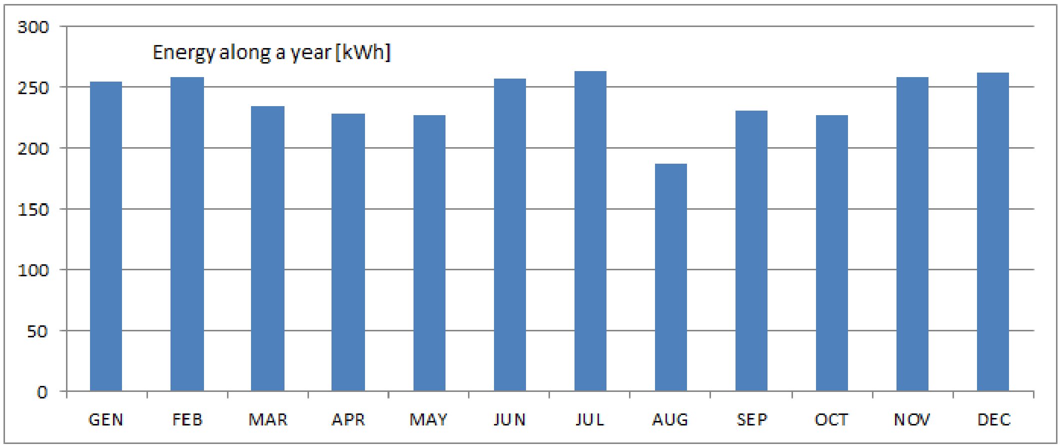


Figure 65: Average monthly energy along one year [kWh] (2012 - users #114÷120)

The Figure 65, in addition to confirm the total energy consumption of the previous graphs, highlights the consumption changes in function of social customs (e.g.: August is the traditional month of holidays for the Italians with a consequent decline in consumption due to the absence from home).

The data shown so far are those totals collected by Energy@home system as "Total", but to be able to manage and optimize this energy flow it is necessary to have disaggregated energy data, i.e., those of each individual appliance or smart appliance. For this reason, below, are shown the disaggregated data, which are critical for the overload control, an argument that will be treated in the next section.

In Figure 66, the disaggregated energy in a winter week along the 24 hours is shown. As the washing machine used in Energy@home tests is a “smart appliance” (i.e. with a particular priority handling in the event of overloading, which will be explained in the subsequent section) it is evident that, in the case of overload, the most appliances involved are: boiler, dishwasher and oven.

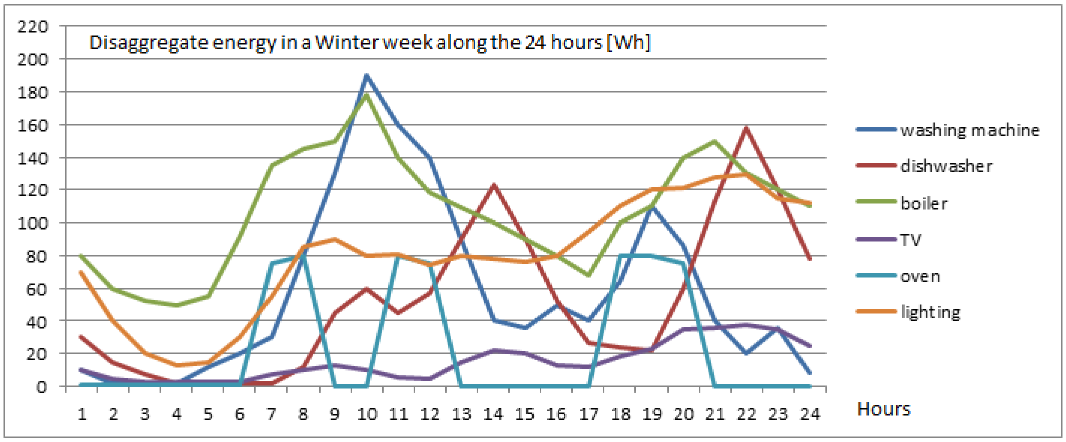


Figure 66: Disaggregate energy in a winter week (2012 - users #114÷120)

The disaggregate energy in a Summer week along the 24 hours (Figure 67) shows how the energy consumption changes with respect to the winter one; different temperatures involve different profiles and different electric appliances (e.g. less boiler, less lighting, more air conditioning etc.).

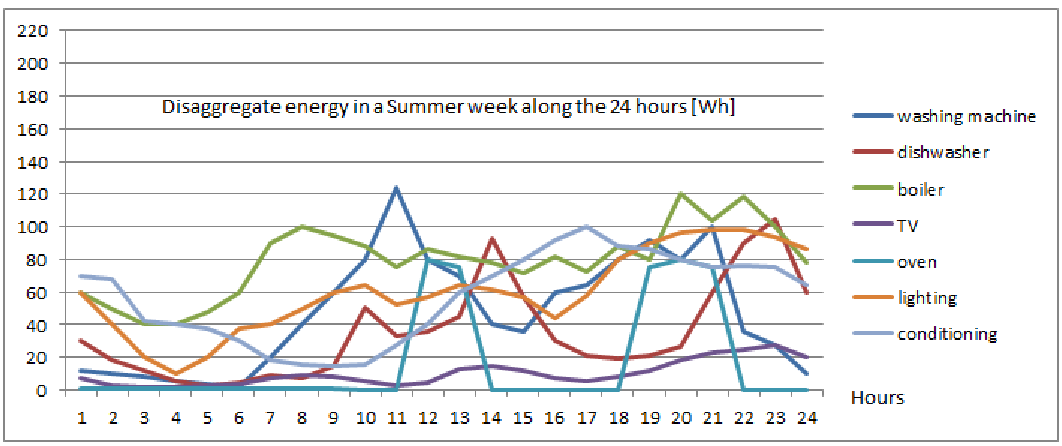


Figure 67: Disaggregate energy in a summer week (2012 - users #114÷120)

Results, problems and possible improvements: The tests described above are lasted a whole year (2012) and have allowed obtaining a consistent data-history containing GB of data.

With the user #119 there was some random problems of radio communication of the HAN nodes due to a ZigBee radio node in the proximity of a microwave oven. It was experienced that the node radio ensures quality of service in a reliable manner if it is away at least 50cm from the microwave oven.

There is need to further refine the incoming data filtering, because on the powerline random spikes may appear that could alter the reality of captured data.

The data mining of these collected data has provided valuable information useful for each final user; for example the final user, simply monitoring its contractual available energy, can reduce the related costs by spreading the use of the most energy intensive appliances along the 24-hour (for more details please see section 4.5.2.2).

4.3.2.2.2 Test on the Monitoring and the Control of the Overload Case

In this paragraph the tests are treated on the monitoring and control overload in terms of power (W). In this first phase of the test the ability of Energy@home was disabled to take initiatives to overcome the overload; more precisely here the Energy@home system performs the function of monitoring of the instantaneous power, simply alerting the user interface about any abnormal events.

Obviously in this first part of the test the ability of communication of messages to the user interface is also verified, both in the indoor via HAN and in remotely via Internet.

In Figure 68 there is shown the functional flow used to keep under control and manage the household appliances avoiding the power-off for overload. In particular, a WEB based GUI (Green circle no. 5) allows the final user, both in home and outdoors, to monitor and control the loads through a notebook, net book, tablet, smart-phone etc.

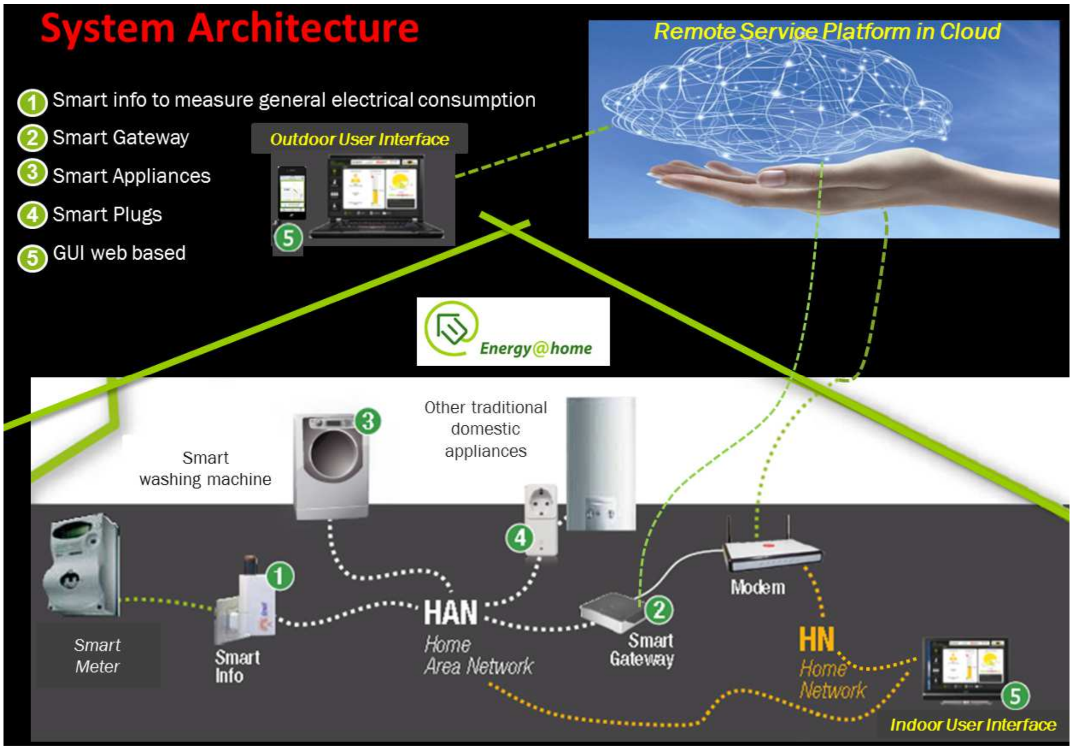


Figure 68: Monitoring and control of the energy flow from E@H toward the user interfaces

The test user ***#114*** has subscribed a 3kW contract and his energy retailer poses the following conditions:

- The customer can get electric power between 3.3kW and 4kW for a maximum period of 3 hours after the power-off occurs.
- If the customer picks up electrical power over 4kW the power-off takes place after 2 minutes.

The Figure 69 shows the case in which the user ***#114*** did not consult its own user interface and a peak power of 4476W has created a power-off at home.

The band 3300 ÷ 3500W becomes dangerous if it is used for a long time (power-off after 3 hours).

When the total instantaneous power used by the house exceeds the contractual limit in the range 3000 ÷ 3500W the home gateway starts to send periodically (every 10 minutes) an “Overload Warning” alarm (Figure 69). This alarm will be reset by sending once the “End of Overload Warning” message when the total instantaneous power returns below the limit.

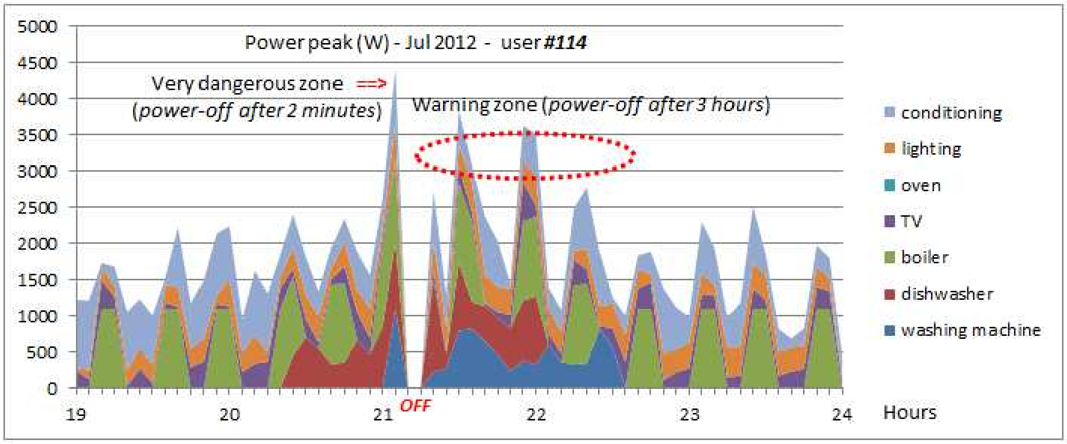


Figure 69: Two real cases of exceeding critical and moderate peak power permissible

As shown in the GUI of Figure 70, when the total instantaneous power used by the house exceeds the 4kW, the home gateway sends instantly an alarm (also acoustic) in countdown style: “Power-down within 120 seconds … 110 seconds …” and so on. This GUI is available and it has been tested for smart TV, notebook, tablet and smart-phone in order to satisfy indoor and outdoor operative needs.

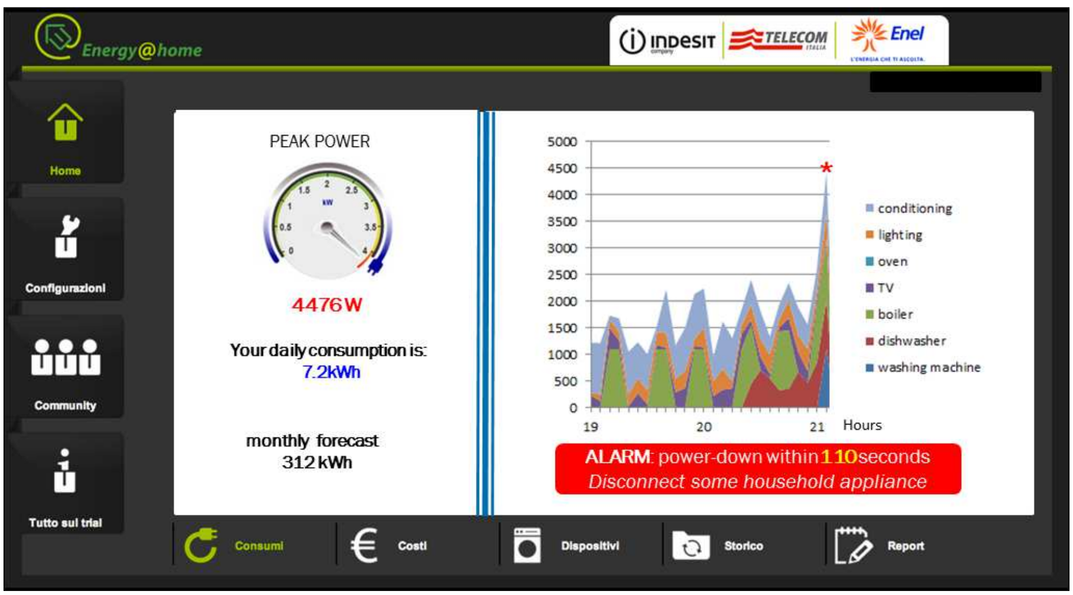


Figure 70: Snapshot of the user interface communication during an overload

Even if in this test phase the Energy@home system was disabled, its ability to take initiatives to overcome the overload had continued; this can be obviously done by the final user through the user interface.

In fact, in the case of risk of power-down the end user can access the page of the user interface shown in Figure 71, and hence switch off one or more appliances by simply clicking on the “on/off” icons. Clicking “off” sends a command that, through the gateway, reaches the involved smart-plug that switched off the appliance.

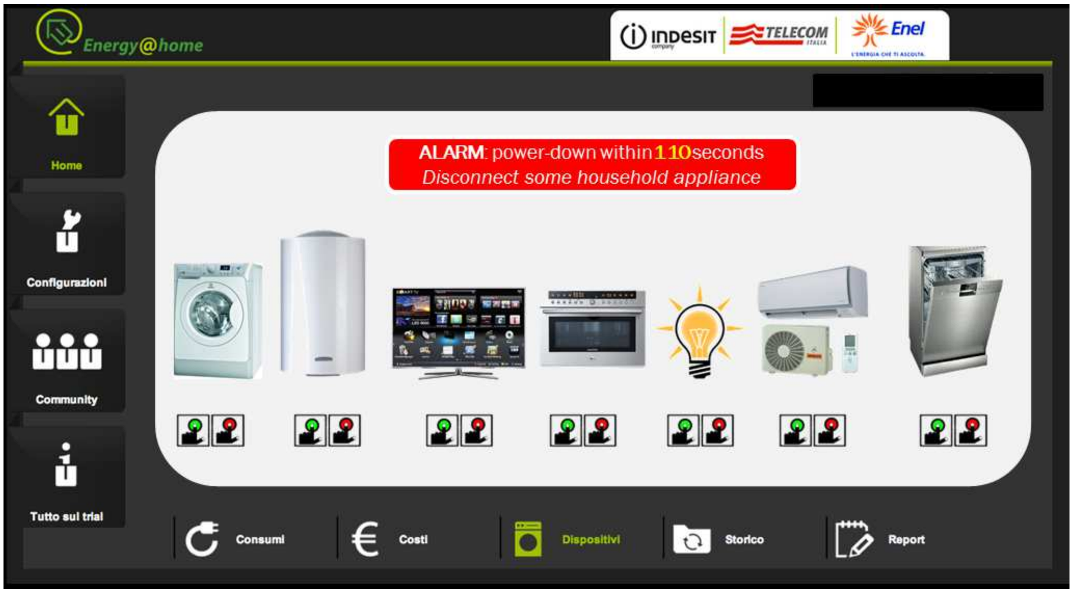


Figure 71: Test on the manual intervention of the final user to avoid an overload

Results, problems and possible improvements: The tests described above have verified the good capability of the Energy@home system to detect power overload situations and communicate them to the final user through the customer interface. In this test phase, it the ability of Energy@home was disabled to take initiatives to overcome the detected overload in order to test also the manual intervention of the end user that, by its own interface (indoor and outdoor), the inactivation of one or more appliances in manual mode was working perfectly.

The only problem is represented by the need to increase the awareness of the end-user on the behaviour to keep in respect of the KIT devices. For example, with the user #115 there was some problems of radio coverage of the HAN nodes due to thick walls. So he has suddenly removed, without notice, a smart plug creating “holes” in the frame of the data that are sent.

A software development to avoid the damages coming from wrong maneuvers of the end-user is in progress.

In the next paragraph the ability of Energy@home to take control initiatives and to negotiate the priorities among the smart appliances and the traditional ones to overcome the eventual overload is treated.

4.3.2.2.3 Test on Management of Priorities among Smart and the Traditional Loads.

In Figure 72 the sequence diagram for the test with user interaction with the E@H control enabled is reported. With the smart appliance in “Programmed” state the user changes a setting and the appliance notifies this change at the home gateway which answers showing the optimal start to the user. Then the appliance requests the related price at the home gateway which answers showing it to the user. In the second section (each section in figure is separated by a green line) the smart appliance is in “waiting to start” state and the user press the “start button”, with the option to choose between the “immediately start (Forced by user)” or “accept the E@H scheduling” (delegating control).

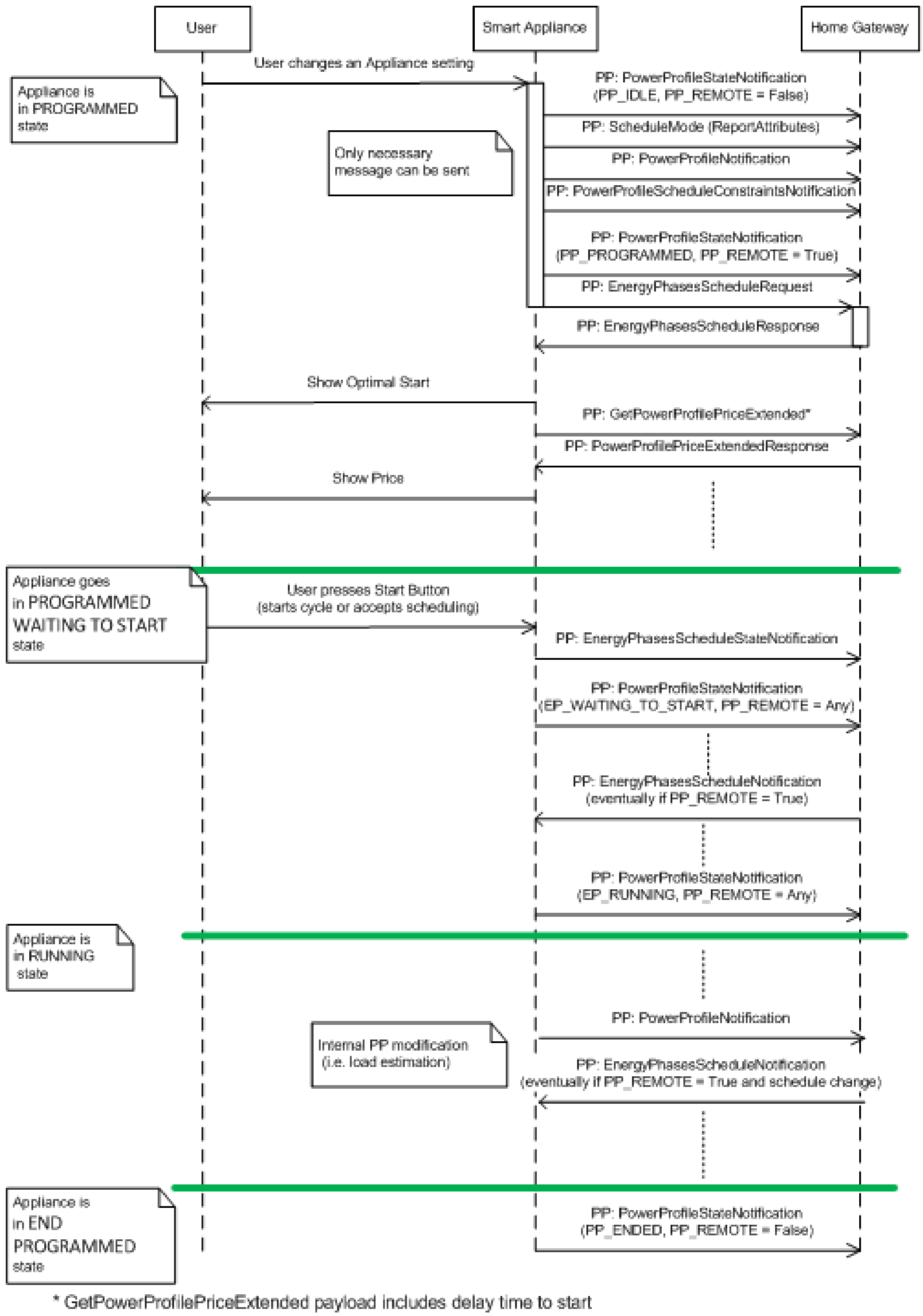
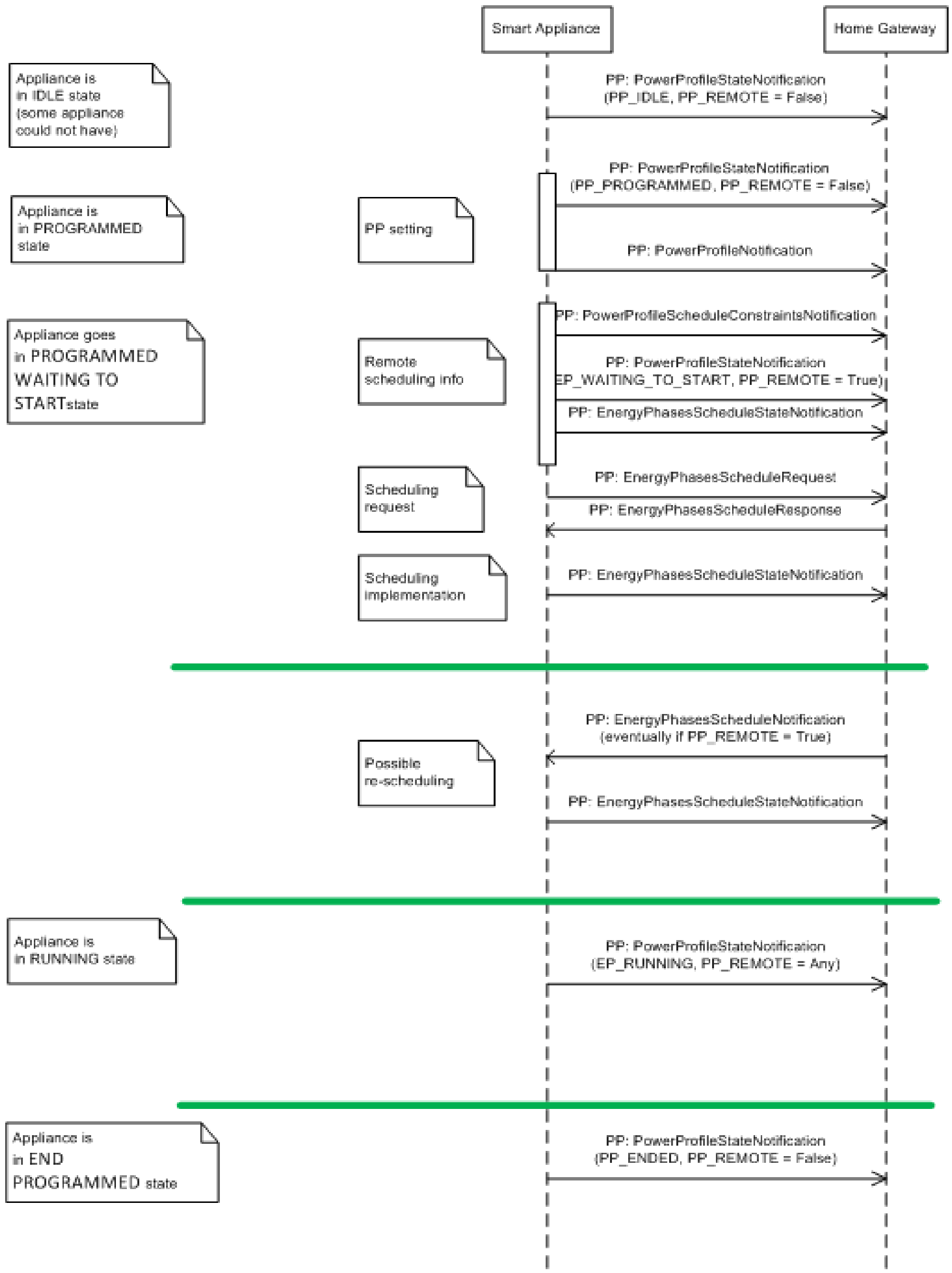


Figure 72: E@H control enabled: Example of sequence diagram with user interaction.

Then the smart appliance sends to the gateway the notification about the user choice (if and how switch from waiting to running state). In the third section, when the appliance starts its running state, it sends its power profile to the home gateway and this replies giving the “acknowledge proceeding” or “change the schedule”. Finally, in the fourth section, when the appliance finishes its work, it notifies at the home gateway the “job concluded” state in order to make available this “requested energy” for other loads inside the home.



* GetPowerProfilePriceExtended can be generated any time by SA if a PP is active

Figure 73: E@H control enabled: Sequence diagram without user interaction

In Figure 73 there is reported another example of sequence diagram of the smart appliance interface. The sequence diagram is very similar to the one before, with the difference that here there is no user interaction and the smart appliance communicates and negotiates its various states with the home gateway. This is the classic example of machine-to-machine communication, where the optimization of the power consumption is completely delegated to a communication protocol between machines.

Given the above, it is now addressed the specific case of this test, i.e. where the smart appliance, although under the control of Energy@home system, can decide whether to stop its cycle or not. The smart appliance used for this test is the washing machine which could not accept an interruption because the clothes in the wash may be damaged.

Figure 74 shows the sequence diagram of reactive control (overload management). A whitegood is running a cycle and, at a certain instant, the user activates a no-smart device.

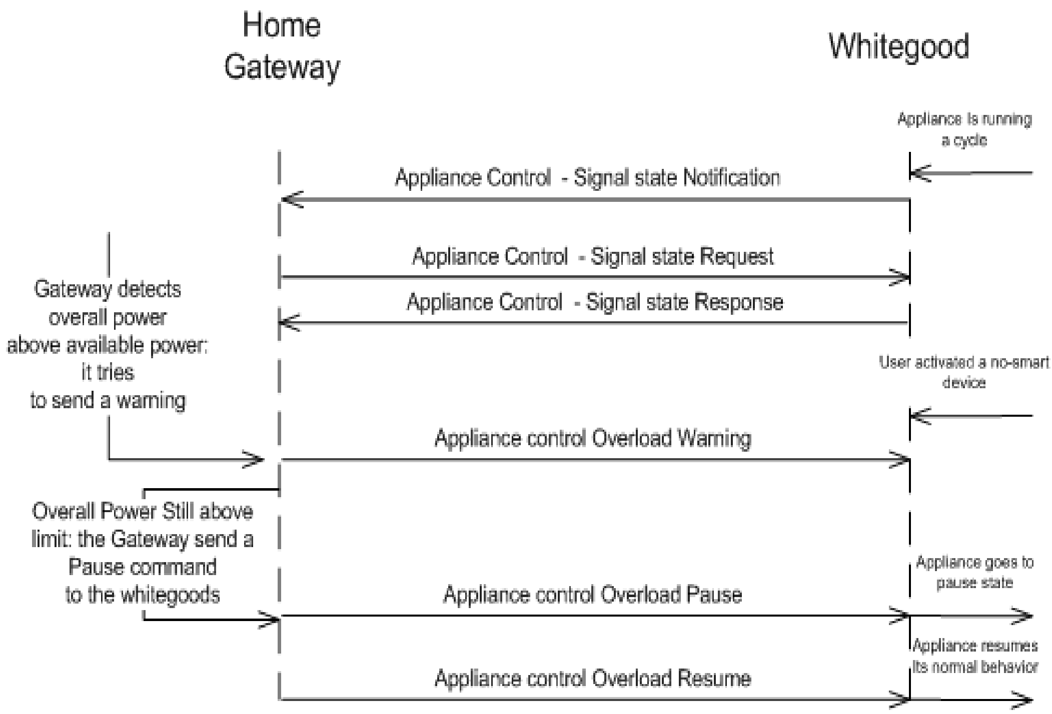


Figure 74: E@H control enabled: Sequence diagram of reactive control (overload management).

As a result of this action, the home gateway detects that the total power consumption exceeded the total available one, and it sends a first warning. If the total power consumption is still exceeding the total available one, the home gateway sends a pause command to the whitegood.

The whitegood checks if the pause can damage something (e.g. the clothes in the washing machine may be damaged) and it acts with the following decisions:

- If the pause can damage something, it continues the cycle and it will pause as soon as possible.
- If the pause doesn't damage anything, it accepts the pause command. Then, when the home gateway will detect that the total power consumption is less than the total available one, it will send a "resume" command and the whitegood will continue with its cycle.

The Figure 75 shows the case of the user #116, where the Energy@home detects an overload at 21:50 o'clock. The home gateway sends a "pause" command to the smart washing machine which answers that it cannot "pause" its cycle because the clothes inside may be damaged.

Then the home gateway checks out a list of priorities of electrical loads in use at that time and decides that it is advisable to unplug the oven. The priority list is predetermined by the Energy@home system, but can be modified by the end user.

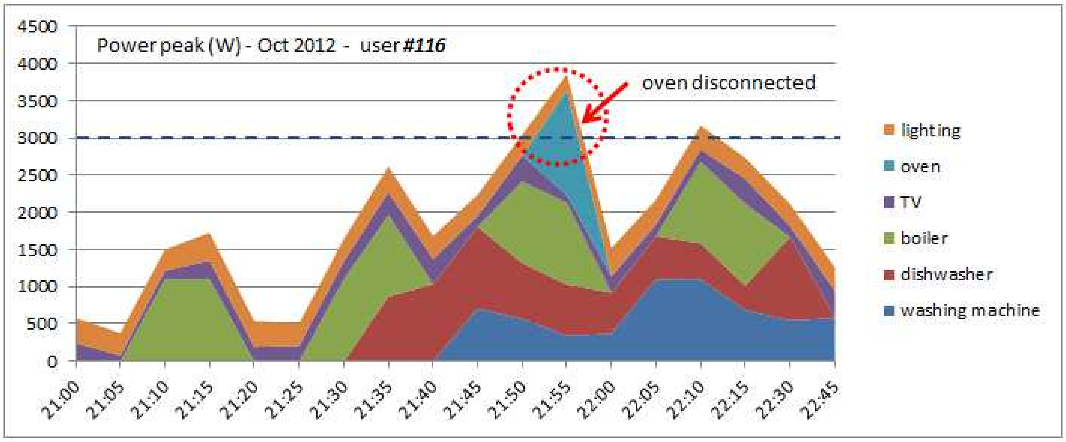


Figure 75: The smart washing machine rejects the pause command; the oven is disconnected in its place to avoid the overload.

The Figure 76 shows the case of the user #119, where the Energy@home detects an overload at 13:10 o'clock. The home gateway sends a "pause" command to the smart washing machine which accepts because in that moment the clothes inside would not be damaged.

Then, when the home gateway will detect that the total power consumption is less than the total available one, it will send a "resume" command and the smart washing machine will continue with its cycle.

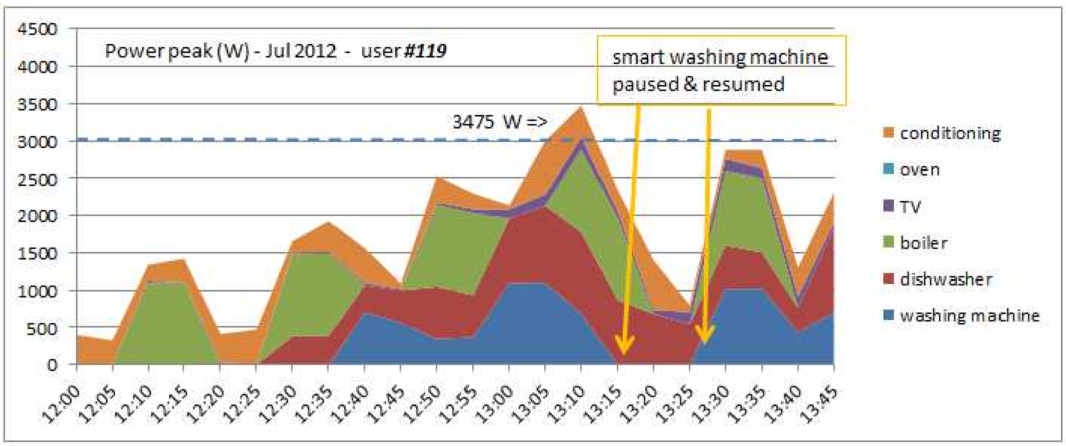


Figure 76: The smart washing machine accepts the pause command to avoid the overload.

Results problems and possible improvements: The tests described above have successfully verified the functionality of the management of priorities among the smart appliance (washing machine) and the traditional ones.

These tests have been successfully verified in two different modes:

1. When the smart washing machine cannot "pause" because its cycle cannot be interrupted without damage the clothes inside. In this case Energy@home disconnects another load consulting a priority list
2. When the smart washing machine can "pause". It then "resumes" its cycle".

At today, the priority list is predefined, but an effective improvement could be introduced by means of an algorithm "smart" that reclassifies in real time what is the load more suitable to be disconnected. Of course, the ability to manual intervention is always left to the end-user.

4.4 DSE WP5: Electric Vehicle Supply Equipment

4.4.1 Experimentation Setup and Test Case System

The experimentation setup used for WP5 is provided by RWTH Aachen University, ACS institute. This setup and the test case system for the power system simulation were described in section 4.1.1.

4.4.2 Conduct of Experiment

The experiment involves study of the impact of a sudden increase of EV charging load on system frequency. Furthermore, it investigates the potential contribution of EVs for primary frequency control in future smart grids. In this experiment, the communication system is assumed to operate ideally, i.e. without any delay, jitter, packet loss, etc.

4.4.3 Experimentation Results

4.4.3.1 Frequency Deviation at Sudden Charging of High Number of Electric Vehicles

It is assumed that the modified IEEE 39 bus system, with the conditions described in Table 8 and Table 9 is operating at steady state at time t = 0. A total number of 200,000 vehicles with an average charging power of 3kW starts to charge simultaneously at t = 3s. Such a scenario can occur - to different extents - for example when tariff incentives are set starting at a specific point in time. The impact of this sudden increase of load due to EV charging on the network frequency is as shown in Figure 77.

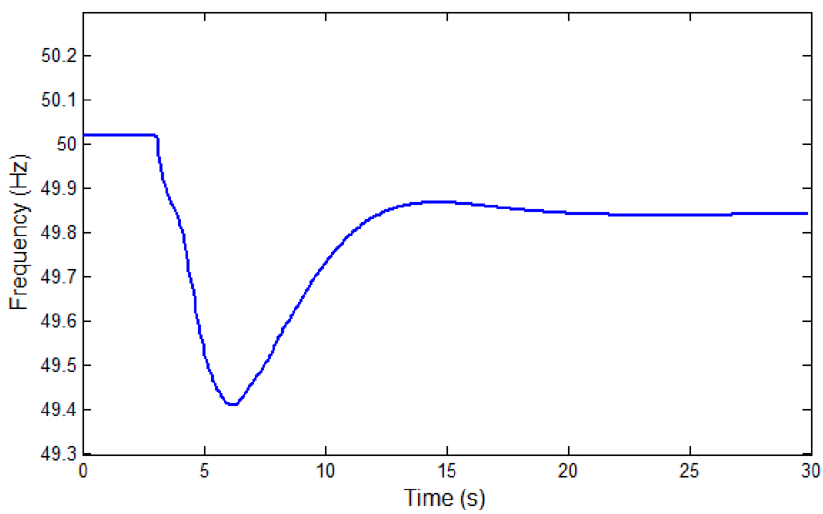


Figure 77: Change in the system frequency following sudden connection of 200,000 electric vehicles

4.4.3.2 Effect of Load Shedding shown in Experimentation

In the next test, it is assumed that these vehicles are already connected to the system, and a total generation of 650MW, which is equal to the generation of wind turbines, and the transmission line (5, 6) as shown in Figure 6 are tripped suddenly at t = 3s. This contingency leads to considerable unbalance between generation and demand and how the power flows through the system. As a result, the frequency of the system starts to decrease. This drop in the frequency activates the primary control action implemented in the governors of conventional generators in the system. Furthermore, the control center, which has detected the frequency drop in the system, sends signals to the EV aggregator at each bus to decrease the charging powers. In this scenario, it is assumed that the communication link is ideal, i.e. the control decisions are delivered to the EV aggregators with no deviation from the original message and with no time delay. The following figures show the frequency response of the system both without and with the electric vehicles contribution:

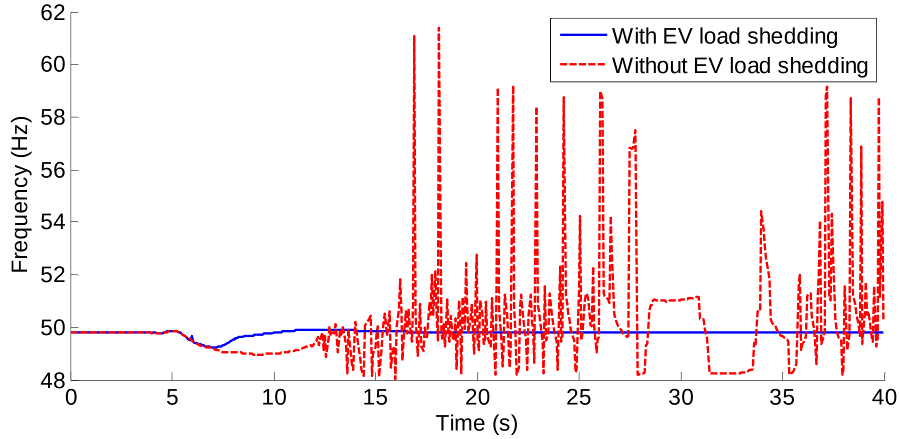


Figure 78: System frequency following sudden loss of a significant part of generation and a transmission line both with and without involvement of EVs in frequency control

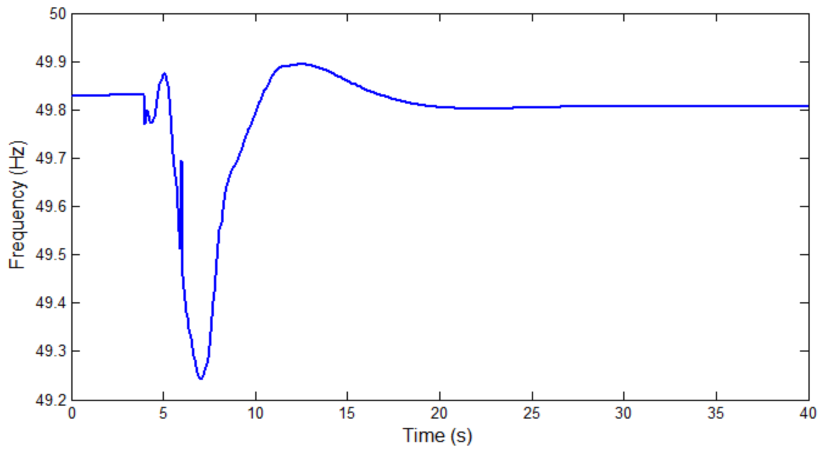


Figure 79: System frequency following sudden loss of a major generation and a transmission line with EVs involved in frequency control

4.4.4 Assessment

As can be seen from the two experimentation steps shown above, charging of electric vehicles at a certain total load level has a non-negligible impact on system frequency during the first seconds, which does not impact the system stability in this case. The frequency deviation following the connection of EVs could then be removed with the help of secondary and tertiary frequency controls. It should be reminded that a sudden increase of charging can be affected by tariff incentives.

The second step of this experiment validates the concept of load shedding and by this shows how electric vehicles can be involved in a beneficial way for power system stability using their batteries as flexible loads. In practice, this can be realized by sending dedicated control signals to smart chargers in order to help the system in restoration of its frequency after loss of generation. As shown in Figure 78, the system has become unstable following the simultaneous loss of a major generating unit and a transmission line in this case, while with the help of electric vehicles, the system has maintained its stability.

4.5 DSE WP6: Demand Side Manager

The “Demand Side Manager” DSE takes into account possible requirements to be provided by different ongoing projects aimed to define the future interactions between clients and electricity market. In the scope of those projects, the clients shall be presented with daily (or even hourly) offers coming from other actors and aimed to modify clients’ behaviour. Offers shall be probably issued by a new player in the energy market called the aggregator, which has the mission to aggregate many small clients and to operate into the energy market presenting them as a whole. The aggregator shall reply to market needs offering services such as power limitation within a given geographical region and temporal slot, peak clipping and peak shifting.

To test this DSE, the following two complementary experiments have been executed:

- The experimentation executed by BeyWatch [18] is an emulation using real measurements from the BeyWatch trial in Paris.
- The Energy@home [19] experimentation for the “Demand Side Management” DSE has begun on December 2011 and it has been analysed a period of one year, that means that real data have been collected coming from 30 private houses till November 30th, 2012.

The purpose of the two proposed experimentations (BeyWatch and Energy@home) is to verify demand-response using market mechanisms, which helps to prevent problems with the electricity grid with ICT in both markets B2C (influencing the contract schemes established between the customers and the grid users) and B2B (managing business relationship between grid users, electricity providers and demand side managers).

The BeyWatch emulation environment and the Energy@home physical infrastructure are described separately in section 4.5.1 and section 4.5.2 in order to avoid confusion between real and emulated parameters.

Anyway their contributions are very synergistic to cover the complete testing of this DSE: While Energy@home is mainly focusing on the development of a communication infrastructure that enables provision of value added energy services in the HAN, BeyWatch extends the scope from single homes to full neighbourhoods.

4.5.1 BeyWatch

For BeyWatch, as explained in the FINSENY D8.2 deliverable [3]**,** the experiments were done to validate the flattening of the demand curve and the optimization in the use of the energy.

The BeyWatch system used is basically composed by two main software blocks:

- BeyWatch agent: It can be seen as the EECS (Energy Efficiency Control System) as depicted in Figure 4. It is installed in the home gateway in each of the houses or individual installations. Beneath BeyWatch agent functions, there is the demand side management functionality as defined by the DSE.
- BeyWatch supervisor: It belongs to the utility domain and is in charge of managing the aggregated demand of the energy, actual and forecasted and to allow the operator to send incentives and counter-incentives to the supervised agents to smooth the aggregated demand curve.

The experimental architecture used is shown in Figure 80, where the most important parts are marked, among them it is possible to see the agent, the Combined Photovoltaic System (CPS): One solar thermal and other photovoltaic, and the hot water tank. Moreover, there are shown the electrical appliances under study, washing machine, dishwasher, fridge and any other appliance plugged into a smart plug. In the case of validating the DSM DSE the fridge and the smart plugs are not going to be taken into account.

The individual values obtained in the analysis of this experimentation for evaluation the DSE will be then extrapolated to a city or neighbourhood level (BeyWatch supervisor level) in order to evaluate the impact on the flattening the demand curve of the energy in that area.

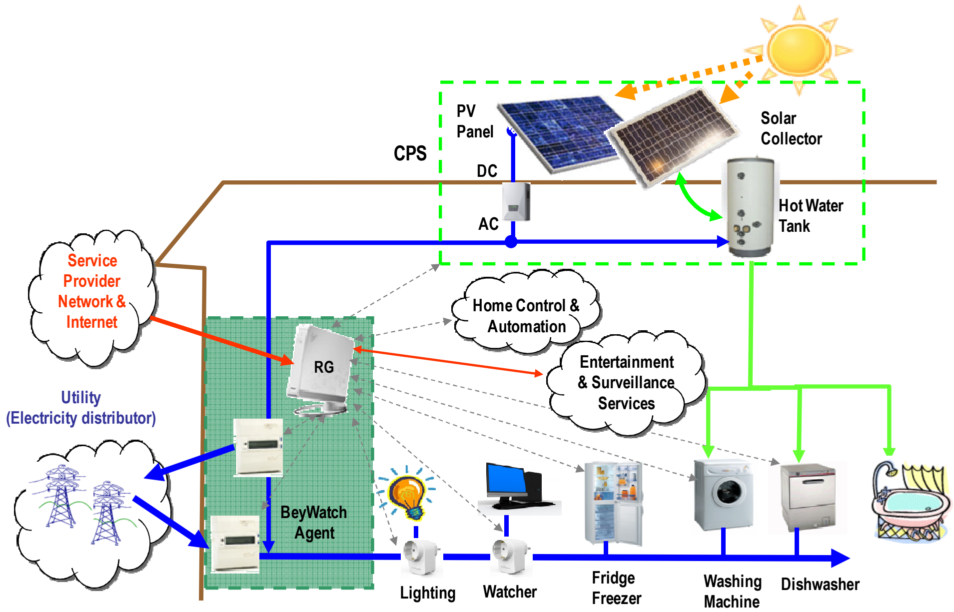


Figure 80: BeyWatch home

4.5.1.1 Conduct of Experiment

The experiments were performed during the BeyWatch project life. Now, we have taken the results obtained then and analyzed for the purpose of the evaluation of the “Demand Side Management” DSE in FINSENY.

The validation plan of BeyWatch took place in 2011, during the months of May, June and July. First using reference tests and then comparing with the results obtained with BeyWatch.

The results that have been analyzed come from the BeyWatch evaluation tests, global system results: Impact of the application of a dynamic tariff and impact of a power cap of a dynamic tariff. The dynamic tariff was taken following a spot tariff assuming that the tariff to the customer is following roughly the same price curve (but with higher levels of prices). The power cap restriction was studied in two ways, when the power was limited and when surpassing the power cap is penalized in the price.

To analyze these results, first a theoretical approach was done to explain what was supposed to be expected after the validation of the data. Then, there is going to be explained the BeyWatch agent behavior, focusing in the functionality covered by the DSM DSE. Finally, it is going to be shown, extrapolating the agent information to neighborhoods and cities, how the DSE helps to flatten the demand curve.

4.5.1.2 Experimentation Results

Theoretical approach

Before proceeding with the analysis of the experimental data, it was studied a theoretical approach to see what would be the expected results.

In Table 24 the objectives of the tests are described and the capabilities used. In this theoretical approach, apart from the demand side manager at home level and the supervisor at utility level, it is going to be taken into account the existence in the installation of a CPS providing hot water to a tank that can be used in some appliances (dishwasher, washing machine) and electrical power to the house. A first sight it seems to be a possible input to the DSM DSE in order to optimize the results.

Then, a priori, expected results should be better for the cases where the DSM is used.

The following table details the list of validation tests that have been taken into account in order to test the DSE. First, tests are performed in order to measure consumption details in case there is no control by the system (tests 1 and 2). These reference tests have been done over the same BeyWatch installation to serve as reference for calculating improvements in the electricity consumption. Then, a list of different combination of control is considered (tests 3 to 6).

		Objective	**CPS**	**Demand Side Manager**	**Supervisor Manager**
Reference tests	1	Monitor consumption, total and per appliance.			
	2	Monitor consumption, total and per appliance, when there is electricity and hot water available from the solar panels.	X		
BeyWatch tests	3	Monitor consumption, total and per appliance, with the management provided by the BeyWatch agent.		X	
	4	Monitor consumption, total and per appliance, with production of electricity and hot water from the solar panels and the management provided by the BeyWatch agent.	X	X	
	5	Monitor consumption, total and per appliance, with the management provided by the BeyWatch system (at agent & supervisor levels).		X	X
	6	Monitor consumption, total and per appliance, with production of electricity and hot water from the solar panels and the management provided by the BeyWatch system (at agent & supervisor levels).	X	X	X

Table 24: Validation tests

The following figures, Figure 81 and Figure 82, show the expected results of the tests in terms of consumed power and money.

The output to the 1st reference test should be the average demand curve with any optimizing capabilities, and it is possible to see that the wave with more ups and downs that has higher power peak values. When using the CPS the general power consumption should be lowered to. While the BeyWatch agent is being used, but not the CPS, the expected result should be a flattener of power consumption, lower power in the peak values and higher power for the valley values. Finally, when using the BeyWatch agent plus the CPS, the combination should obtain the best result, the flattest curve and the lowest power consume. With respect to the power consumption the BeyWatch supervisor doesn’t make any difference because it takes care of the tariff and the economic part.

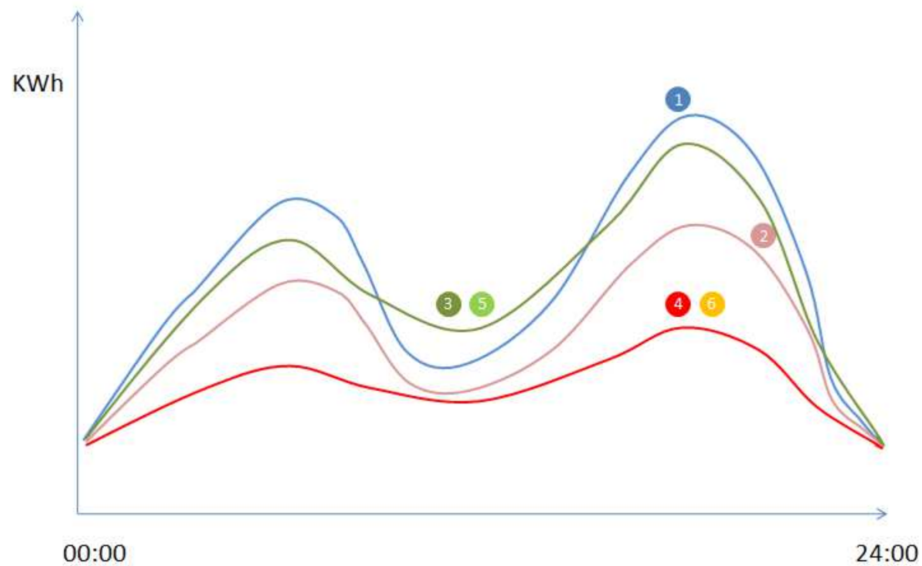


Figure 81: The expected results of the experiments in terms of power

In Figure 82, the expected results with respect to the cost have the same waveform but for the case when the BeyWatch supervisor is used, that should lower the price. Being the case when the CPS and BeyWatch agent and supervisor are used for the optimum result. The demand curve should be flattened.

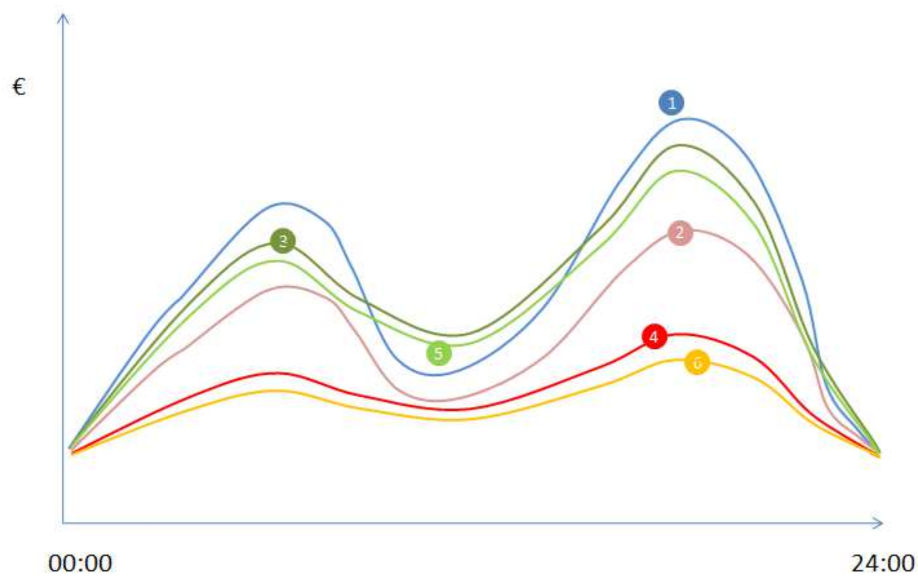


Figure 82: The expected results of the experiments in terms of money

Demand Side Management DSE experimentation results

When analyzing the BeyWatch agent experiments, the importance of including a hot water tank and the CPS information for the agent to take the optimum solution was observed. Therefore, the DSM DSE should also take into account those signals as inputs, and a new and improved definition of the DSE should be taken into account as reported in section 5.5.

First the behavior of the DSE depending on the tariff is going to be shown; when it is flat or spot. In the graphs the power consumption is plotted when the agent is used and when is not.

In Figure 83 the result is with flat tariff. Also the hot water tank temperature is plotted, and the vertical lines show when the user launched the program and the deadlines for the appliances. The DSE schedules the best moment for each appliance to be used.

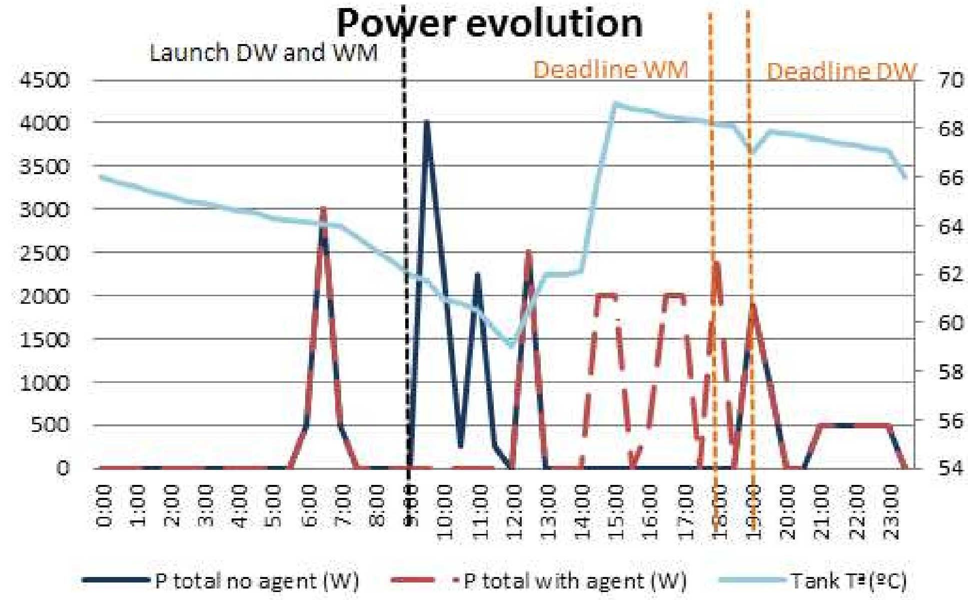


Figure 83: Power evolution with flat tariff

When the DSE is not in use, the dishwasher and washing machine are activated at the beginning of the day, while the DSM DSE takes into account the desired deadline of the customer and when the water tank is hotter, therefore it saves energy and money.

In Figure 84 the behavior of the DSM DSE is shown when the tariff is not flat.

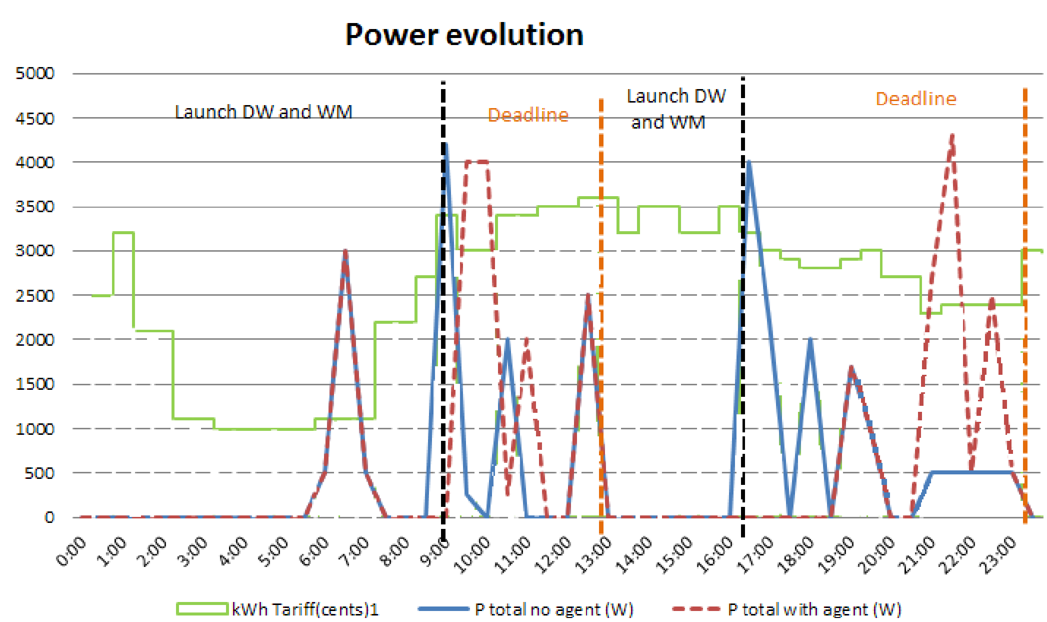


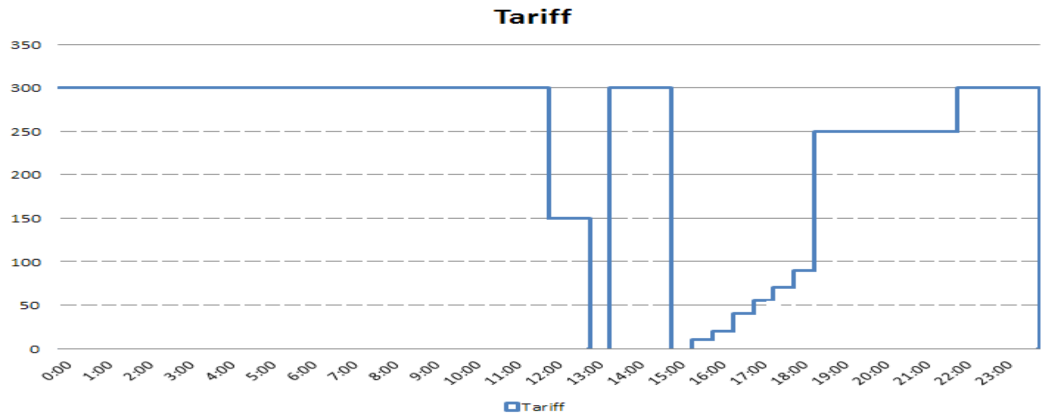
Figure 84: Power evolution with spot tariff.

In this case, the DSE checks the valley prices within the range time that the client has requested. The result will be that the total cost will be lower than without the intervention of the DSE.

The influence of contracting a power cap was also tested, when the tariff is not flat.

The substrate load shown in these figures is the load generated by other appliances apart from the dishwasher and the washing machine.

To see the effect of the DSE, there are going to be shown three plots, one with the non-flat tariff, one with the DSE and the optimum solution when the client saves the most and another showing the human behavior.



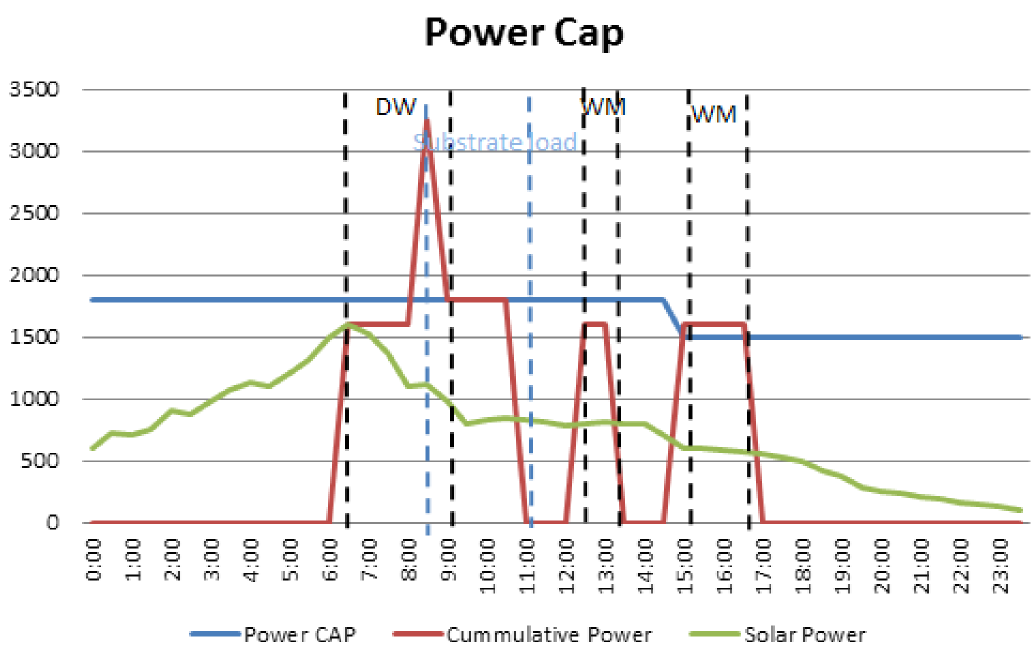


Figure 85: Power evolution with power cap and DSE activated.

In this test the solar energy from the CPS was also taken into account, therefore, even if it seems that the cumulative power surpass the power cap, actually is not that because it has to be subtracted and the final value is lower than the power cap. It is possible to see that the DSE starts the appliance when the produced energy by the CPS is the greatest and when the tariff is the lowest. In consequence, the cost is the lowest.

In Figure 86, it is a simulation of what a user would have done without activating the DSE.

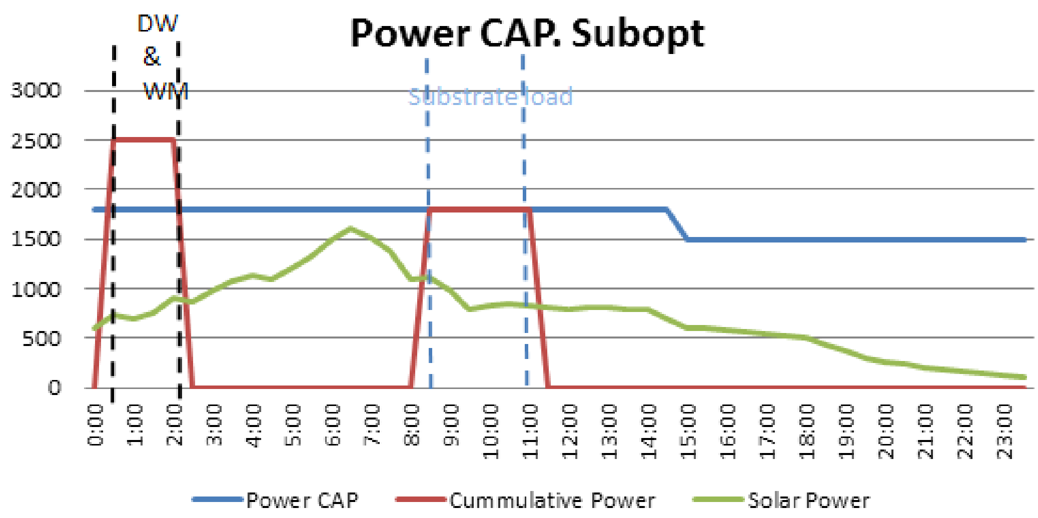


Figure 86: Power evolution with power cap and human user.

When the human is the user, he starts the washing machine and the dishwasher, without taking into account the solar energy available and the price tariff. As a conclusion, the cost is greater as he didn't take advantage of the incentives.

When using a power cap, it is possible to establish a penalty that it is registered as paying double than the regular tariff.

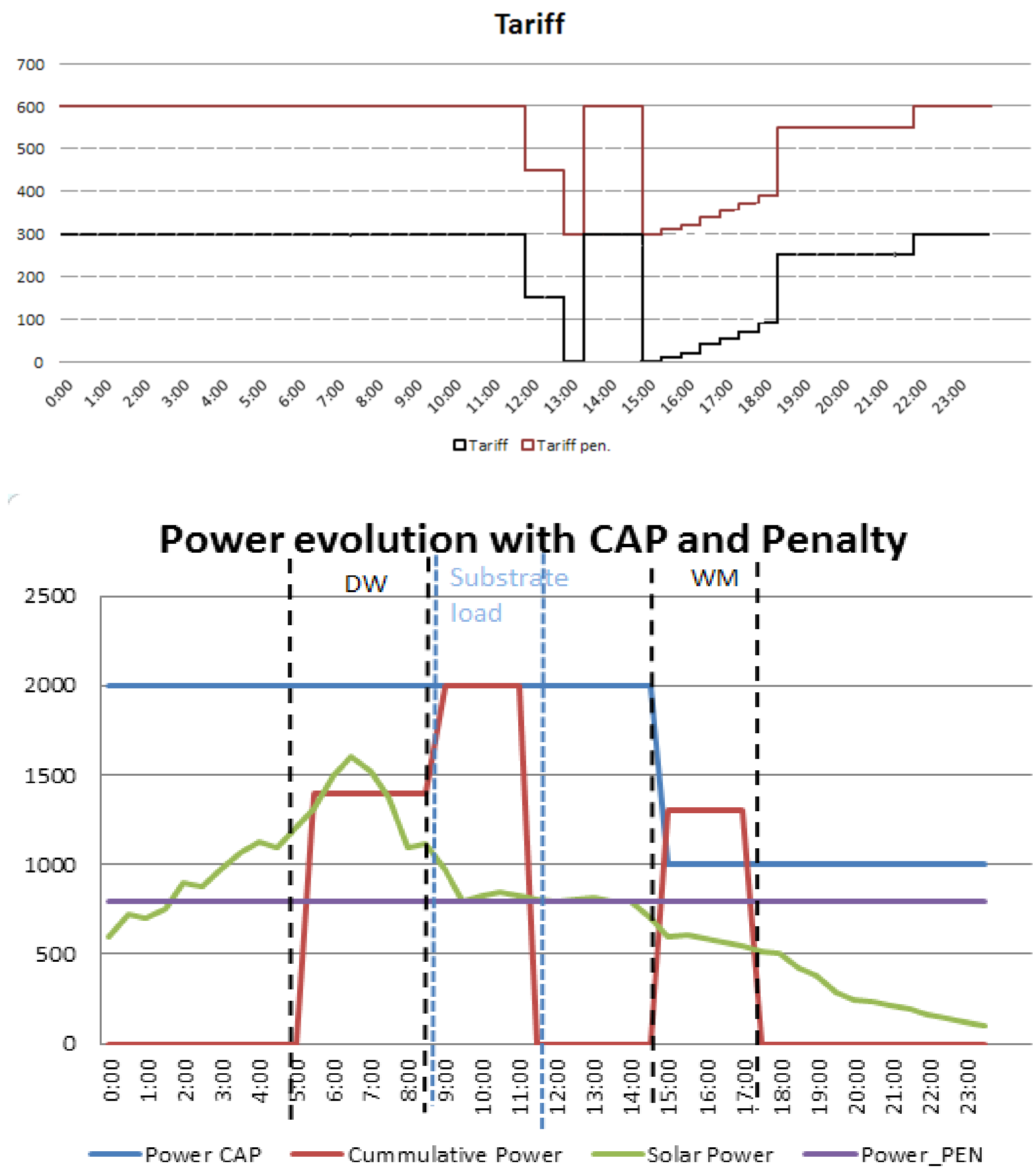


Figure 87: Power evolution using penalty power and DSE activated.

To have a control of the power cap and not being penalized, it is very useful to have a CPS signal to control when the generated power has a peak to use the appliance in that moment and spend less of the general power with minor option to overtake the power cap.

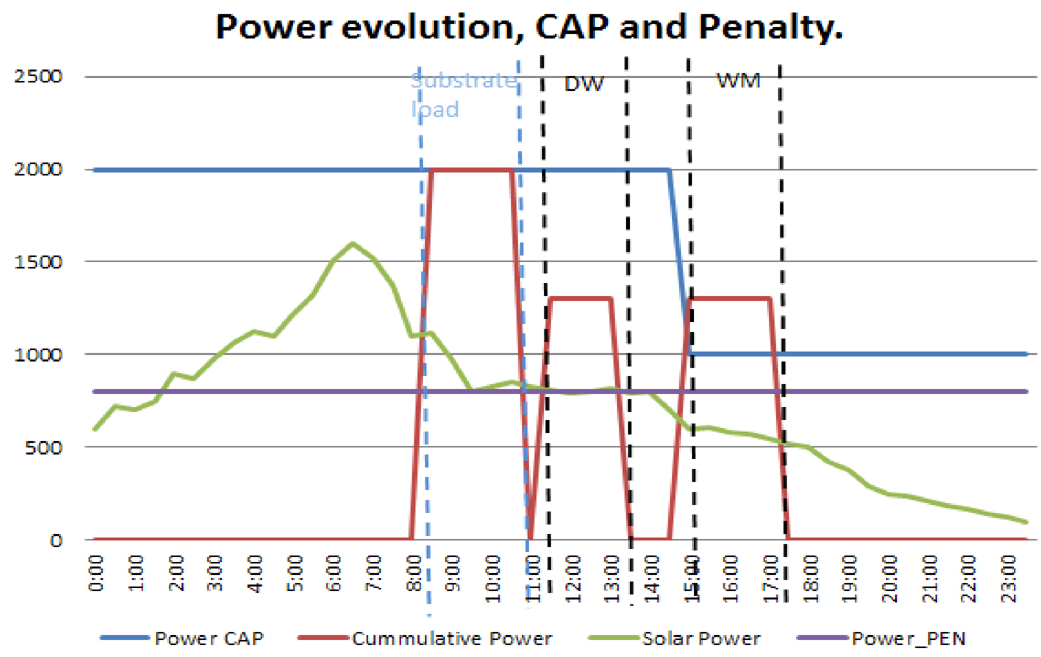


Figure 88: Power evolution, power penalty, human user

With the human user the result is more expensive than with the DSE, as it was to be demonstrated.

It was analyzed the data obtained in experimental tests in order to see how the DSM DSE effectively saves money. In addition to check that the suggested modifications, including the CPS, have been proved to obtain better results.

The experimental tests analyzed were:

- Experimental test 1: Impact of solar thermal on dishwasher start.
- Experimental test 2: Cost savings for washing machine and dishwasher.
- Experimental test 3: Employing both low cost tariff and hot water.
- Experimental test 4: Cost-determined scheduling for a number of appliances
- Experimental test 5: Delay dishwasher to take advantage of water temperature surge.

The following graph, Figure 89, shows the difference in the cost between the human and the DSE, it also includes a percentage of the saving in each test. In Table 25 there are shown the numbers.

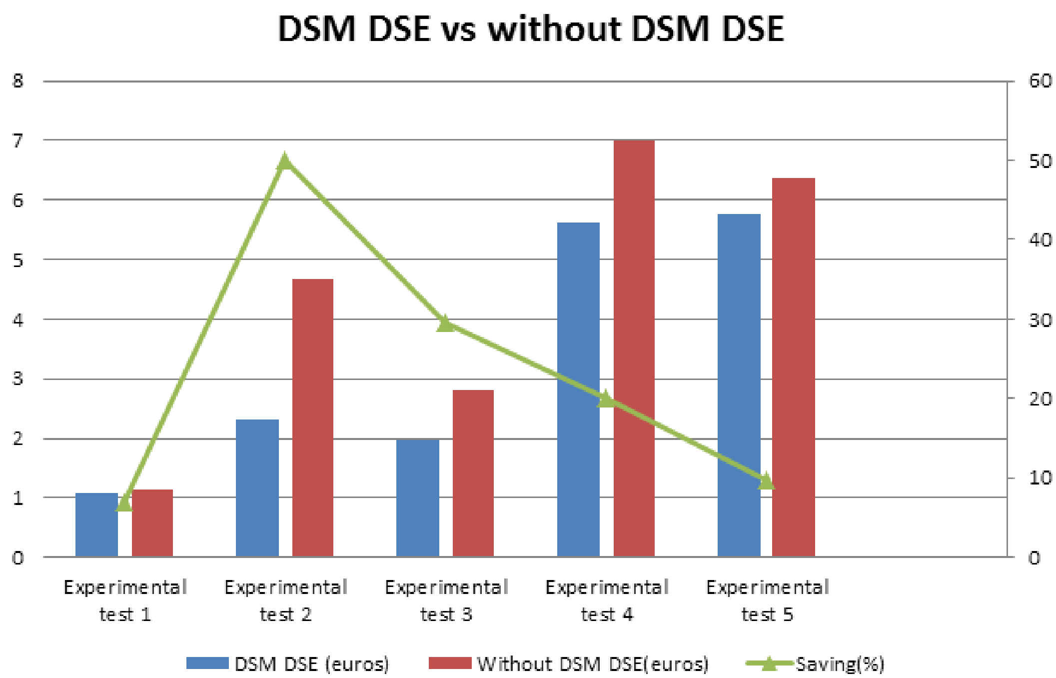


Figure 89: DSM DSE test results

	With DSE (cost €)	Without DSE (cost €)	Savings (%)
Experimental test 1	1,07	1,15	6,96 %
Experimental test 2	2,33	4,66	50,00 %
Experimental test 3	1,97	2,80	29,64 %
Experimental test 4	5,61	7,01	19,97 %
Experimental test 5	5,75	6,37	9,73 %

Table 25: DSM DSE test data

Flatten the demand curve in a city or neighborhood

After testing a single home, there were studied the implications of the penetration of the DSM DSE in neighborhoods and cities. To study the influence of the DSM DSE in flattening the demand curve, the results of single homes to different penetration simulations were extrapolated.

First of all, the cities of study were selected because of their differences in the weather:

Location	Average temperature	Hot/Sunny day	Cold/Cloudy day
Paris	12 ºC	25%	75%
Madrid	14ºC	60%	40%
Palermo	30ºC	90%	10%

Table 26: Cities under study weather

Then the influence of the CPS was checked, and from that results, it was obtained that the use of the hot water tank reduced the consumption significantly (around 20% and 30%). It was also noticed that in hotter regions the consumption was lower; however, this reduction wasn't as noticeable as the use or not of the CPS.

Adding the influence of the DSM DSE to the CPS, the overall consumption of the washing machine and the dishwasher was obtained, depending on the use of the DSE and the city weather, as it is shown in Figure 90, for a house in each city. The consumption of the heater and boiler is more related to the weather.

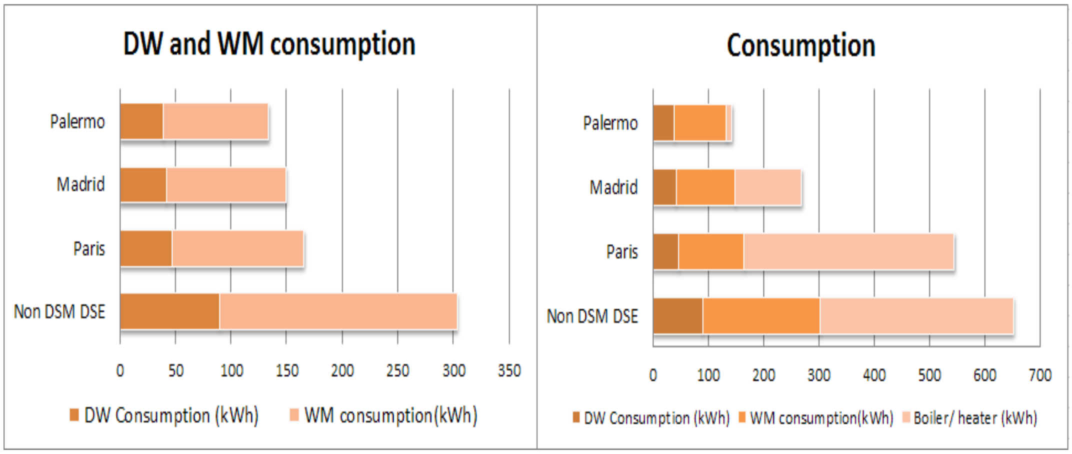


Figure 90: Energy consumption depending on the cities

After seeing the impact of the DSM DSE in the consumption of the different cities, there were extrapolated the values for Paris and analyzed as the annual energy saving depending on the DSM DSE penetration. It is shown in Figure 91 the annual energy consumption versus DSE penetration and the percentage of the savings in each case. The main conclusion is that when the penetration of the DSE is 100% the annual saving is of 13.8%.

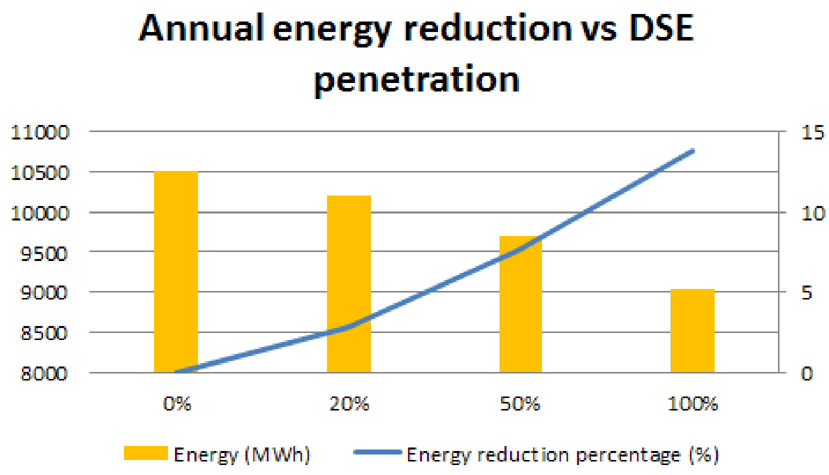


Figure 91: Annual energy reduction vs. DSE penetration

Finally, it was studied how the demand side curve was flattened. The main purpose is to avoid energy peaks, for instance, the DSM planner can regulate that when the dishwasher is working, the washing machine should wait until that one is finished so energy consumed is not accumulated.

The demand curve shown in Figure 92 is a typical one, where we can see that there are ups and downs depending on the day hour. The purpose is to flatten it in order to avoid the peak values that penalize electricity price to final users and impose high requirements to the grid. The figure shows how using a demand side manager as the one proposed in the DSM DSE influences the energy demand curve, after the extrapolation exercise, using the data obtained in individual house testing.

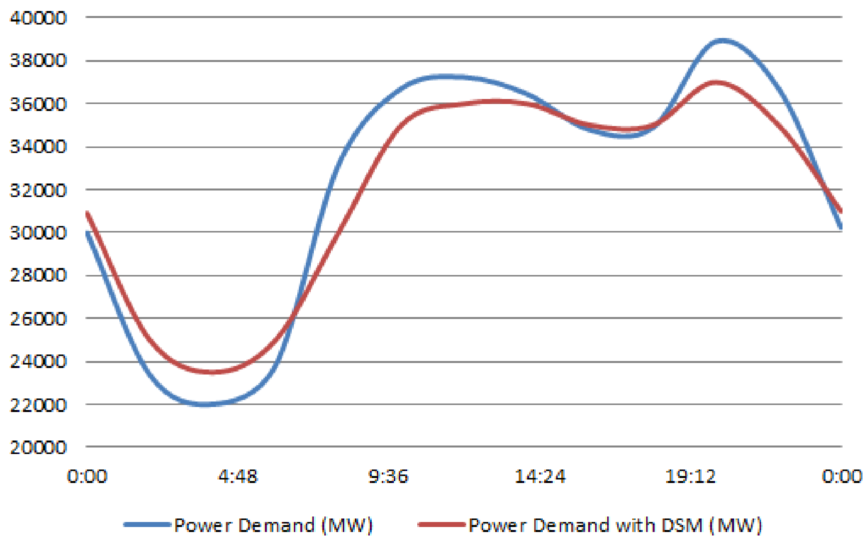


Figure 92: Flattening the energy demand curve

One way to study the flattening of the demand curve is to see where the peaks of voltage are concentrated.

The following graph, Figure 93, shows, depending on the penetration of the DSE, the range of energy values in kWh, where the percentage is greater. It is possible to see that when the penetration is 100% the values between 1 and 2.5MWh represent the 18% of the overall energy, while, when there are not DSEs, there is a 17% of values between 3.5 and 5MWh that are considered peak values.

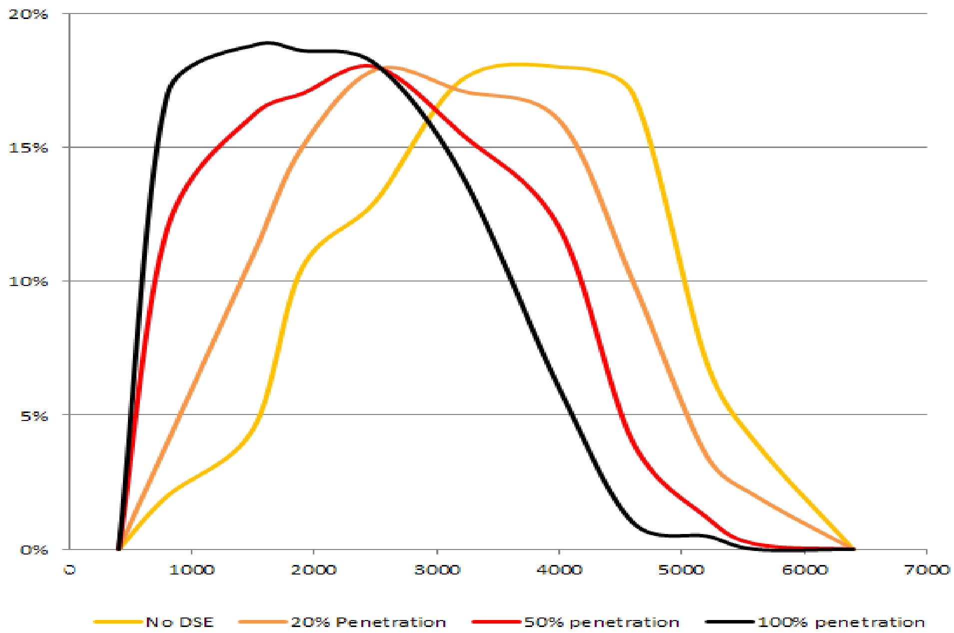


Figure 93: Peaks evolution depending on the penetration.

As a conclusion from last figure, it can be said that there is a noticeable difference with respect to peak values in using the DSM DSE or not. They are mostly reduced.

4.5.2 Energy@home

The “Demand Side Manager” DSE is tested also through the Energy@home system, a physical infrastructure for conduct experimentations within private homes with the goal to monitor, control and optimize the electrical power consumption.

As already described in the FINSENY D8.2 deliverable [3], chapter “5.2.2 - Real experimentation for the DSE”**,** at the time of writing, Energy@home test infrastructure is installed in 30 private houses. By the first quarter of 2013 it is planned to extend this to 100 houses.

A detailed description of the test architecture and its components has already been provided in section 4.3.2.

Comparing the Figure 60 (“Supervisory Controller” DSE) and the Figure 94 (“Demand Side Manager” DSE), the only differences are:

- From the final customer side, the energy box is simply replaced by the home residential gateway that allows data exchange, through Internet, between the devices operating in the HAN and the remote service platform.
- From the demand side manager side, the remote service platform hosts powerful software requested by the demand side manager services.

In other words, unlike the data flow for the DSE tests shown in Figure 61, here great part of the “intelligence” to manage this DSE has moved from the energy box (home gateway + OSGi) to the remote service platform. The reason of this is simple: In certain software applications, the “Demand Side Manager” DSE requires more power computation than was available in the home gateway.

The remote service platform is actually running on servers in Innovation Lab (Telecom Italia Lab in Turin) and it is planned to be moved on Telecom Italia Cloud Computing Services.

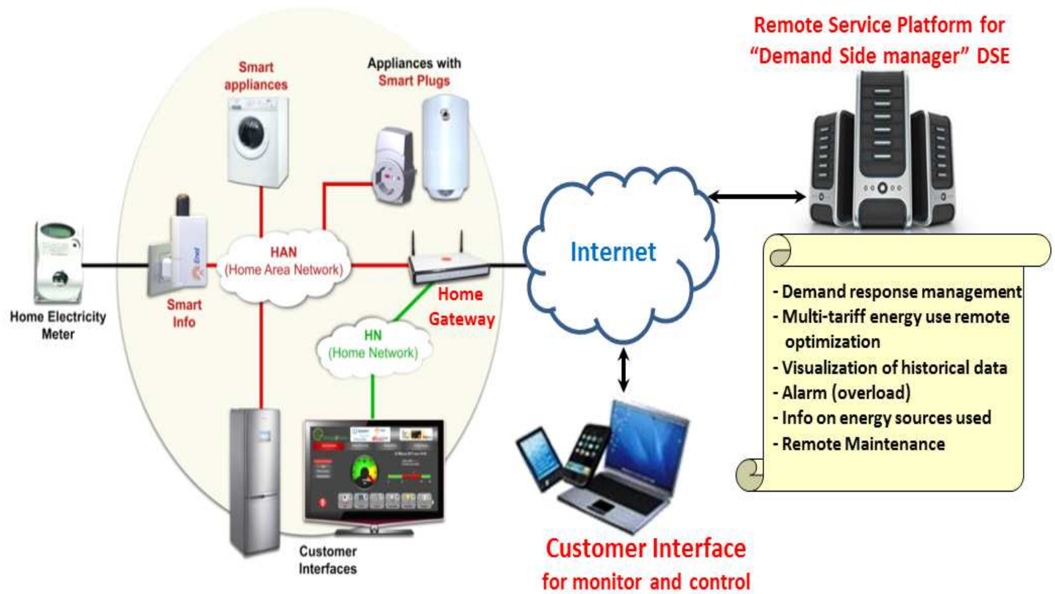


Figure 94: Test architecture for the “Demand Side Manager” DSE

As shown in Figure 94, for the tests of the “Demand Side Manager” DSE the following components have been used:

- A hardware remote service platform to support the software needed to run the test of the “Demand Side Manager” DSE.
- A software running on the remote service platform to provide services such as: Demand response management, multi-tariff energy use remote optimization, visualization of historical data, alarm (overload), info on energy sources used and remote maintenance.
- In each private house hosting the “Energy@home KIT” that is equipped as follows:
  - 1 smart meter

- 1 smart info
- 1 energy box
- 5 smart plugs with a local meter, a switch, and ZigBee radio communication.
- 1 smart appliance with embedded ZigBee radio communication.

4.5.2.1 Conduct of Experiment

The experimentation for the "Demand Side Management" DSE has begun on December 2011 and was carried out for a period of one year that means that real data coming from 30 private houses till November 30th, 2012 have been collected.

In each private house under test there was already installed an ENEL smart meter and the relative electricity supply contracts had a power limit of 3kW or 4.5kW.

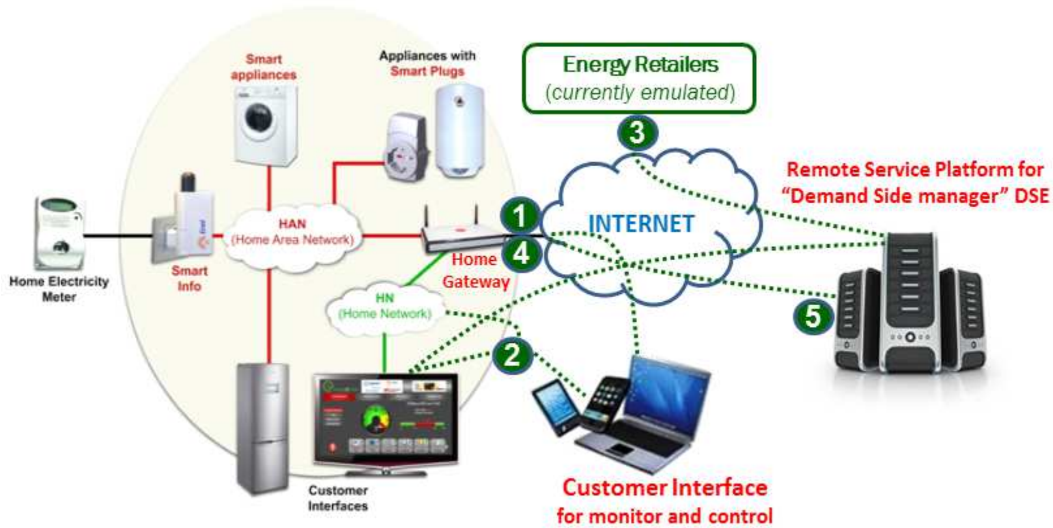


Figure 95: Services applied and/or emulated for the "Demand Side Manager" DSE test

With reference at the Figure 95, the services applied and/or emulated for this "Demand Side Manager" DSE experimentation are:

1. **Demand response management:** It acts a mechanism to manage customer consumption of electricity in response to supply conditions, for example, having electricity customers reduce their consumption at critical times or in response to market prices.
2. **Visualization of historical data:** This service provides customers historical and statistical information on their energy consumption, disaggregating the global energy time variations with the one coming from the single smart appliances. The remote service platform allows the storage of the total and single appliance's energy consumption. The home gateway can access and aggregate those data to present them to the user through a browser. The home gateway allows external applications in the home network to retrieve the stored data.
3. **Info on energy sources used:** Through this service (at today only emulated), the energy retailer could deploy an application able to provide clients with the energy sources mix used to supply his/her appliance, specifying the percentage of renewable sources, the CO_2 footprint and similar information. This allows increasing the final customer ethical awareness.
4. **Multi-tariff energy use remote optimization:** It provides an optimization of appliances usage in order to optimize energy cost according to the variable energy tariffs. This is meaningful for all those appliances which are activated by the customer and performs a specific operating cycle, such as a washing machine, oven and dishwasher. The most important exception is the fridge, which operates continuously.
5. **Remote Maintenance:** Thanks to this remote service, if the customer experienced some problems with the home energy management, a Web application on the home gateway could present the status of the HAN including the devices list, the devices status (i.e. joined to the HAN but not responding), etc. Also warning and alarm could be activated in case of communication problems.

Summarizing, the above tests for the “Demand Side Manager” DSE are focused at obtaining the following informations and actions:

a. Display information on energy usage like instant power, historical data, contractual information and similar, from the whole house (coming from the Smart Info) and from every single smart appliance. The level of details and graphical layout of their user interface is freely defined by every device.
b. Transmit control message to smart appliances to request a modification of their behaviour.
c. Configure smart appliances to modify their power consumption profile (e.g. a personal computer used to configure a thermostat to activate the controlled load only in certain time slots).
d. The software application, which implements the user interface, could be local in the device or remotely hosted in another device (e.g. the home gateway) and accessed through Web services.
e. Through the monitoring of the number of accesses of the final users at the “Energy@home WEB interface” it has been possible to evaluate their interests and their changing habits in relation to the energy saving.

All the tests described above make use of real data coming from private houses. The received data are then applied to the following two software components:

- The first software is used to filter and aggregate the received data in order to interpret and represent them graphically.
- The second software, starting from the real coming data, calculates the energy costs for the final customer as function of the daily period of use in the multi-tariff environment.

Due to privacy-related reasons, the identity of end customers have been replaced by numerical identity; in particular the seven users that have been selected here deemed to be more significant for the test of the DSE in question.

The adopted format for the user identities follows the rule shown in the following example:

“User #114”, where **#1** means *“Phase 1” Energy@home experimentations*” and **14** means that it is the final user number 14. According to this concept the analysis results from the seven end users identified from the number #**114** to the number **#120** will be reported.

Also for the tests of the “Demand Side Manager” DSE, the power consumption and related costs of the year preceding the trial (that is, when in their homes had not yet installed the Energy@home KIT) for each of the seven end users are available.. This information is essential to understand how it has changed the awareness of the end user against its management.

Finally, an analysis is shown on the awareness of the end users about the energy saving by monitoring the amount and type of accesses to the Web interface of the system Energy@home.

In the next “Experimentation results” section, the obtained results of these tests will be detailed.

4.5.2.2 Experimentation Results

From these tests of the “Demand Side Manager” DSE, the following five macro-results have been obtained:

1. To verify the advantages of the self-consumption of self-produced energy versus its sale on the electrical network.
2. To verify the change in awareness and in the habits of the end users.
3. To verify the frequency of the local and remote access at the customer interface.
4. To verify the service (today only emulated) where the energy retailer could deploy an application able to provide clients with the energy sources mix used to supply his/her appliance, specifying the percentage of renewable sources, the CO_2 footprint and similar information. This allows increasing the final customer ethical awareness.
5. To offer at the end user the ability to sign a contract to more low power thanks to the possibility to keep under control the peak load, thus saving money every month.

In the following paragraphs the obtained results of these tests will be detailed.

4.5.2.2.1 Test on the Convenience of the Self-Consumption of Self-Produced Energy

As well known, the Feed-In tariff schemes have been successful in many countries around the globe. Such schemes are based on private power producers feeding all electricity they generate into the public grid against payment of a pre-determined price that is guaranteed for a set period of time.

However, local utility companies are concerned that a large amount of privately generated renewable energy could have a negative impact on the grid. In fact, there is no need to feed any self-generated electricity back into the grid. It makes more sense for households to use the generated energy themselves.

Instead of providing incentives for energy being fed into the grid, it therefore makes more sense to incentivize self-consumption of self-generated electricity. So, today many local utility companies offer a higher energy price if the prosumer self-consumes its self-produced energy instead of sell it to the grid.

The Italian Ministerial Decree “Quinto Conto Energia” introduced on July 5th, 2012 redefines the way of incentives for the production of electricity from photovoltaic cells. In particular the self-consumption of the self-produced energy is incentivized, as shown in Figure 96.

CONDITIONS	
Annual consumption [kWh]	3000
Annual production [kWh]	3000
Power plant [kW]	3
Premium rate on the energy consumed on site [€/kWh]	0,126
Comprehensive rate (introduced into the network)	0,208
Rate energy taken [€/kWh] (taken from the network)	0,173

% Self-consumed energy	Energy (in kWh)			Gain (in Euro)			
	Self-consumed	Annual production	taken from the network	consumed on site	Introduced into the network	taken from the network	TOTAL GAIN (EUR)
0%	0	3000	3000	0,0	624,0	-517,6	**106,4**
5%	150	2850	2850	18,9	592,8	-491,7	**120,0**
10%	300	2700	2700	37,8	561,6	-465,8	**133,6**
15%	450	2550	2550	56,7	530,4	-440,0	**147,1**
20%	600	2400	2400	75,6	499,2	-414,1	**160,7**
25%	750	2250	2250	94,5	468,0	-388,2	**174,3**
30%	900	2100	2100	113,4	436,8	-362,3	**187,9**
35%	1050	1950	1950	132,3	405,6	-336,4	**201,5**
40%	1200	1800	1800	151,2	374,4	-310,6	**215,0**
45%	1350	1650	1650	170,1	343,2	-284,7	**228,6**
50%	1500	1500	1500	189,0	312,0	-258,8	**242,2**
55%	1650	1350	1350	207,9	280,8	-232,9	**255,8**
60%	1800	1200	1200	226,8	249,6	-207,0	**269,4**
65%	1950	1050	1050	245,7	218,4	-181,2	**282,9**
70%	2100	900	900	264,6	187,2	-155,3	**296,5**
75%	2250	750	750	283,5	156,0	-129,4	**310,1**
80%	2400	600	600	302,4	124,8	-103,5	**323,7**
85%	2550	450	450	321,3	93,6	-77,6	**337,3**
90%	2700	300	300	340,2	62,4	-51,8	**350,8**
95%	2850	150	150	359,1	31,2	-25,9	**364,4**
100%	3000	0	0	378,0	0,0	0,0	**378,0**

Figure 96: The self-consumption of the self-produced energy is incentivized (3kWh contract case)

With reference to the Figure 96, if a self-production is assumed equal to the consumption (3000kWh per year) it is observed that the prosumer earns € 106.40 in a year if he sells all the self-produced energy, while he would earn € 378.00 if consumed throughout the self-produced energy.

Given the above, in the Figure 97 the used primary and self-production metering in E@H is shown. The energy production of any on-site generation plant is monitored and recorded by a smart meter (it is marked in Figure 97 with the label M2 and the self-produced power with the vector P).

Figure 97: Primary and self-production energy metering in E@H

In such case the primary smart meter (M1) monitors and records both the energy picked-up from the power distribution network (vector E) and the energy put into it (vector U).

The home consumption of energy (vector C) is calculated as the contribution of both a part from the on-site generation plant and from the power distribution network.

The vector C is so calculated: **C** = **E** + (**P** – **U**).

E: Primary meter M1	(Current Summation Delivered)
U: Primary meter M1	(Current Summation Received)
P: Self-production meter M2	(Current Summation Received)

In Figure 98 the sequence diagram is shown about the management of the process for self-production and primary meter in Energy@home.

As first step, the home gateway requests a specific report on power consumption info at a specific smart appliance and requests a report on the general consumption info at the Smart Info M1. Finally, the home gateway requests a report about the general power self-production info at the production meter M2.

Each of the entities questioned by the home gateway responds to requests by sending a reporting data. The application running on the home gateway uses these report information to determine the percentage of use of the different appliances within the home and also reports the self-production of energy.

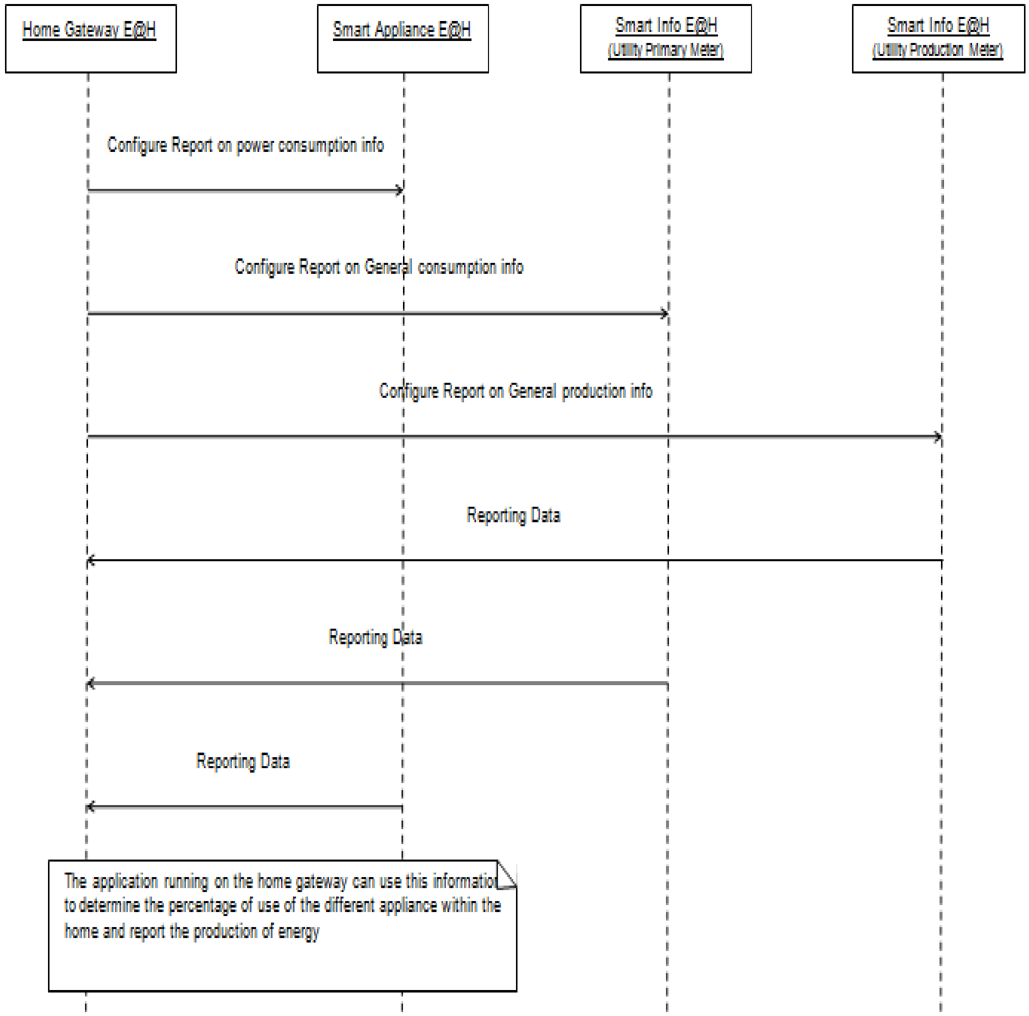


Figure 98: Management of self-production and primary meter in Energy@home

With Energy@home configured for the Figure 97 scenario, the prosumers #115 and #117 have been tested for a period of a year (2012).

As it is possible to see from the Figure 99 and from the Figure 100, it is important “HOW” the self-produced energy is used from the prosumer.

In particular, the prosumer #115 consumes the most self-produced energy (76%) and at the end of the year he earned 431 € (Figure 99). By contrast, the prosumer #117 consumes only a part of the self-produced energy (47%) and at the end of the year he earned 199 € (Figure 100).

This confirms that, irrespective of the quantitative capacity of self-production of energy, the choice of self-consumption of the produced energy is always rewarded.

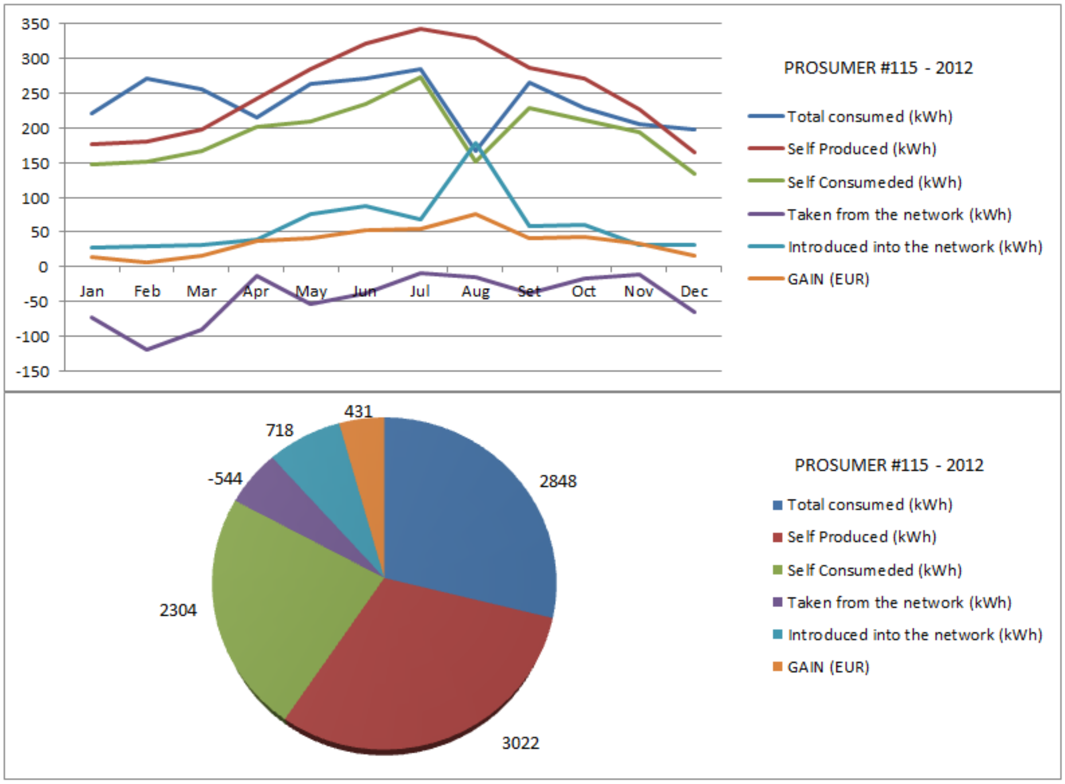


Figure 99: The prosumer #115 self-consumes 76% of the self-produced energy

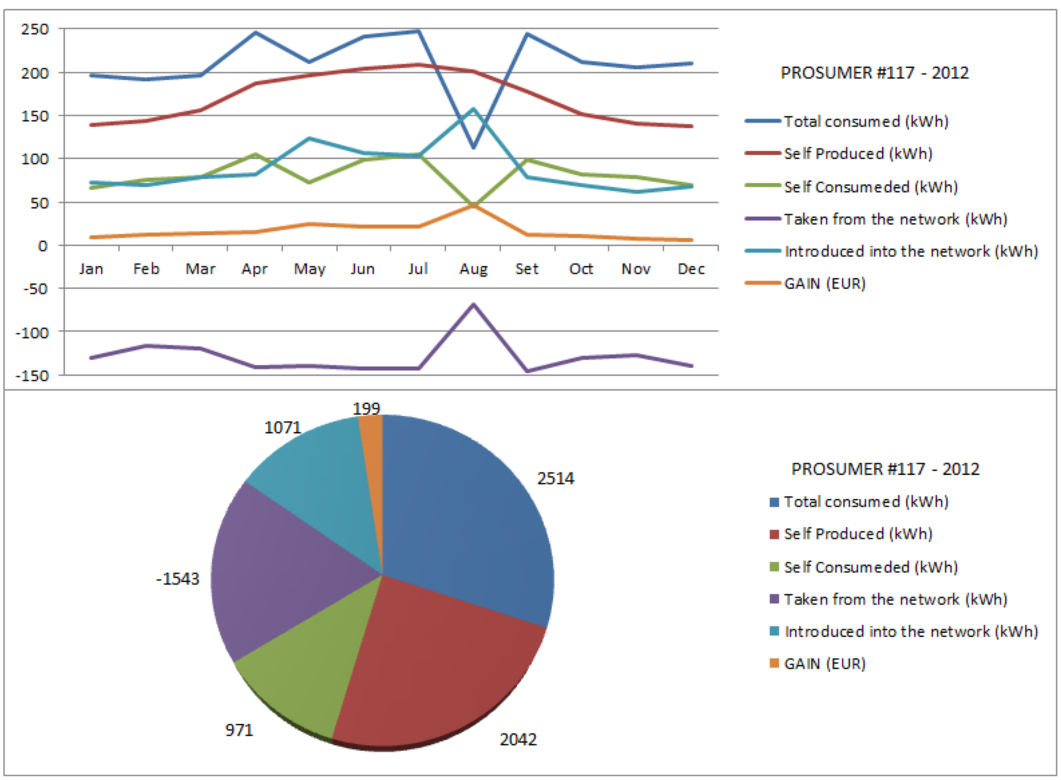


Figure 100: The prosumer #117 self-consumes 47% of the self-produced energy

Results problems and possible improvements: The tests described above have successfully verified the ability of Energy@home system to handle even the auto-production and energy consumption.

Although there are no drawbacks to report for these tests, definitely an improvement to be introduced is the automatic management of the energy self-consumption in order to minimize the energy required at the network. This can be done with the use of “smart” algorithm that in real-time exchanges optimally the energy source between the self-produced system and the power network access.

4.5.2.2.2 Test on the Change in Awareness and in the Habits of the End Users

In the tests made in the 2012, the electricity tariffs in force in Italy were articulated on the two following hourly bands:

- F1 band: From 8 to 19 in the days from Monday to Friday, excluding public holidays,
- F23 band: From 19 to 8 a.m. in the days from Monday to Friday and all hours of the day Saturday, Sunday and national holidays.

The advantage of the two-tier prices is such that any single client pays for the electricity consumed at different times in the fairest way. In fact, everyone pays the right price in relation to the way they use electricity.

The Table 27 shows the economic conditions for the customers having a 3kWh bi-hourly contract. As it is possible to see from this table, the cost of energy varies between bands F1 and F23 but also varies depending on the amount of energy consumed (kWh) over the last year.

DOMESTIC CUSTOMERS (*)

(*) Home of residence with committed power up to 3 kW

2012	Bi-hourly		Network Services	General Charges	Bi-hourly total price (€/kWh)	
Energy share (€/kWh)	F1 band	F23 band	fixed costs	fixed costs	F1 band	F23 band
kWh/year: from 0 to 1800	0,09874	0,06906	0,00461	0,020336	0,123686	0,094006
from 1801 to 2640	0,10239	0,07271	0,03925	0,030046	0,171686	0,142006
from 2641 to 4440	0,10635	0,07667	0,07670	0,043116	0,226166	0,196486

Table 27: Economic conditions for customers with 3kWh bi-hourly contract

The new system also encourages more knowledgeable and efficient use of valuable resources like electricity, with positive effects on energy conservation, environmental protection and developing more eco-friendliness, for the benefit of all.

The Figure 101 shows the change in awareness and in the habits of the user #116: Even if the power consumption in 2012 is approximately equal to that of 2011, the band F23 has been used much more because the user interface of Energy@home showed its convenience of use.

In the industrial sector tiered pricing for bands are applied for some time and made it possible to reduce consumption especially during the hours of greatest demand, reducing the need to build new power plants. The new two-tier prices system can also provide opportunities for savings in the bill, concentrating consumption in the hours at a lower cost.

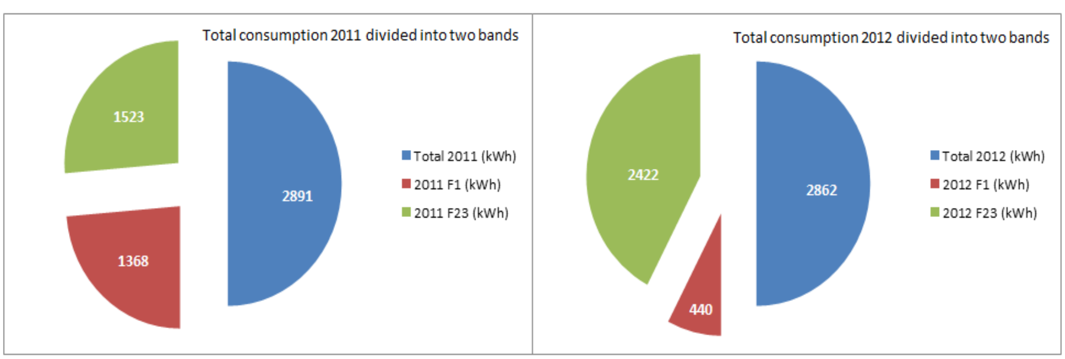


Figure 101: Change in awareness and in the habits of the user #116

The Figure 102 shows how the change in the habits of the user #116 allows cost savings. It is noted that the annual savings is only 40 euro, but this is due to the fact that prices of F1 and F23 bands are still too close. However, day after day, new offerings are emerging from other competitors that allow annual savings far greater.

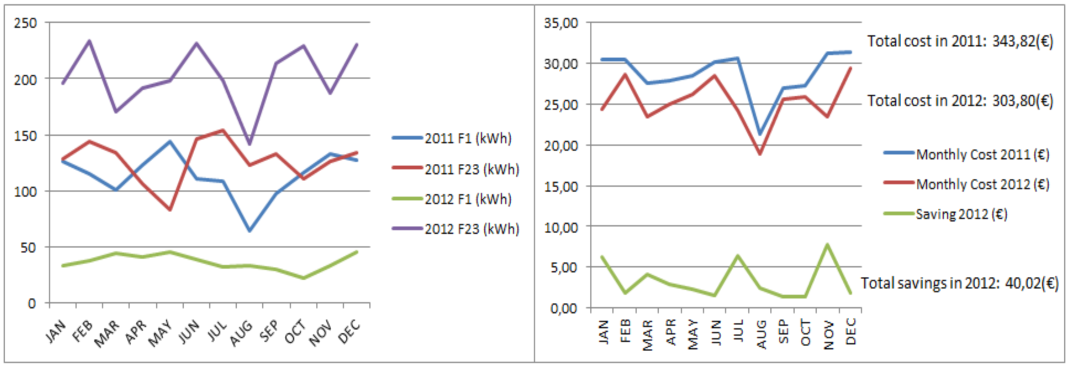


Figure 102: Change in the habits of the user #116 and its consequent cost savings

Results problems and possible improvements: The tests described above have successfully verified. The performance of this DSE experimentation depends from the computing power of the remote service platform.

This computing power demand increases with the increase of the number of end-users who use this platform. In particular, when multiple users require services that involve the use of heavy algorithms it was observed a drop in performance of response times.

This means that in future the switch from the testing phase to the one on large scale service will be necessary to use structures of cloud computing. Precisely for this reason, in short-term the remote service platform will have to move from the servers in Innovation Lab (Telecom Italia Lab in Turin) to the Telecom Italia Cloud Computing Services.

4.5.2.2.3 Test on the Frequency of the Local/Remote Access at the Customer Interface

This assessment tests, contrary to appearances, is of great importance to understand how and for how long the end users see the graphical interface of the system Energy@home.

In fact, the greatest risk is that the user, after the natural intense consultation in the early days, abandons the use of the interface thus invalidating the efficiency of the control system, of the energy savings and of the associated cost savings.

For these reasons it is conducted a test based on tracking the number of hits in the time around the user interface, both indoor and outdoor.

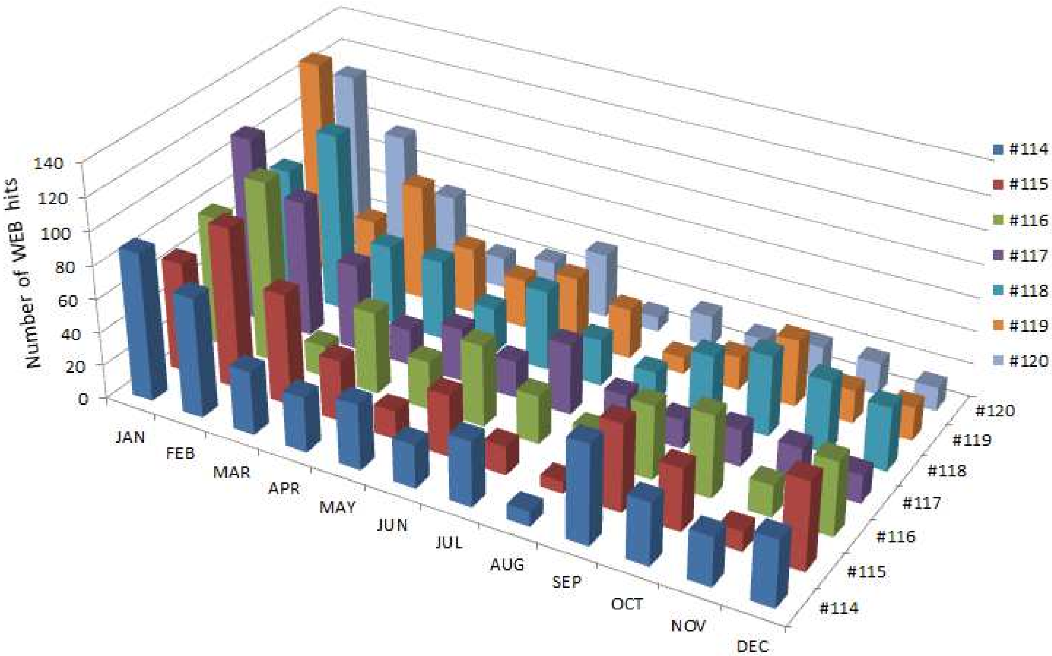


Figure 103: Number of Web hits along the year

As it is possible to see in Figure 103, in the first quarter of 2012, there has been a high attendance to the personal webpage of Energy@home. Then, as was to be expected, there was a progressive decrease in visits that continued until the end of the summer; this is because the user had selected with the experience the little data that really interested him.

So, in autumn a "Community" service has been activated to the end user that did resume attendance at webpage of interest.

In the "Community" service, there is the possibility to compare own power consumption and own energy costs with the ones of other users (in the respect of the privacy, using the nick-name). Also, newsletters, questionnaires and important messages to save energy are periodically sent. End users can also exchange messages; in short, a sort of social network for energy was installed.

A possible improvement consists in promoting the competitions for end users who uses energy more intelligently; the winners will receive a bonus of free energy in kWh. However, this is possible with the economic participation of the Ministry of Energy, because it is improbable that the energy retailer has an interest in promoting these competitions.

Results problems and possible improvements: The tests described above have successfully verified the traceability of access to webpages of the interface of Energy@home. All communication tests went to good end by remote service platform to end users and between users.

4.5.2.2.4 Test (in Emulated Way) on the Kind of the Energy Offered by the Energy Marketplace

The test described below, reflects faithfully the use case described in the FINSENY deliverable D6.1 (section 4.5.3 – "Colored Ethical Bid") where the final user needs to be aware of the kind of energy that he consumes.

In fact, his choices about the consumed kind of energy contribute to the ecological sustainably in our homes and cities. For that, the final user must know "what kind of energy he is consuming" and "how and where" will be disposed of as waste the elements used to produce this energy. E.g., the final user chooses nuclear energy to save money, he should also know where and how will be disposed the nuclear waste and how much it costs the community in economic and ecological terms.

To do so, the energy information provider provides information to the final user about the mix of the available energy sources: Each kind of energy is represented (on the PC or the smart phone) with a different color (e.g.: red=nuclear, green=renewables, and so on all variations between red and green).

This use case has been “emulated” through an Energy@home test. Here “emulated” means that all the process is “real” but the retailer offer is “simulated” because until now this service is not available.

The snapshot of Figure 104 shows the power purchase proposal with different sources of origin. Through the graphical user interface of Energy@home it prompts the end user what forms of energy he would be willing to buy, taking into account the origin, the price and the environmental impact.

Plant Type	Cost (EUR/kWh)	Cost (EUR) for 3000kWh/year	GreenHouse Gas (GHG) Emission	Make your ethics choice	
Geothermal	0,098	294,00	Low	YES	NO
Hydro	0,092	276,00	Low	YES	NO
Solar farms	0,176	528,96	Low	YES	NO
Offshore wind	0,213	640,32	Low	YES	NO
Onshore wind	0,111	334,08	Low	YES	NO
Tidal power	0,313	939,60	Low	YES	NO
Biomass	0,109	327,12	Low - Medium	YES	NO
New nuclear	0,108	323,64	Low - Medium	YES	NO
Natural gas turbines with CO2 capture	0,110	330,60	Medium - High	YES	NO
Coal with CO2 capture	0,142	424,56	Medium - High	YES	NO
Natural gas turbine, no CO2 capture	0,101	302,76	High	YES	NO
Conventional Coal	0,099	297,00	High	YES	NO

Figure 104: Choice of the type of energy to be purchased sent on the user interface

Results problems and possible improvements: The tests described above have successfully verified the interaction between the platform of remote service and the user interface.

Obviously the result of ethical choice on the origin of energy will have statistical significance only when it will be applicable to a sufficiently large number of end users.

The result of statistics on a large scale will represent valuable information for retailers that will know to which source of energy and in what percentage the customers will buy.

4.5.2.2.5 Test on the Control the Peak Load to Switch at an More Economic Contract

It often happens that an end user subscribes a contract of electrical power of 4.5kW because the one of 3kW procures service interruptions due to the overload. In Italy, the 4.5kW contract has a cost per kWh of 46% greater of the one at 3kW; moreover, the fixed costs per year of the 4.5kW contract are of 124€ instead of 43€ for the one at 3kW.

In the test described below are the results that have allowed the user #118 to pass from a contract of 4.5kW to one of 3kW, with a significant cost saving in terms of bill.

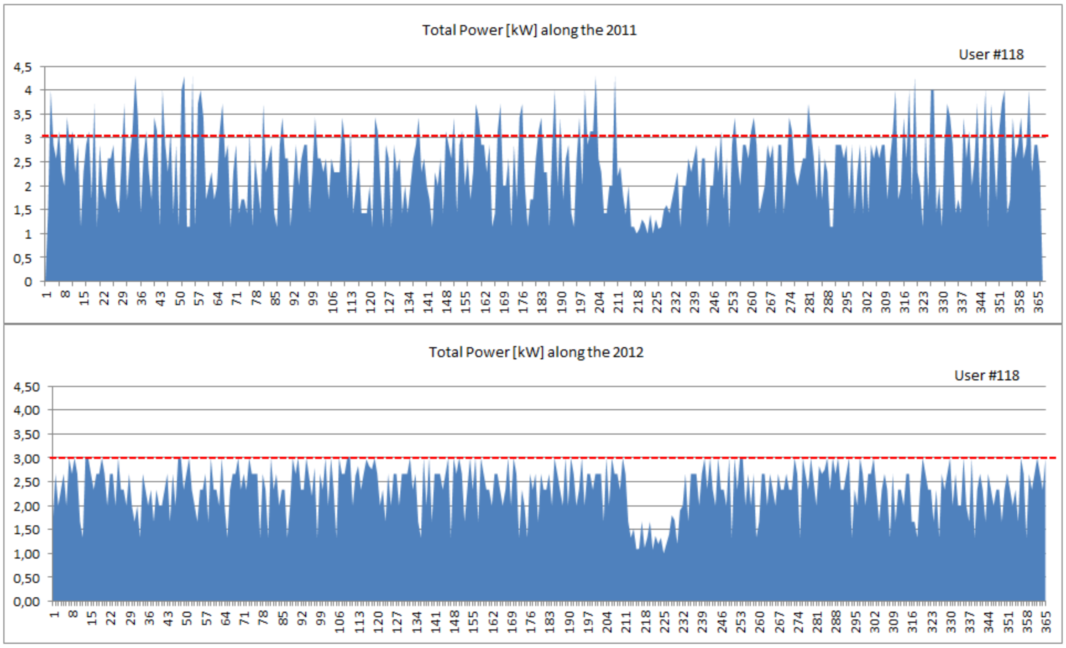


Figure 105: Contractual retrocession keeping under control the peak load

As shown in Figure 105, the monitoring and the control capability of Energy@home system has allowed to spread the power peaks in the hourly slots less loaded, remaining so always within the limits of power of 3kW.

The user #118 has consumed in 2012 almost the same energy of 2011 (2734kWh in 2011 and 2822kWh in 2012); however, it is interesting to note how the density of the distribution of power peak is much more smoothed in 2012, allowing staying under the limit of the power of 3kW.

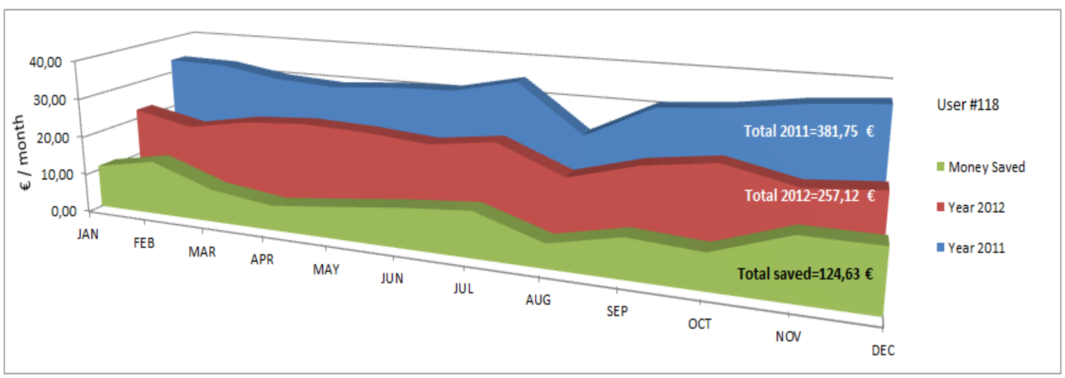


Figure 106: Annual savings achieved with the contractual retrocession (from 4,5kW to 3kW)

Keeping in account the difference of price, above specified, between the 3kW contract and the one at 4,5kW, the Figure 106 shows that for the user #118 it has been possible to save in a year 124€ thanks to the contractual retrocession (from 4,5kW to 3kW).

Results problems and possible improvements: The test involved the combined use of access to historical data through the remote service platform and the monitoring and management of peak power via the Energy@home. The communication system and the access to the database via Web worked properly. A possible improvement consists in a more sophisticated "peak clipping" algorithm. In fact, today the priority list of the "disconnectable loads" is predefined, but a smart algorithm can reclassify in real time what is the load more suitable to be disconnected. Of course, the ability to manual intervention is always left to the end-user.

5. Final Specification

5.1 DSE WP2: Gateway for Secondary Substations using S3C GE

The DSE of WP2, "Gateway for Secondary Substations using S3C GE", was experimented in the project. The experimentations at the ACS institute in RWTH Aachen and at the PREDIS Laboratory in Grenoble INP (in the context of the EU FP6 funded INTEGRAL project) consisted of simulated devices and emulated connections, e.g. parameters according to an LTE network. The Generic Enabler (GE) S3C, which can provide the redundancy management of the connectivity of one or more operators or technologies, was not available.

The key findings from the experiments made at the ACS institute were that with increase of the delay and packet loss in the communication system, the power system frequency may drop to lower values following sudden decrease in the power generation. Although the delay and packet loss did not cause any serious problem for the system stability and control in the tests, it cannot be concluded that communication disturbances such as delay and packet loss may not endanger the secure operation of the power system in a general case.

The experiments made at the PREDIS Laboratory showed that if a typical latency from the Internet (typical long latency 160ms) is used in a Smart Grid application with the self-healing ADA function implementation, the performance can be as bad as 40 seconds for the complete fault detection, isolation and restoration process.

With respect to the specification of the DSE "Gateway for Secondary Substations using S3C GE", the following aspects can be highlighted and shall be paid attention to:

- Standards, encodings, data model:
  - The modern cellular radio technologies run by the public telecommunication operators are viable for the usage as a communication channel in the Smart Grids.
  - The latencies in the networks shall be low enough to support e.g. the required self-healing performance of the distribution system.

Some communication disturbances that may have minimal effects in today's systems may result in severe problems in future power systems, which have less inertia from the large rotating masses. The communication networks have to be faster and less subject to disturbances than they are today.

The updated WP2 DSE specification for "Gateway for Secondary Substations using S3C GE" is presented in Table 28.

Title	GATEWAY for Secondary Substations using S3C GE
Lead partner	Timo Kyntäjä (WP2), Jukka Salo (WP8)
Domain	Distribution / DER
Zone	Station / Field
Interoperability layer	Communication
Entity (S/C) and references	S (Single)
Description	Secondary substations can be identified as aggregation points for all sensors and actuators in the Low Voltage (LV) and MV network (sensor/actuator network based on Powerline Communication (PLC)). Digital Subscriber Line (xDSL) or General Packet Radio Service (GPRS) routers have today been deployed in several secondary substations for communication with the central operation centre. This domain specific enabler will develop a gateway fulfilling all xDSL/GPRS routers' current requirements, and adapting it for Fibre to the Home (FTTH)/ Long Term Evolution (LTE) interfaces and for the use of S3C GE. The gateway consists of existing standard solutions (TCP/ User Datagram Protocol (UDP)/IP stack), GEs (S3C), and DSE's (IEC 60870-5-104)

Detailed description	This gateway should use the S3C GE for an improved use of the public network. It may fulfil ICT requirements identified in WP2, and in concrete those for the MVDAC scenario. This equipment will be installed in all electrical locations, and special environmental conditions and dimensions shall be taken into account. In particular, it should be fed in Volts Direct Current (VDC) taking advantage of the already available batteries. The secondary substation is a kind of aggregator element of different services (Telecontrol, PLC smart metering aggregation, safety, other measures), so this router should manage different virtual networks. This router will also encrypt the communication using Internet Protocol Security (IPSEC) or a similar method. This router should make it possible for the applications to use a static IP address even if the operator network would deliver only dynamic IP addresses. This kind of gateway could also be installed in a DER element, and the distribution company should access to this router through a specific virtual network even if the Subscriber Identity Module (SIM) card or the access has been contracted by a third party.
Expected inputs	Data from the communication interface to be transferred between a grid control application and the RTUs. RTUs then interfaces with the actuators and sensors.
Expected outputs	Data from the communication interface transferred between a grid control application and the RTUs.
Interface to other functional entities or GEs	S3C
Standards, encodings, data model	HSPA, LTE, FTTH, IEC 60870-104, Device Language Message Specification / Companion Specification for Energy Metering (DLMS/COSEM), PLC Note: Further testing is needed to know whether the Wideband Code Division Multiple Access (WCDMA) technology would be viable as a communication channel in the future power systems with less rotating (generator) masses.
ICT requirement name	Connectivity infrastructure Interoperability on Communications Technology (CT) layer Connectivity Services Reliability and availability on CT layer Quality of Service (QoS) for Connectivity Packet loss Connectivity Communication services Dedicated or shared transport infrastructure Latency Reliable data transport over heterogeneous networks

Table 28: Final WP2 DSE specification

5.2 DSE WP3: IEC 61850 Protocol Adapter

The results of experimentation in phase I cannot be directly used for microgrid architecture design nor WP3 DSE specification. But the experimentation shows the effect of delays and disturbances in the communication systems. Thus additional requirements can be derived from these results.

The “IEC 61850 Protocol Adapter” DSE refers to an IEC 61850 stack implementation (client and server). Since IEC 61850 is a main candidate for a data model standard in FINSENY microgrid architecture, it is also a good choice to take into account IEC 61850 related communication services that are connected to this standard family. This stack is envisaged to be used for communication with DERs, secondary substations or home energy management systems within microgrid.

While communication services are related to IEC 61850 are already used and verified, there are still pending issues for defining the microgrid scenario data models as it is presented in deliverable 3.3. However standardization work is progressing.

Beside advanced communication technologies offering high throughput and low latency the IEC 61850 stack implementation is required for introduction of microgrid architecture.

The following table summarizes the WP3 “IEC 61850 Protocol Adapter” DSE.

Title	IEC 61850 Protocol Adapter
Lead partner	WP3
Domain	Distribution / DER / Customer
Zone	Operation / Station / Field
Interoperability layer	Communication / Information
Entity (S/C) and references	S(Single)
Description	IEC 61850 stack implementation (client and server). This stack will be used on smart energy gateways for DERs, secondary substations or BEMS as well as in the communication front-end of the MGCC.
Detailed description	To guarantee the efficient information exchange throughout a distributed control system common standards are a must. The complexity of the control task requires standardized information models, support for simple and complex data types, meta data and well-designed data repositories and processing units. For these conditions there are only a few standard solutions ready to be used in the near future, especially for devices of “classical” and renewable power generation in the electrical smart grid. One of the most prominent future-oriented solutions for electrical grids is the IEC 61850 protocol family. The main advantages of IEC 61850 are: • It uses the strengths of the Open Systems Interconnection (OSI) 7 layer communication model, • It standardizes data models for electrical applications, • It defines Data Types and Communication Services, • It models devices, functions, processes and architectures, • It describes the engineering and configuration Process, • It provides examples of typical applications in electrical substations, • The data is organized in devices in a standardized way, • The devices are “self-descriptive”, either online (e.g. Multimedia Messaging Service (MMS) protocol) or offline (SCL), • IEDs not only provide the data itself but also the information about data types used, its structure and complete naming, • IEC 61850 supports application-oriented architectures by introducing meaningful semantics, • IEC 61850 defines application specific data like Protection Time Overcurrent (PTOC) logical node or Circuit Breaker (XCBR) logical node, etc.

Expected inputs	IEC61850 information to be translated into internal data format, internal data to be translated into IEC61850 information
Expected outputs	IEC61850 information translated into internal data format, internal data translated into IEC61850 information
Interface to other functional entities or GEs	Internet of Things (IoT)
Standards, encodings, data model	IEC 61850, TCP/IP

Table 29: Final WP3 DSE specification

5.3 DSE WP4: Supervisory Controller as Service

5.3.1 Discrete Supervisory Control with MileSEnS Simulator

WP4 discrete tests with MileSens	DSE configuration before the test	Problems and relative improvements identified during the tests	DSE final specification after the tests
Tests on specific programmed simulation scenario with different initial configuration parameters	A priori general rule applied in top down fashion to specific configuration	Time hazards and races occurring in specific sensors & entities configuration Example : delays and blind spots on presence detection	Change trigger for controller with time offset: offset may be evaluated by trial and error as a result of multiple simulations. For demonstration reason, the time offset can be adapted to the movement speed of people and the features of sensors in order to make the effect of the DSE more visible.

Table 30: Modifications in final WP4 DSE specifications on MileSEnS simulator

The rest of the specifications stayed the same as described in section 4.3.1.2.2.

5.3.2 Continuous supervisory control with Energy@home

The WP4 DSE ”Supervisory Controller as Service”: at first this DSE is parsed in a sophisticated simulation framework (MileSEnS), using an environment to validate it in any layer and, afterwards, some features have been tested through the Energy@home, a physical infrastructure for conduct experimentations within private homes with the goal to monitor, control and optimize the electrical power consumption.

Table 31 compares the initial DSE template with the one finally coming from the test results.

WP4 tests with Energy@home	DSE I/O before the test	Problems and relative improvements identified during the tests	DSE final specification after the tests
Tests on detailed energy data collection and its historicization	**Input** Power data collection coming from: • Smart Info • Smart plugs with a local meter, a switch, and ZigBee radio communication. • Smart appliance with embedded ZigBee radio communication • Energy Box: This is also the HAN controller. It is an ADSL home gateway with OSGi (Open Service Gateway initiative) framework and HAN wireless communication capability. **Output** Data mining and data historicization obtained from: • Remote Service Platform: it manages the data mining algorithm and the data historicization.	**Input** • With the user #119 there was some random problems of radio communication of the HAN nodes due to a ZigBee radio node in the proximity of a microwave oven. It was experienced that the node radio ensures quality of service in a reliable manner if it is away at least 50cm from the microwave oven. • There is need to further refine the incoming data filtering, because on the power line random spikes may appear that could alter the reality of captured data. An algorithm based on the shape and the duration of the spike can efficiently skip this inconvenience. **Output** None	**Input** • In addition to the specific inputs described before the test, the following ones are also needed: • During the Energy@home KIT installation, the placement of the radio nodes have to be at least 50 cm away from certain appliances (e.g. microwave oven) in order to avoid transmission interference. • An algorithm to refine the incoming data filtering, because on the power line random spikes may appear that could alter the reality of captured data. **Output** No additional specifications for the output are requested.

WP4 tests with Energy@home	DSE I/O before the test	Problems and relative improvements identified during the tests	DSE final specification after the tests
Test to keep under control and manage (at home and outside) the household electrical devices avoiding power-off for excess of load.	**Input** • The information coming from the data mining algorithm (managed by the Remote Service Platform) are sent to a GUI allowing at the final user, both in home and outdoors, to monitor and control the loads through a notebook, net book, tablet, smart-phone etc. • Wi-Fi and ZigBee protocol communications are supported from the indoor operations, while GSM/GPRS/3G communications are supported for outdoor nomadic operations. **Output** • Aggregate Info & graphic on the User Interface. • Control actions from the User Interface.	**Input** • The test for detect an overload and manually disconnect a load through the user interface (in indoor and outdoor scenario) was working perfectly. The only problem is represented by the need to increase the awareness of the end-user on the behaviour to keep in respect of the KIT devices. For example, with the user #115 there was some problems of radio coverage of the HAN nodes due to thick walls. So he has suddenly removed, without notice, a smart plug creating "holes" in the frame of the data that are sent. A software development to avoid the damages coming from wrong maneuvers of the end-user is in progress. **Output** None	**Input** In addition to the specific inputs described before the test, it requires the addition of: • A software application able to recognize the imprudent and sudden removal of a radio node without notice in order to stop that data collection and avoiding “hole” in the data historicization. Moreover, the application should send instantaneously a message on the user interface remember him to avoid similar actions in the future. **Output** No additional specifications for the output are requested.

WP4 tests with Energy@home	DSE I/O before the test	Problems and relative improvements identified during the tests	DSE final specification after the tests
Test to check the functionality of the management of priorities among all the smart appliances and the traditional ones.	**Input** • The power consumption data coming from the smart info, smart plugs and smart appliances are collected by the home gateway **Output** • If the total power consumption exceeded the total available on the home gateway, a “pause” command is sent to the smart appliances. • If the “pause” command is not accepted by the smart appliance then another load is disconnected by consulting a predefined priority-list	**Input** • The tests have successfully verified the expected I/O functionalities of the management of priorities among the smart appliance (washing machine) and the traditional ones. **Output** • An effective improvement could be introduced replacing the actual priority-list with an algorithm "smart" that reclassifies in real time what is the load more suitable to be disconnected to avoid overloading.	**Input** No additional specifications for the inputs are requested. **Output** In addition to the specific outputs described before the test, it requires the addition of: • An algorithm "smart" that reclassifies in real time what is the load more suitable to be disconnected to avoid overloading.

Table 31: Final WP4 I/O DSE specification

Other tests with Energy@home have been conducted for WP6 and described in this document in the sections 4.5.2 and 5.5.

5.4 DSE WP5: Electric Vehicle Supply Equipment

The importance of electric vehicles for the power grid was proven in two experiments, see section 4.4.3. The effect of system frequency decrease can be avoided by a scheduled charging, the negative effects of tripping of transmission lines can be partly compensated with feeding back energy from electric vehicles' batteries. In any case intelligent charging equipment is needed. This equipment should be remotely manageable to support at least the turn on/ turn off command. The DSE of WP5, the "Electric Vehicle Supply Equipment", is such equipment. Table 32 shows the final DSE specific after the experiments. Compared to the initial DSE specification (see Table 6) the communication interface should also support the receiving of management commands like charging mode (especially turn on/off). Furthermore the communication standards should be extended to all current common communication standards (fixed and wireless) and not only 3GPP, because for a huge amount of vehicles it is necessary to support the power grid stability. Thus, all EVSEs should be addressable independent from the location. Additional the localization inside the SGAM framework must be slightly updated compared to the initial DSE specification.

From these additional requirements and updated conditions follows the WP5 final DSE specification (Table 32).

Title	Electric Vehicle Supply Equipment
Lead partner	Jesse Kielthy (WP5), Thomas Loewel (WP8)
Domain	DER / Customer
Zone	Station / Operation
Interoperability layer	Communication / Component
Entity (S/C) and references	S (Single)
Description	Metering and charging information is concerned with all metered information of charging processes. This includes the metered data at the EVSE, in particular in relation to the time. Significantly, a smart EVSE utilises intelligent technology to allow remote monitoring and control. In this instance, the smart EVSE will enable Grid Operators to stop, start or limit the charge of an EV as part of an overall demand side management solution. End-users will also be able to remotely communicate with the EVSE to schedule a charge or receive information updates. Overall the EVSE supports actively the load balancing process and thus the optimal use of renewable energy.

Detailed description	Deployment requirements: • Charging Points • Mobility Data Management Functional Requirements: • Technological: All this information is of technical nature and is needed as an input for (planning) (dis)charging processes. However, this information is typically derived from the respective systems. • Economic: The domain is set to the customer as electric vehicles consume energy triggered by the consumers, and they can be used as a DER in the V2G scenario. Besides the information available in the EVSE and the supporting systems, also respective messages sent to electric vehicles and their users (e.g., information regarding the current or scheduled (dis)charging processes, connection messages inside the electric vehicles) represent information on charging process and equipment. • Legal: As cars are used by humans, status information of cars might be mapped to individuals. This requires the same privacy protection as with user information • Operational: Information on the EVSE can be of static nature (e.g., supported charging modes and payment methods) or dynamic nature (e.g., current and planned availability and reservation). • Schedule: In the SGAM framework, electric-vehicle information is located in the customer and DER domain and in the operation zone. • Cultural: Privacy protection for user information
Expected inputs	Communication interface (from EV and from Back-end) to exchange meter data with EV, to get price signals, to support the authorization, to get management commands (e.g. charging mode), etc.
Expected outputs	PWM signal (from EVSE to EV, to set the charging mode); Communication-Interface (to EV and to Back-end) to exchange meter data with the Back-end, to support the authorization, etc.
Interface to other functional entities or GEs	I2ND.CDI, I2ND.NetIC
Standards, encodings, data model	GSM, UMTS, LTE, xDSL, PLC
ICT requirement name	Monitoring of EVSE Aggregate EVs to virtual power plants Control of EV (charging signals)

Table 32: Final WP5 DSE specification

5.5 DSE WP6: Demand Side Manager

By the results of the evaluation of the DSE by the two different facilities (BeyWatch and Energy@home) we can derive that new input parameters are needed to be added to the definition of the DSE in order to include the impact of the solar power and the water tank temperature into the scheduling of appliances in the house.

Title	Demand Side Manager
Lead partner	Engineering S.p.A.
Domain	Market and Enterprise
Zone	Distribution / DER / Customer
Interoperability layer	Information / Communication
Entity (S/C) and references	S (Single)
Description	The domain specific enabler “Demand Side Manager” is a software module included in an energy management system in charge of the management of DSM signals intended to flatten the electrical demand curve in a specific area. A B2C marketplace (eMarket4DSM) assumes the availability of an infrastructure (hardware and software on board / bundled) where consumers have installed an energy efficiency control system at home that monitors and controls the energy consumption of appliances, by changing their programming parameters. Optionally, the existence in the house of a combined photovoltaic system is also considered providing power to the house and heating the water in a tank connected to white appliances. An EECS equipped with a DSMgr will be able to be activated by DSM signals from the demand side operator (typically the DSO) based on the subscribed conditions and user preferences.
Detailed description	The core idea of the domain specific enabler is to manage the DSM signals from the operator side to the home area network (via a device control system) in order to influence the flattening of the demand curve of the energy consumed in some areas. This is only possible with an entity (normally software) in each electrical installation (buildings, houses ...) that can ensure security and effective programming of the appliances to avoid any inconvenience. The approach is that the DSM operator can effect some “changes” in the default contract values / parameters of the various contract classes with the aim of incentivizing / dis-incentivizing consumers / residential agents to exhibit the expected or hoped for consumer behavior (with regard to electricity consumption during critical hours). For that intent, the DSM operator sends signals to the installations affected in the target area. These signals should be managed for a re-scheduling in the operation of the electric appliances (consumer appliance control actions) depending on some conditions as e.g. the incentives, contra-incentives, power cap, penalized power, sell/buy price (of electricity), power available from solar panels, water temperature in a tank heated by a solar panel and the preferences of the final user. Anyway, the final user has always the option to cancel the response of the DSM signals at any moment or any period of time no matter the DSM conditions subscribed in the contracts.
Expected inputs	DSM signals from the demand side managers (from the smart grid); incentives / disincentives; user preferences (e.g. type of energy such as nuclear or solar) / priorities (time range in a day when automatic actions are allowed); price information; contract information (from the eMarket4DSM); rough power consumption data (coming from the energy monitoring systems provided by the EECS); (eventually) rejection of the forthcoming actions on the controlled appliances activated by the DSMgr; water temperature generated by the solar panel and power supply by photovoltaic solar panel.

Expected outputs	Consumer's appliance control actions; Notification (to the consumer) of forthcoming actions on the controlled appliances activated by the DSMgr and the incentives/contra-incentives for attending DSM signals
Interface to other functional entities or GEs	IoT - Gateway Data Handling, IoT - Device Management, I2ND - Connected Devices Interfacing, SECURITY- Identity and Privacy Management, DATA - Publish/Subscribe Broker and APPS - Marketplace
Standards, encodings, data model	Communication protocol among GEs and DSE: REST, HTTP(S)
ICT requirement name	User Software Agent System Power limits information Contract information Tariffing signals and profile Energy source information hourly-daily

Table 33: Final WP6 DSE specification

The following figure shows the new architecture of the identified domain specific enabler by WP6: Demand Side Manager including the new inputs of the DSE as explained before.

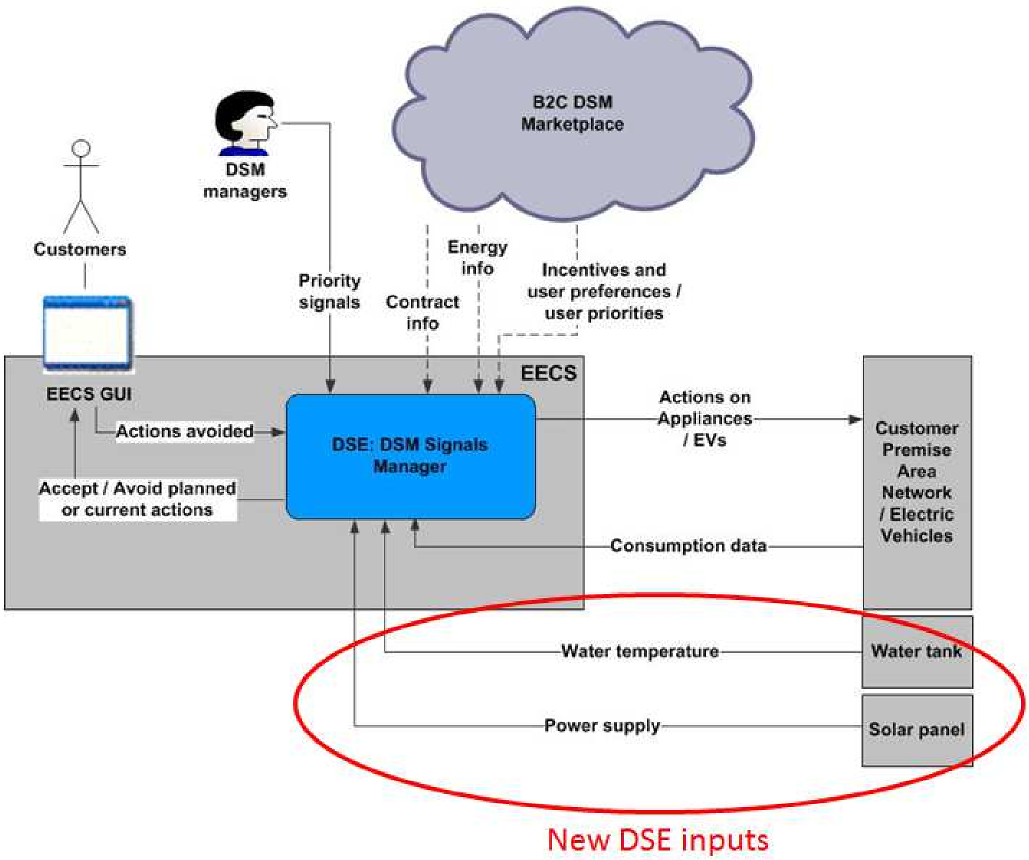


Figure 107: Final DSE architecture

6. Conclusion

The purpose of this deliverable was the collection of the most prominent domain specific enablers. These DSEs specifications were delivered by the scenario work packages assisted by work package 7. The specification of the initially selected DSEs was based on theoretical work and on the experience of the contributing partners from ICT and energy domain.

To demonstrate the practicability and to validate the theoretical work, the selected DSEs or their environment have been experimented in previously selected experimentation facilities. For that the Institute for Automation of Complex Power Systems at RWTH Aachen University was chosen to conduct the experiment of “Gateway for Secondary Substations using S3C GE” DSE and to demonstrate the need of the “Electric Vehicle Supply Equipment” DSE. The Grenoble INP Lab supports also the experimentation of the “Gateway for Secondary Substations using S3C GE” DSE. The Energy@home system and the BeyWatch system were used for the experimentation of “Supervisory Controller as Service” DSE and the “Demand Side Manager” DSE. These experimentations based partly on real data collected over one year. The experiment of the “IEC 61850 Protocol Adapter” DSE was also conducted at RWTH Aachen University and shows the impact of the major disturbances in communication systems.

The diversity of the experimentation facilities reflects the broad scope of the experiments, closely connected with the selected DSEs (e.g. “Demand Side Manager”) or to investigate the need and impact of the DSEs (e.g. “Electric Vehicle Supply Equipment”).

Most of the experiments demonstrate the practicability or the need of the selected DSEs. The initial specification of the DSEs was already well elaborated. During the experiments some new input/output parameters were identified. These new parameters were considered in the final specification that is shown at the end of this deliverable. Also some standards, encodings and data models had to be updated in the final specification of the selected DSEs.

As stated in the beginning of this deliverable the updated final most prominent domain specific enablers are:

Work package	Domain specific enabler
WP2	Gateway for Secondary Substations using S3C GE
WP3	IEC 61850 Protocol Adapter
WP4	Supervisory Controller as Service
WP5	Electric Vehicle Supply Equipment
WP6	Demand Side Manager

Table 34: Final selected domain specific enablers

7. References

[1] General FINSENY Glossary of Terms v2.4

[2] FINSENY deliverable D8.1: FINSENY Experimentation Lab Set-up

[3] FINSENY deliverable D8.2: Experiments and evaluation

[4] INTEGRAL fp6 project: http://www.integral-eu.com/

[5] INTEGRAL deliverable D8.1: Definition of test and evaluation procedures

[6] INTEGRAL deliverable D8.2: Evaluation of the Results and Guidelines for EU Research

[7] Y. Mu, J. Wu, J. Ekanayake, N. Jenkins, and H. Jia, "Primary Frequency Response From Electric Vehicles in the Great Britain Power System," accepted for inclusion if a future issue of IEEE Transactions on Smart Grid (as of Feb. 2013).

[8] M. Rosa, et al., “Quantification of the Increase in The Amount of Renewable Power Sources, Namely Wind Power, that Can Be Safely Integrated in Some EU Countries,” Mobile Energy Resources in Grids of Electricity, Deliverable D3.2, February 2012. Available at: http://www.ev-merge.eu/images/stories/uploads/MERGE_WP3_Del_3.2_Task3.3_Part_III.pdf

[9] http://www.rtds.com/applications/high-speed-power-system-studies/high-speed-power-system-studies.html

[10] http://wanem.sourceforge.net/

[11] http://www.opnet.com/solutions/network_rd/modeler.html

[12] “Potential Penetration of Electric Vehicles in Irelands Road Vehicle Fleet,” Strategic Planning Unit, National Roads Authority, Ireland. February 2011. Available at: http://www.nra.ie/Publications/TransportResearchandInformationNotes/RepositoryforTRIMPublications/file,17990,en.pdf

[13] “ELECTRIC VEHICLES Roadmap,” Sustainable Energy Authority of Ireland. Available at: http://www.seai.ie/Publications/Energy_Modelling_Group_/SEAI_2050_Energy_Roadmaps/Electric_Vehicle_Roadmap.pdf

[14] Electricity Statistics, Egrid. Available at: http://www.eirgrid.com/operations/systemperformancedata/electricitystatistics/

[15] “All-island Generation Capacity Statement 2011-2020”, EirGrid. Available at: http://www.eirgrid.com/media/GCS%202011-020%20as%20published%2022%20Dec.pdf

[16] “National Renewable Energy Action Plan, Ireland”, available at: http://www.dcenr.gov.ie/NR/rdonlyres/03DBA6CF-AD04-4ED3-B443-B9F63DF7FC07/0/IrelandNREAPv11Oct2010.pdf

[17] J. Tang, J. Liu, F. Ponci, and A. Monti, “Adaptive Load Shedding Based on Combined Frequency and Voltage Stability Assessment using Synchrophasor Measurements,” to appear in the IEEE Transaction on Power Systems

[18] BeyWatch project: http://www.beywatch.eu/

[19] Energy@home project: http://www.energy-home.it

[20] C. G. Cassandras and S. Lafortune, “Introduction to Discrete Event Systems”, Springer-Verlag New York, Inc., Secaucus, NJ, USA, 2006