OPPORTUNITIES FOR MANAGING CONSUMPTIONS AND THE INTERACTION WITH ENERGY NETWORKS

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Abstract – The paper describes activities for development and testing of an ICT infrastructure providing local energy management functionalities. Functions are developed in a virtual environment, then they are verified and validated in the CESI RICERCA's test facility which also helps to evaluate their integration with the already installed home automation systems like security, lighting, heating management.

Keywords: Demand Side Management, Distributed Energy Resources, Energy Efficiency, Communication technology, Modeling and simulation

1 INTRODUCTION

In recent years the European power sector has been undergoing considerable changes. The Directive 2003/54/EC established common rules for the internal electricity market and extended to all customers the possibility to choose their own energy retailers. In this frame, energy market liberalization and diffusion of local automation systems may jointly promote a new role for the energy users, who will change from passive consumers to active customers. Their ability to participate to the market will be substantially represented by their possibility to modulate their own load profile as result of market (i.e. price) or network signals (i.e. emergency).

Households may soon become active “nodes” of the electric network which could also provide services both for the network (e.g. power modulation) and the market (e.g. reduce energy price volatility). Availability of responding users may also become a precious resource for electrical system which may ask (and remunerate) active customers to modulate their demand during critical situations therefore avoiding nasty consequences of rolling blackouts.

To get the most advantage from this opportunity it is necessary to provide a platform which is interoperable with home and building automation systems and that supplies several functionalities as communication with distributor/retailer, interaction with consumers and management of loads, energy storages and local micro generation. This platform will have to achieve a global energy optimisation in residential and tertiary buildings by the way of complex strategies considering not only energy and gas prices, but also customer's preferences and environment parameters such as seasons, weather conditions, daily min/max temperatures etc.

Availability of local generation, together with energy storage units, may on the one side improve electric system security and on the other side increase energy management possibilities therefore improving energy efficiency. Local generation may imply power flows towards the network instead of consumption only. Therefore also local generation both from fossil and renewable sources will have to be integrated into the optimisation strategy.

Cost-effectiveness of the proposed solution is achieved by the use of commercial off-the-shelf components and technologies to build the whole infrastructure; *open* environments and protocols are also used to maximize dynamic interaction (upgradeability) and interoperability.

2 LIBERALIZED ENERGY MARKET AND DEMAND SIDE MANAGEMENT

2.1 Demand Side Management and Demand Response Services

From July 2007 all European customers have the possibility to choose among several energy retailers who attract their customers by providing a variety of different contracts. Already in some Countries and much more in the future end users will be offered energy prices reflecting real energy costs. Power demand growth is costly not only for consumers but also for producer, since power plants providing peak power are rarely used yet expensive to maintain and operate. Retailers may enhance their offer adding further special tariff schema, e.g. “green energy” (from Renewable Energy Sources, RES) or different prices for the energy taken from, or made available to the network for any time of the day. *Dynamic pricing* includes pricing that varies by time of day to reflect the higher cost of generating electricity during peak hours. To catch this opportunity, users will have to increase their awareness and to change their consumption habits.

The term *Demand Side Management* (DSM) of the electric power is used to encompass the planning, implementing and monitoring of initiatives aimed at stimulating final users to modify their demand habits, hopefully without decreasing the present level of the offered services [1]. Two classes of DSM actions are usually considered:

load-level measures, which aims at shifting the load curve to lower or greater demand levels or shifting loads from one energy system to another.

load shape measures, which seeks to re-shape the load curve over very short (minutes-hours-day) to longer (days-week-season) time periods.

Although the primary intended effect of demand response programs is to reduce electricity use during times of peak load, most demand response programs also shows a small conservation effect [2].

A typical DSM load shape strategy is the proper modulation of electricity price with time-of-use (TOU) tariffs. As a basic requirement, the operation on loads and the effective implementation of DSM strategies require and involve availability of timely and detailed beyond-the-meter information, with no cut down of service quality. To reach this aim, DSM strategies have to be achieved through the use of proper measurement and control structures, additionally final user's premises need to be reached with high speed and reliable communication channels.

Demand Response (DR) services are much more related to the need of reducing power demand during short periods of time (critical peaks) that should occur only few times in one year. They typically include interruptible and curtailable programs for commercial customers, direct utility control of residential load, e.g. air conditioners, and the introduction of Critical Peak Pricing tariffs. In addition, by reducing the demand for electricity during peak periods, the need for new power plants and upgrading of distribution networks could be reduced or eliminated.

All these actions (network or market driven) are to be managed by ICT systems located in some nodes and levels of the Electric System.

Cost reduction and provision of ICT integrated solutions for flexible management of interactions between LV customers and the network are challenges of the present research. They drive development of new technologies and architectures. Some solutions are already available and field tested.

3 ICT ARCHITECTURE

"Active Customers" connected to a LV distribution grid, are managed by a Load and Generation Management system (called FRIDOM-FCBT) which is located in the MV-LV substation (fig. 1). FRIDOM-FCBT monitors relevant network parameters at substation level and send messages to active customers in order to involve them into a cooperative strategy aimed at maintain an adequate quality of service.

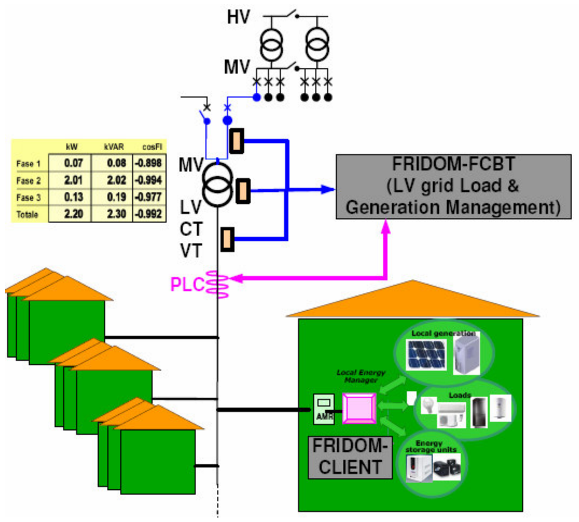

Fig 1 Management of power flow in a LV network

CESI RICERCA is currently investigating functional requirements for Load and Generation Management systems to be located in MV/LV substations. They have to manage information sent by distribution utilities, traders and retailers, events generated by MV/LV substation automation systems, events generated by the MV network to elaborate un-ambiguous data structure to deliver to final LV customers either equipped with simple e-meter, e-meter with gateway functionality for Direct Load Control (DLC) or system for Local Power & Energy Management (FRIDOM-CLIENT).

3.1 Load shedding in emergency situation

In case of load shedding in emergency situation [3] a load reduction order is originated by the Independent System Operator (1). The order to reduce power consumption ΔP in a well defined area, within a certain time ΔT and for a certain duration Δt, is conveyed to all Distribution Companies.

After receiving the reduction order, each Distribution system operator should calculate the $\Delta P_{1\div n}$, $\Delta T_{1\div n}$, $\Delta t_{1\div n}$ required for each of the *n* MV/LV sub-stations serving the area, then proceed ordering power reduction (2). FRIDOM-FCBT is in charge of the load management of the whole LV grid fed by MV/LV transformer. Therefore when receiving orders from the Distribution Company, it proceeds to reduce or augment the power, either directly controlling smart sockets and appliances or by "negotiating" with home automation systems.

The service interruption may imply a refunding that is sent to customers through their trader/retailer (4 and 3). The figure shows also the exchange of information that occurs for market (6, 7) and billing (5) purposes.

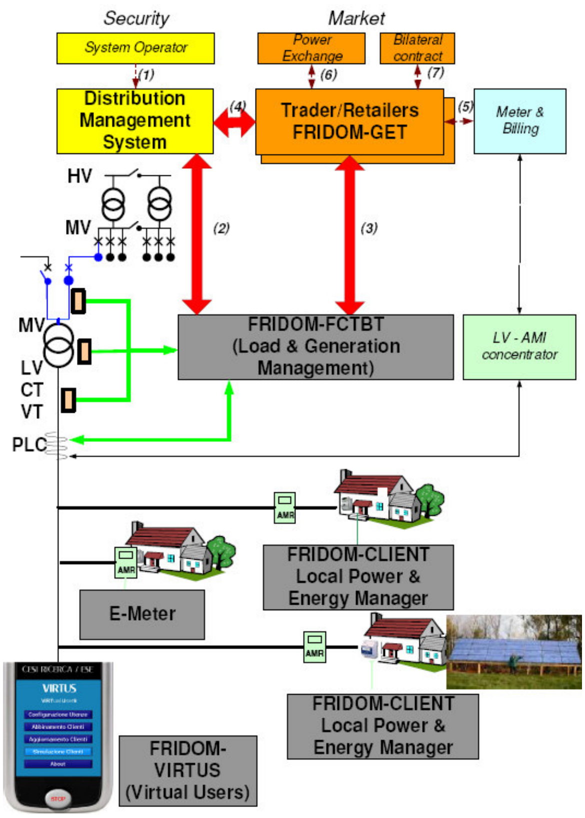

Fig. 2 Overall Communication infrastructure

4 LOCAL ENERGY & POWER MANAGER

The Local Energy Manager (FRIDOM-CLIENT) provides *load* and *heating management*, i.e. the possibility of switching off/on some appliances when particular circumstances occur or decide whether if it is better to use electric or gas devices for HVAC purposes. The Local Energy Management System combines signal received from retailer (tariffs) and user preferences regarding comfort and maintains maximum power flow with the network under a specified threshold (that may change every hour). For heating aspects, two different systems are simultaneously present: gas heating (blower + fan coils) and electric air-air heat pump. Changing the power threshold the user can obtain several functionalities: the simplest function avoids automatically energy meter disconnection when power absorption exceeds contractual limit; the "emergency" function sheds power absorption as a result of an emergency signal received from the distribution utility. To increase "savings", the platform permits to determine dynamically which loads are to be used or disconnected, as price and user requests change. Depending on gas/electricity prices, external temperature and desired temperature for each room (set-point), the manager calculates current heat pump COP (Coefficient Of Performance) and decides to use only gas heating, or heat pumps, otherwise both of them.

CESI RICERCA activity is also focusing on management of energy storages at customer premise, not only to increase user security level but also to provide services to the network. For example, user demand could be reduced for short time by means of a proper storage unit that supplies critical loads. Furthermore, load and local generation management functions could be improved in case storage units are present.

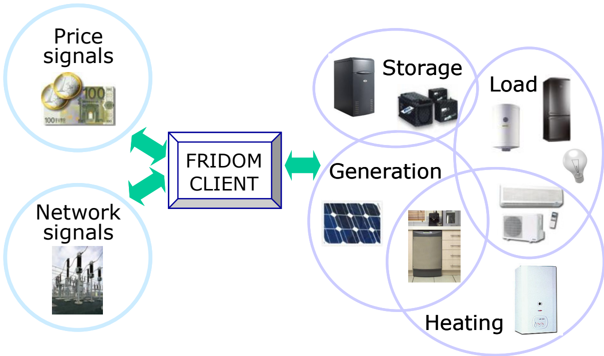

Fig. 3 Local energy manager & gateway

5 FUNCTIONS DEVELOPMENT

Different strategies for load control may be applied to evaluate their performance and reliability in response to system or market signals coming from outside the house (utility, retailer). A development environment for Demand Side Initiatives (verification & validation environment, *DSI-VVE*) has been created with the aim to develop and to test the above mentioned functionalities in a virtual case [4].

DSI-VVE supports creation and testing of home automation functions, evaluation of their features and identification of further improvements, before their actual implementation on a real target. The first system undergoing DSI-VVE is the FRIDOM-CLIENT which is a Local Energy Management System combining signal received from retailer (tariffs) and user preferences regarding controlled appliances and their priority. It provides automatic load disconnection and re-connection to maintain maximum power flow with the network under a specified threshold (that may change every hour). DSI-VVE follows the so called "V" life-cycle approach for function development (fig. 4).

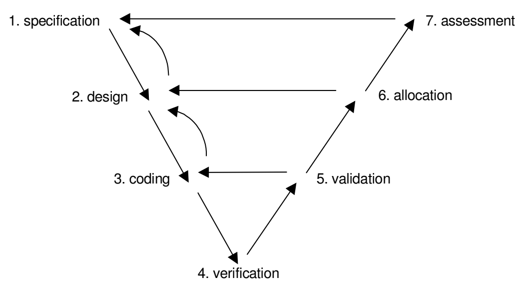

Fig. 4 DSI-VVE development process

The first specification phase provides *requirements* for the function to be considered in the next step; we use a natural language, e.g.:

> *comfort function*: "to avoid automatically energy meter disconnection when power absorption exceeds contractual limit. The user should be able to specify a priority level for each appliance in order that important loads go on working."

Requirements are then represented in a formal scheme using state and transition diagrams (design phase). Further step is the source code writing (coding); the code is then embedded into external libraries called by a Labview® application specially developed (verification). The virtual environment is composed by these four steps; the same code is then used to validate and assess functions performance when operating in a real case: on the CESI RICERCA test facility.

CESI RICERCA test facility and environment for the evaluation of energy management applications addresses following aspects:

- consumer's attitude to use energy as function of the energy price;
- generation of load profiles for each different class of customers;
- identification of appliances to be considered for load management, including priorities, criticality, maximum interruption time etc.
- monitoring of real and apparent power for each managed home appliances (dishwasher, lighting and so on);
- load profiles for managed or unmanaged appliances, and their changes in response to price and system signals.

Emergency and energy savings functions were the first to be developed; besides the current flat tariff for domestic user many others were verified. They range from spot market price to daily defined for each Italian congestion zone. An automatic procedure may provide various options for several retailers and for different kind of customers. Also remuneration for local generation (mainly from photovoltaic conversion) can be considered.

Starting from a simple load management, it is possible to move towards an overall energy management comprising not only electric loads but also electric and heat storage units and eventually also local generation.
Unlike load control, heating management doesn't require fast intervention time, this is due to thermal inertia of building. This inertia allows the disconnection of whole electric devices (e.g. electric heat pump or fan coil) for short time without significant reduction of the perceived comfort and can be favourably exploited in combination with load management.

To enable users to define their profile, the platform allows to set several parameters. For example, the user could prefer to reduce consumption under a specified power level only when the energy price exceeds a certain value. This attitude is translated into a numeric value by means of an additional parameter, the *available power* P_{av}, that is taken into account by the load manager algorithm. The relation between P_{av}, the contractual power and the price expresses just the user's attitude to consume in a certain instant. It is worth underlining that P_{av} is not a fixed value but depends on price or other factors that could vary during the day. The emergency signal could be represented also by a strong increasing of price (critical peak price), therefore the consumer may reduce his consumption.

Periodically the load manager measures power absorption to establish if some controlled load should be turned off to remain under the current P_{av} level; each controlled load is associated with a priority level which define also the disconnection order (fig. 5).

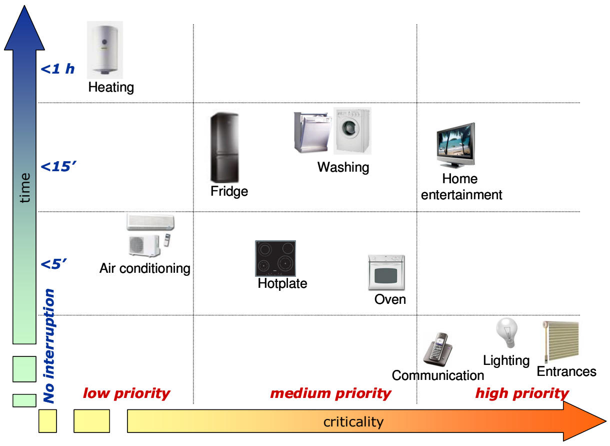

Fig 6 Home appliances vs Criticality and maximum interruption time

5.1 Virtual Testing

The *virtual environment* (SICA) simulates a real field, i.e. a residential building, a family and their appliances. Each load is represented by an average consumption over 15 minutes or a more accurate daily average profiles obtained from measurement on real appliances [5]. To test the system with different schemes, besides current flat energy tariff for domestic user other profiles are considered. In addition SICA is able to replicate thermodynamic behaviour of any building: it is sufficient to specify building characteristics. Even outdoor condition (sun radiation and wind) and the thermal input from appliances to each room are considered. This model was adjusted on the real test facility, selecting proper walls material and geometric sizes, and position of each loads.

A validation of the Simulated field was carried out: passive performance (no heating devices), static and dynamic behaviours was verified. The following diagram shows temperature patterns for the test facility in passive behaviour: real and calculated temperatures are given. The simulation model performs reasonably. It is worth underlining that activity's goal is not to create a close model of a building but to develop energy management functions, therefore this virtual environment has the only purpose to support that process.

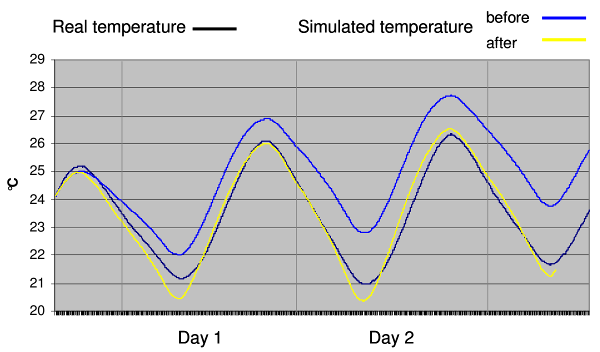

Fig. 6 Passive behavior: real and simulated temperature pattern (before and after parameters adjusting)

An additional application called VIRTUS (VIRTual UserS), was created to simulate a large number of LV customers (~400) connected to a MV/LV substation. This allows to simulate the effect of several signals (price, emergency) sent to users and to evaluate performance of the communication architecture:

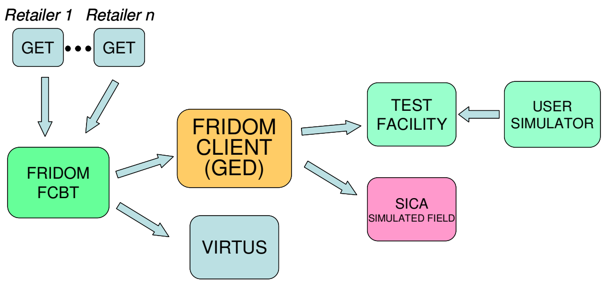

Fig.5 FRIDOM architecture.

Starting from requirements, already developed functionalities include:

- *Emergency*: FRIDOM-CLIENT reduces automatically energy consumption as a result of an emergency signal received from the distribution utility. This emergency signal could be delivered by means of the AMI (Automated Metering Infrastructure) or other communication media (Internet, GSM, …). It could request either to lower consumption under a specified power level or establishing a specified remuneration to the consumer.
- *Savings*: when energy price exceeds a fixed level, customers may decide to reduce their energy usage. FRIDOM-CLIENT permits to set different strategies, as price and user requests change. In this case also, the price signal could be received from the retailer by means of several communication channels, not only by the AMI.
- *Energy storage management*: to improve load manager functions and security level for some critical applications, storage units are included in the house energy management. Such equipment could enhance also "saving functions", as support for short period to some (small) domestic appliances when energy price is high.
- *Integration* of electric and heating management: depending on gas/electricity prices, external temperature and desired temperature for each room (set-point), the manager calculates current heat pump COP (Coefficient Of Performance) and decides to use only gas heating, or heat pumps, otherwise both of them.
- *Local generation management*: a kind of *local dispatchment* become possible thank to some appliances (dishwasher and washing machine especially) that could be activated in favourable generation conditions.

5.2 Testing on the real facility

As stated before, strategies tested in virtual environment are deployed on the real test facility. Here performance and reliability are verified on a real case both in reply to system and market signals coming from utilities and retailers and taking in account user's preferences like the level of comfort: e.g. it is not possible saving energy only by reducing electric heaters and forgetting the minimum room temperature.

CESI RICERCA test facility (fig. 7) may count on two identical 60 m^2 buildings quite similar to residential houses [6]. These buildings allow several tests on different local energy management strategies but also to simulate the presence of a real family living in that houses. This is achieved thanks to an application that operates domestic appliances as a people of a family may do ("user simulator"). In addition, a complete monitoring and data logger system is present.

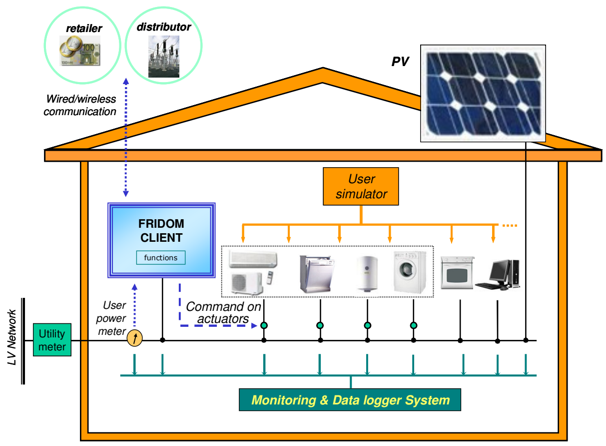

Fig 7 Test facility

The whole environment is based on *commercially available* systems that allows the user to add further functions. It is created in a *open* environment, using a Java platform developed according to OSGi specification, and an *open* protocol specifically created for home automation applications, *OpenWebNet* (created by BTicino SpA [7]).

TCP/IP protocol and XML format were considered because they are widely used and it is likely that they will becoming a *de facto* standard also in this domain. As already mentioned, they allow fast prototyping and to move easily from virtual environment (SICA) to real test facility, changing only the device to which FRIDOM CLIENT communicates ("just move the plug from a socket to the other", see the following schema).

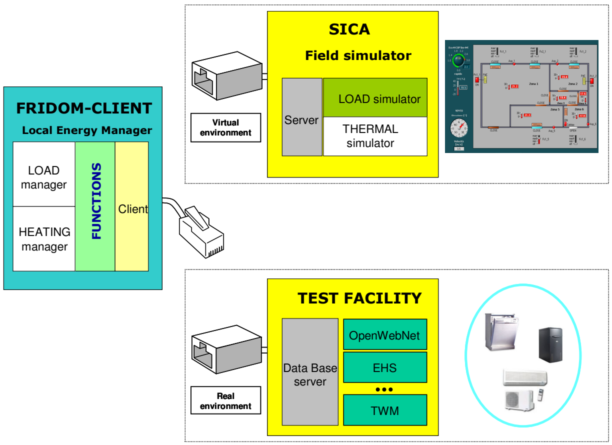

Fig. 8 From Virtual to Real testing

Preliminary results on load control show that general strategies work as planned, intervention time meets electric metering requirements, communication are adequately reliable. In current Italian situation, where a pronounced difference between peak and off-peak prices does not exist, load management alone could get only modest savings. But outcomes confirm that architecture undergoing test is suitable for providing services for Demand Side Initiatives in distribution network.

Tests were run also with both *load control* and *heating management* working together. Comparison between normal gas heating and integrated electric-gas management is already in progress. Depending on external temperature, and therefore current heat pump performances (COP), gas heating instead of electric heating is used. Heating management is not based only on economic savings but could include environmental features, such as CO_2 emission.

Considering a 0.2 €/kWh flat tariff for electricity, 0.63 €/m^3 for gas and 23°C as uniform set point, fuel consumption over a winter week was measured. With daily average temperature ranging over 7.3÷10.5 °C, a consumption of 71.9 ÷ 108.8 kWht/day was observed. This leads to 4.7 ÷ 9% savings by comparison with gas heating.

Monitoring system highlighted that home automation system shows an energy consumption of 1.1 kWh/day. This equals, on a yearly basis, a "class B" fridge. Therefore, an additional activity aimed at improving energy conservation started. For example, each actuator could be chosen according to its normal status (close/open) to minimize stand-by consumption. With regard to the energy management itself, information from security system that windows/doors are open could be used for switching off the heating or cooling of the specific room.

Finally, the local energy manager is already able to store and to display consumption and cost curves, increasing users awareness [8].

6 CONCLUSIONS

Opening of the energy market represents an opportunity both for utilities and customers. A combination of long-term investments and availability of responding users may help in facing critical situations on distribution networks: active users may modulate their load profile according to market (energy price) and network signals (emergency). Distributed Energy Resources and especially Renewable Energy Sources represent a further opportunity for small users to participate to the energy market. ICT and more specifically automation technologies will play a major role providing the necessary support to the liberalised market increasing network reliability and security.

Energy end-users will change from passive consumers becoming active customers. Improving customer participation to the market, requires a platform that provides several energy management functions.

FRIDOM-CLIENT platform is modular, to fit specific levels of complexity and adapt its functionalities to building characteristics and different customers. In old flats it is very difficult to add a complete system but it is possible to put a very simple energy manager providing comfort and savings functions. International experiences show that such devices could be promoted together with a variable energy tariff policy [8]. On the contrary, in new houses or in small office buildings with already installed complex home/building automation systems, energy management functions could be added profitably with little or no additional cost.

We are aware that at present time there are many home automation solutions and also several *demand side management* projects. Our goal is to develop a platform dedicated to rational use of energy and promoting interaction between users and network, using only commercially available devices. This activity wishes to demonstrate the practical feasibility of such a solution, its cost and benefits.

Acknowledgments

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