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Energy conservation and smartgrids: new challenge for multimetering infrastructures

G. Mauri, D. Moneta, and C. Bettoni, *CESI RICERCA*

***Abstract*--Operation of future power systems will be shared between central and distributed generators. Control of distributed generators will need to be aggregated to form microgrids or 'virtual' power plants to facilitate their integration both in the physical system and in the market. Even customers will be part of the "network loop", both producer and consumer of electricity="prosumer". New business models are imposing to favour the flexible integration of the different stakeholders and to overcome often conflicting interests. Forthcoming Advanced Meter Management systems (AMM) may support rational management of different energy resources and provide optimized management of smart grids. However there is the need of the adoption of a set of widely accepted open standards capable of guaranteeing the interoperability of systems and devices produced by different manufacturers, supporting metering of electricity, gas, water and heat.**

***Index Terms*-- Electric Variables Measurement, Power Distribution, Electric Control Equipment, Smart Multi Metering, Demand Side Management, Demand Response, Advanced Metering Management Systems.**

I. INTRODUCTION

To provide services such as power, heating or cooling, already different energy sources can be used, gas, electric heat pumps or district heating/cooling. In a smart grid 'prosumers' (consumer+producer) will reasonably choose at any time the most convenient energy resource.

In such a scenario, smart metering will have to accomplish the important role of providing prosumers not only with appropriate fiscal reading of relevant parameters, but also with the possibility to deliver market and network signals.

For example, changing the gas/electric power price ratio will cause one of these resources to became preferable against the other; the economic ratio threshold is different for each prosumer, according to energy conversion technology that they adopt. In order to achieve the different goals, prices of gas/heat/electric power and their relative ratio need to be carefully managed and promptly made available to prosumers.

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II. BACKGROUND

A test facility dedicated to experiment rational use of energy, effects of network and price signals on prosumers and the interaction of prosumers with energy networks has been set up. Already available commercial devices were used to develop the complete infrastructure that allows effective management of energy in customers premises and eases the interaction between active customers and the network. The infrastructure that was set up allows the provision of data from smart meters to market actors in various ways in order to enable the implementation of energy efficiency measures, enhance monitoring and management of grids, help in optimising and automating market processes and improve services for prosumers. Meter data can be accessed by the several market players whilst prosumers are expected to receive price and network signals and have easy access to meter and historic consumption data. Smart metering can both send information and requests both to prosumers and Distribution System Operators (DSOs). The party responsible for collecting and administrating meter data will have to make these data accessible to all other authorised market players in a non-discriminatory way. The figure below (Fig. 1) outlines the advanced multi-metering infrastructure for smart grid.

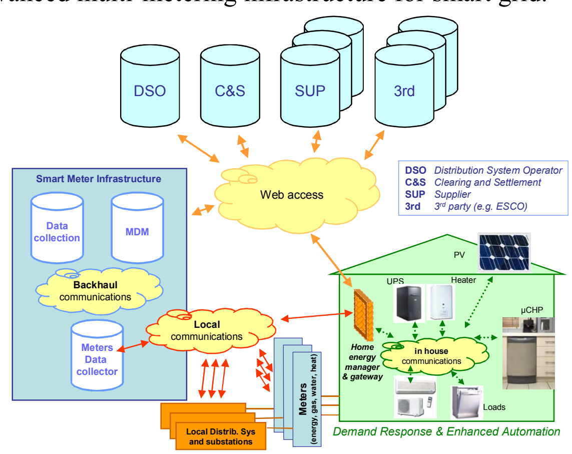

Fig. 1 Multimetering infrastructure for smartgrids

Active customers may rely on Local Energy Management (LEM) applications which are able to get signals sent by energy retailers and DSOs and manage generators and loads according to customer's preferences, also maintaining power exchange with the network under a given thresholds (that may change even every hour). CESI RICERCA active customer simulator comprises a 60 m^2 building, representing a house with living room, kitchen, bedroom and bathroom. The facility allows carrying out several tests on different energy management strategies and it may also simulate user habits thanks to an appropriate sub-system which operates domestic appliances as a real family may do living in that house. The facility (Fig. 2) is equipped with:

- commercial home automation system;
- set of common appliances;
- LEM that provides smart energy management;
- "user simulator" that switches on and off home appliances according to several profiles representing different family compositions
- heating system (boiler + fan coils and heat pumps)
- photovoltaic conversion system
- storage unit (UPS).

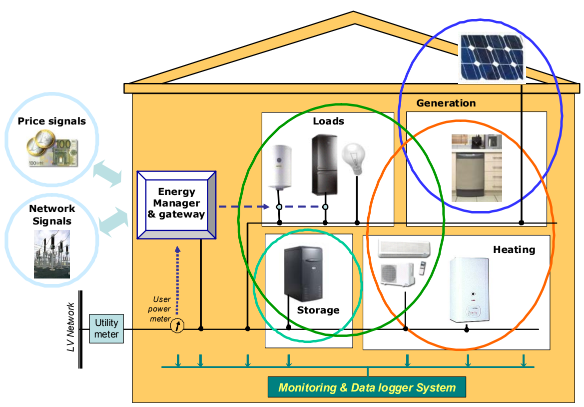

Fig. 2 Energy sources and loads managed by the LEM

LEM adopted was created in a *open* environment, based on a Java platform developed according to OSGi specification. It uses an open protocol specifically created for home automation applications, OpenWebNet (from BTicino SpA [3]). TCP/IP protocol and XML format were considered because they are widely used and they are likely to become a de facto standard also in this domain. The whole environment is based on commercially available hardware components where additional functions can easily be added to. A monitoring and data logging system allows data collection for the off-line evaluation of the energy management applications, like: loads management, storage management, local generation management and heating management.

III. Load Management

Load Management systems allow switching on and off appliances when particular circumstances occur. An effective system for Load Management takes into account aspects like the consumer's attitude to use energy as function of the price, the list of appliances and their priority, their criticality levels and their maximum interruption time, load profiles of different appliances and the possibility to change it in response to price and system signals.

IV. Storage Management

Highly automated environment asks for high reliance on energy supply and quality of power. Electric storage units are to be included in the energy management of end user premise in order to improve load management functions and security level of critical applications. As long as interruption of power supply lasts, storage units provide energy for critical devices i.e. communication, lighting and critical automation like opening and closing of doors. According to battery level and before finishing storages the energy management system has to switch off prosumer's critical devices (starting from the less critical) to extend life of most critical services. Such function may also be used to enhance "saving" since storages may be used to feed (small) appliances when energy prices are high (i.e. critical peak price periods).

V. Local Generation Management

Several Countries are promoting diffusion of small dispersed generators, especially from renewable sources or μCHP. Customers with such systems may provide energy flows from and towards the network according to external circumstances like heat request during the cold season. Therefore local energy management systems have to manage the net power exchange with the network and act to maintain it within fixed amounts. Local energy dispatching becomes possible by controlling some appliances (e.g. dishwasher, washing machine) that can be (de)activated according to power availability. Power in excess can be used for charging Pluggable Electric Vehicles (EPV).

VI. Heating Management

During last few years sales of reversible air/air heat pumps has strongly increased. That was mostly due to the availability of several models and cost reduction. Now more and more houses are equipped both with air/air heat pumps and gas heating. Integration of electric load and heat management has to take into account gas/electricity prices, external temperature and the temperature set for each room at any time of the day. In this case LEM calculates the current heat pump COP_i (Coefficient Of Performance, thermal energy in heating kWh_t/ electric consumption kWh_e) and decides whether to use gas heating, heat pumps, or both of them.

VII. EXPERINCE WITH "DUAL-FUEL" HEATING

The actual Coefficient Of Performance of heat pumps is mainly depending on external temperature. Manufacturers provide COP_n measured at "standard conditions", that is outside air temperature of 7° Celsius and a relative humidity of 85%. The instantaneous COP_i of an heat pump depends from many parameters, however the most significant one is the outside temperature. Following semi-empirical formula can be used to approximate the instantaneous COP_i:

$$COP_i = COP_n * K_t$$

where:

COP_i - COP's value at temperature Te
COP_n - COP at standard conditions (Te 7°C and RH 85%)

and:

$$K_t = 0.7809+0.0313 * Te$$

COP_n can also be identified from the energy class as indicated by the European Directive (02/31/EU) as reported in following table 1.

A	3,60 < COP
B	3,60 ≥ COP > 3,40
C	3,40 ≥ COP > 3,20
D	3,20 ≥ COP > 2,80
E	2,80 ≥ COP > 2,60
F	2,60 ≥ COP > 2,40
G	2,40 ≥ COP

Table 1 Energy classification of the Heat Pump

Convenience of using electric heat pumps or gas heating can be calculated either maximizing the economic or environmental benefit. Those conditions can be effectively represented by comparing COP_i with COP_{econ} and COP_{env}. COP_{econ} is function of the price of electric power and gas, and of the yield of the gas heating generator as shown in the following formula:

$$COP_{econ} = \frac{PCI \cdot \frac{R_c}{100} \cdot €_{kWhe}}{€_{met}}$$

where:

$P.C.I$ lower heat power of gas [kWh/m³]
R_c yield of the gas heating generator [%]
$€\ kWh_e$ price of the electric energy [€/kWh]
$€_{met}$ price of the electric energy [€/m³]

COP_{env} is obtained comparing CO_2 emissions of the heat pump (average CO_2 emission of Italian power plant park for producing a kWh_e) and CO_2 emission of the adopted gas condensation generator for a kWh_t.

$$COP_{env} = \frac{CO_{2NationalGrid}}{CO_{2GasHeating}} \cdot \frac{R_c}{100}$$

where:

$CO_{2NationalGrid}$ amount of carbon dioxide produced for each electric kWh provided to the user [kg/kWh_e]
$CO_{2GasHeating}$ amount of carbon dioxide produced for each thermal kWh provided to the user [kg/ kWh_t]
Rc yield of the gas heat generator [%].

Fig. 3 shows COP_{econ} and COP_{env} versus the COP_i of the heat pump. The calculation is based upon: gas price of 0.59 €/m³ gas, electric power price of 0.17 €/kWh, average emission of Italian power plant park of 0.50 kgCO_2/kWh_e, a gas heating generator emissions of 0.25 kgCO_2/kWh_t, PCI=9.59 kWh/m³, and Rc=90%.

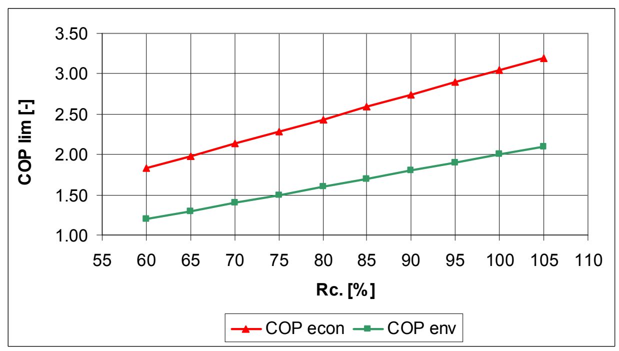

Fig. 3 COP_{econ} economic and COP_{env} environmental

Heat pumps are economically convenient for COP_i greater than COP_{env} or while they are environmental friendly for COP_i greater than COP_{env}. whist in the opposite case gas heating turns out to be preferable (e.g. given a gas heating generator with yield equal to 0.8, the heat pump becomes convenient in case the COP_i is greater that 2.2 from the economic point and greater than 1.6 from the environmental perspective). In case COP_i is in between 1.6 and 2.2, use of the heat pump will still provide less CO_2 emission than gas heating, however that will not be convenient for the prosumer. Actually LEM will use gas heating instead of the heat pump. A good gas/electric power price ratio should reduce the difference between the "economic return" and "environmental performance".

VIII. TESTS ON SIMULATED AND REAL FIELD

Tests have been run during several weeks in the winter and spring seasons. CESI RICERCA facility equipped with a condensation gas heating generator (able to modulate between 6.9 ÷ 19.6 kW_t operating at 60°/40° Celsius) connected to five fan-coils and two air/air heat pumps (with an outside and an internal unity).

The comparison between single fuel (gas) conventional heating and dual-fuel integrated electric-gas management was carried out, considering a 24h flat electric power tariffs (0.2€/kWh), gas (0.63€/m^3) and homogeneous temperature of 20°Celsius for the whole house. Fig.4 shows the case when the instantaneous COP_i (purple) drops below the COP_{econ} (green) because of a lower external temperature. When that happens heat pumps are switched off (orange) and gas heating is preferred. Notice power absorption of fan coils (blue) increasing a little. When daily average temperature ranges between 7.3 ÷ 10.5 °C, a consumption of 71.9 ÷ 108.8 kWh_t/day was observed. In this case dual-fuel heating leads to a saving between 4.7 ÷ 9% by comparison with use of the condensation gas heating generator alone. It is worth underlining that heat pumps used in the experiment were not recent (class "D"), therefore there is margin to increase further savings using more efficient heat pumps (i.e. class "A").

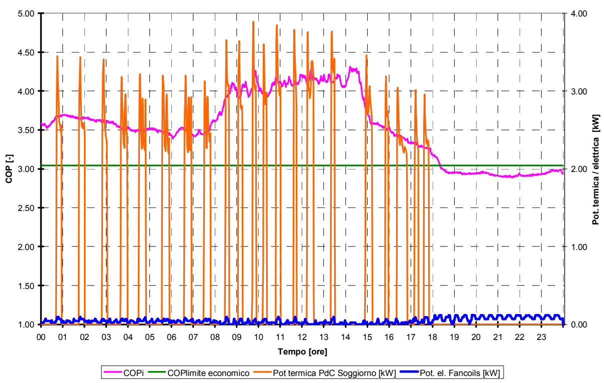

Fig. 4 left axis: COP_i (purple), COP_{lim} (green); right axis: heat pump demand (orange) and fancoil demand (blue).

Additional tests were carried out during a colder period, considering 1st quarter 2009 prices (17.15 [c€/kWh]/79.33 [c€/m^3]). This survey demonstrated again that ratio between gas and electricity prices entrails to prefer the latter option for heating. By applying the "economical" strategy presented in cap. VII, heat pumps (i.e. reversible air conditioners) were called to service when the external temperature was exceeding -4°C, being them more convenient than use of common gas heating.

However a great demand of electricity will necessary reflect on low voltage distribution network. AMM systems will have to help facing such new scenario by delivering proper control (network) and price signals [4].

IX. MULTIMETERING

The conventional function of Automatic Meter Reading (AMR) is changing in the direction of smart multi-metering or multi-functional AMM systems capable of creating value for energy consumers, network operators, metering operators and retailers, becoming a recommended first step for the establishment of the SmartGrids. It is widely acknowledged that smart meters will provide better services for customers in several ways: not only by more accurate metering and billing, but also by easing the supplier switching process and by facilitating demand response to price and network signals that will reach the consumer. AMM technology will also allow consumers to be much more aware of electricity prices and CO_2 emissions associated with their consumption.

Although there exist commercial systems capable of partially supporting AMM, there is a worrying lack of interoperability among these systems, preventing the large deployment of smart multi-metering technology. The main obstacle to the large-scale adoption of full AMM is the absence of a set of widely accepted open standards capable of guaranteeing the interoperability of systems and devices produced by different manufacturers.

January this year, many European utilities, manufactures and research centers started working together in a European Project called "OPEN-meter". The project aims at defining an open standard for smart multimetering for power, gas, heat and water. Multimetering will allow utilities to provide new services, creating value for active customers, retailers, distribution networks and meters operators. New services will encompass automatic meter reading, remote (re)connection and disconnection of prosumers and also flexible tariff management for electric power, gas, water and heat. Prosumers could be eventually provided with real time price for each different energy sources e.g. to support use of electric power or gas according to the actual benefit for the system.

X. CONCLUSION AND FUTURE ENHANCEMENT

The paper outlined the activity which focussed on the comparison between traditional gas heat management and the dual fuel management and the importance of providing the end user with the right differential price ratio for gas and electric power. Forthcoming AMM systems may facilitate rational management of different energy resources and support optimized management of smart grids. There is the need of the adoption of a set of widely accepted open standards capable of guaranteeing the interoperability of systems and devices produced by different manufacturers, supporting electricity, gas, water and heat. That is the main objective of OPEN meter project. In the future scenario active customers will be very much interactive with smart grids preferably throughout a dedicated smart multimetering infrastructure providing them with all the information they need to be an active node of a smart grid. The main objective of the OPEN meter project is to specify a comprehensive set of open and public standards for AMM, supporting electricity, gas, water and heat metering, based on the agreement of all the relevant stakeholders in this area, and taking into account the real conditions of the utility networks so as to allow for full implementation.

XI. References

[1] G.Mauri, D.Moneta, P. Gramatica, "Automation system to support smart energy behaviour of small customers", *SmartGrids for Distribution* - CIRED, paper 0058; 23 - 24 June 2008. Frankfurt.

[2] R.Meda, D.Moneta, G. Mauri, P. Gramatica, "Verification & Validation Environment for automation functions supporting Demand-side initiatives", *Proceedings 19th Int. Conference on Electricity Distribution - CIRED* ,# 530 21-24 May 2007, Wien.

[3] http://www.myopen-bticino.it/index.php?newlang=english

[4] C. Chemelli W. Grattieri "Demand Response: Technology Requirements for an Emerging Business" ANIPLA International Congress, November 2006, Rome.

XII. Biographies

Giuseppe Mauri was born in Varese, Italy, on February 24, 1969. He graduated from the Polytechnic of Milan in 1994. In 2000 he was granted a PhD by the University of York.

His employment experience included the Joint Research Centre of the European Commission and the University of York and CESI. He is with CESI RICERCA from 2006. His special fields of interest include dependability analysis, functional safety, technology for demand side management and smart metering.

Diana Moneta was born in Milano, Italy. She graduated from the Polytechnic of Milan in 2002.

She is with CESI from 1993 and CESI RICERCA from 2006. Her special fields of interest include technology for demand side management and smart metering, and optimization of distributed resources.

Carlo Andrea Bettoni
His employment experience included Automation Research Centre of ENEL (main Italian Electrical Power Utility) and CESI. He is with CESI RICERCA from 2006.
His special fields of interest includes software infrastructure for system automation and technology for demand side management and smart metering.