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A MULTI-UTILITY SMART METERING ARCHITECTURE TO IMPROVE ENERGY EFFICIENCY

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Abstract - Smart meters are essential tools to increase energy efficiency of buildings and grid. However, to get a real benefit from them, an effective integration between the different energy domestic metering devices and display, as well as a suitable post-processing of such a big amount of measurement data is crucial. In this paper the authors present a new integrated smart metering system for home applications. This system is able to acquire data consumption of electricity, gas, heat meters and to convey it on a single smart platform able to process and give back to the user useful information about the efficiency and the health of its power plant.

Keywords: Smart meter, energy efficiency, in-home display, energy diagnosis

1. INTRODUCTION

Recent European Directives (e.g. the directives of the Third Energy Package and the Energy Efficiency Directive) oblige member states to define strict roll-out plans for introducing smart meters in natural gas and electricity distribution networks, also at domestic level.

On the other hand, the current spreading of energy certification of buildings on one hand and the recent EPBD Recast pushing the construction of the so called "Nearly Zero-Energy Building" (NZEB), are fixing a totally new scenario.

In this context, it is crucial to certify the actual performance of buildings (on the basis of real measurements of total energy consumption) and to effectively manage in real-time the energy plants of the building by means of the RES production data of the NZEB itself and not only from the energy consumptions ones.

Due to EU Directives, Member States have to implement legal framework for the smart meters installation. On the base of two dimensions (National Legal and regulatory framework and progress in implementation), Member States can be actually classified in: i) “dynamic movers”; ii) “market drivers”; iii) “ambiguous movers”; iv) “waverers”; v) “laggards” [1].

Italy is considered a “dynamic mover”, since about 32 millions of electrical energy smart meters have been already installed and the actual in progress roll-out procedure of about 15 millions of natural gas smart meter to be installed by 2018.

Smart metering technology directly or indirectly promotes energy efficiency through its potential impact on the end-user behavior. Smart meters, in fact, allow to provide end-users clear and complete information about their energy consumption data over time. Therefore, a better information should help both to quantify the return on investment for energy efficiency interventions, and to a reduction of energy waste. Furthermore, smart meters are indispensable tools for the development of smart homes, smart grids and smart cities.

On the other hand, traditional meters of electrical energy, gas and heat does not provide detailed and updated information on actual energy consumption. As a consequence, also energy consumptions billing is often inadequate and unfaithful in respect to the actual real consumptions of the end-user [2][3].

The current independent configuration of most utility services has actually opposed the development and spreading of smart metering in many European countries. In Italy, for example, the communication standard of electric smart meters is substantially different from the natural gas one.

The simultaneous real time measurement of the various energy sources distributed at home level would be useful to provide final consumer to perceive his own actual energy consumptions. In fact, only a comprehensive overview of the energy balance of all energy sources can induce effective changes in consumers behavior. On the other hand, the sharing of remote communication structures among different utility services may also greatly reduce the combined costs for communication, thereby reducing the costs for the final consumer too.

In this paper the authors present a new smart metering architecture based on multi-metering to enable: i) a local integration of measurement data; ii) a direct feedback to the consumer about his actual energy consumptions; iii) energy data post-processing for energy diagnosis and fault detection purposes. This new architecture shall improve the consumer sensibleness and awareness. On the other hand, it will facilitate the implementation of appropriate strategies to improve energy efficiency in buildings and networks.

2. SMART METERING AND ENERGY EFFICIENCY

The potential benefits resulting from the integration of smart meters on a single platform can be purely economic and strictly technical at the same time. In particular, the data of the same consumer concentration from different meters would make:

i. consumers aware of their consumption in real time;
ii. consumers actively participate in the energy market;
iii. energy diagnosis and audit to be accurately performed;
iv. energy plants to be conducted efficiently.

2.1. Customer awareness

Several studies in the literature [4] about consumers tendencies consider as essential to install a direct reading display to allow consumers to instantly and continuously check their energy consumptions.

The main feature of direct feedback is that consumers have an immediate information (in real time) and local, or easily accessible directly on the meter or associated with it through a separate in-house-display (IHD). On the contrary, the remote location of the meters far away from the consumers (i.e. in cellars, external boxes, entrance hall of the building) often inhibits consumers to get immediate feedback about his energy consumptions.

On the other hand, an indirect feedback doesn't allow consumers to access energy consumption data directly and in real time. Consequently, answer and corrective actions are necessarily deferred in time and space. Nevertheless, Internet as an indirect medium can still provide further feedback useful for additional analysis and advice in the longer term.

The cost-benefits analysis of the direct and indirect feedback is currently very controversial. Indirect feedback is supposed to lead to an average reduction of 3-4% of energy consumptions, whereas the direct feedback can greatly increase these saving up to 6-10% . Other authors conservatively estimate this energy saving to be about 5-6% [3][4].

The use of a single interface device associated with the smart multi-meter system would significantly reduce the costs and complexity of the system. On the other hand, the installation of multiple devices for each user (i.e. electrical energy, natural gas, heat, water) would make partial and confused communication with users.

Available data should allow consumers to easily distinguish among both high and low levels of electrical energy consumption (current intensity of consumption), and among peak hours and hours of vacuum in the supply (including price of the actual tariff). Furthermore, they should be presented both in energy units and cost. For this reason, the integrated smart multi-meter system with IHD should communicate, together with the numerical data (via display), different alarm events. These latter, in fact, seems to be extremely effective on changes in consumer behavior. In particular, the following events should be particularly significant: i) a rapid deviation from average consumption; ii) exceedance of pre-set thresholds during peak hours; iii) the change in tariffs; iii) monthly thresholds exceedance (e.g. average monthly consumption).

2.3. Active participation of the consumers

In recent years, the technical evolution and the substantial modification of the regulatory and legislative issues has produced a substantial change in the energy market. In fact, EU energy policies have brought, from one hand, to the diversification of energy sources, on the other hand to a significant increase in distributed generation plants, especially in the electricity market.

As for example, in Italy, the number of electricity distributed generation plants connected to the distribution network, has increased from about 1500 in 2006 to over 500000 in 2013 with a market that is increasingly made up of the so-called "prosumers" (i.e. producer-consumer). In this scenario, for the effective management of the networks it become essential to know in real time both productions and consumption of the different energy carriers to avoid dangerous imbalances between production and consumption.

To avoid overload problems and to improve efficiency of the networks, many utilities are pursuing a network management strategy more and more devoted to the "demand side management". With this management strategy it will be possible to reduce peak demand, to shift consumption from peak period to periods of low demand (valley-filling), to reduce the final energy consumptions. To achieve a more efficient distribution of the energy demand, several tools could be considered (e.g. the variation of the tariff system, the introduction of specific incentives, the access to information, the control by the utilities, the consumer education).

The smart multi-metering would also implement optimally the logic of "demand side management" moderating both the specificity of "prosumers" (related to the double measurement of energy produced and consumed), that the complexity of hybrid energy systems (e.g. boilers and heat pumps) which need to compare the measurement of the different carriers to shift consumption from an energy system to another.

2.3. Energy Diagnosis

The availability of detailed data consumption in real time enables to perform energy audits, to evaluate specific indicators and benchmarks and also to adopt "fault detection and isolation" strategies.

In particular it would be possible to verify and identify failures or malfunctions of the meters avoiding dangerous disputes through: i) the "physical redundancy" (i.e. different meters installed in series), ii) the so-called "analytic redundancy" (which funds on the relationships between different measured variables as mass and energy balances on a restricted part of the network or on an energy system), and iii) logical statistics and observations of anomalies in time series based on self-learning of anomalous situations compared to the different process variables (e.g. degree-days vs. heat consumptions).

Also in this case the application of such techniques in the case of smart multi-meter would allow to concentrate in a single local system the acquisition of the necessary climatic data and calculation routines with obvious advantages of cost and effectiveness of the solutions. These could be applied not only to energy diagnosis purposes, but also to other issues such as: i) meter tampering, ii) meter

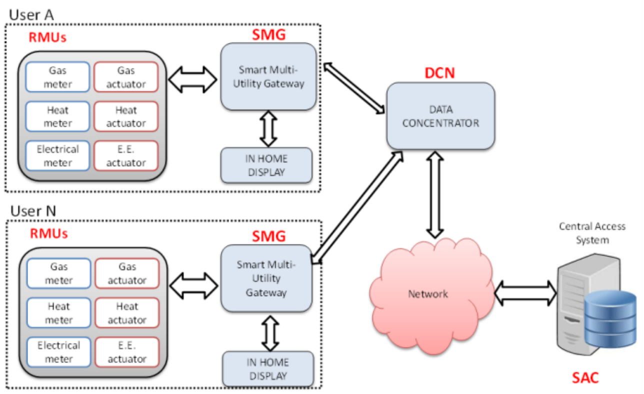

Fig 1: The proposed smart metering and actuation architecture

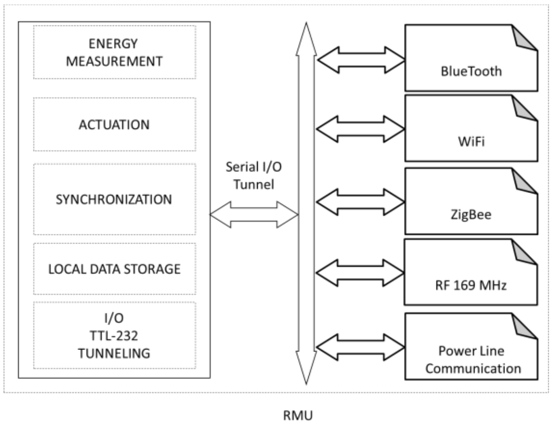

Fig 2: The architecture of the RMU

overloading, iii) false zero flow, iv) energy losses and v) and abnormal consumptions (energy theft).

2.4. Energy Efficiency Improvement

Real time data about energy consumptions and the integration with other climatic and consumption parameters as well as, finally, data post-processing is essential both to optimize energy systems usage (i.e. consumer habits), and to carefully evaluate the need of maintenance and retrofitting of energy systems themselves. A precise profiling of energy consumption allows, in fact, to analyze with reliability the pay-back period of the investments to improve energy efficiency and to adequately plan plant maintenance.

3. THE REALIZED SMART-UTILITY METER ARCHITECTURE

3.1. The general architecture

The proposed smart metering architecture is presented in Fig. 1. The core of the system is composed by the Remote Measurement Units (RMUs) in compliance with Directive on Measurement Instrument (MID) [5]. In particular, for each user three RMUs have been developed to measure natural gas, heat and electrical energy. Each RMU is equipped with a suitable actuator that allow the user or the system administrator regulating or turning off an energy resource. A general description of the realized RMUs together with the explanation of the actuators is proposed in the following sub-section.

Each RMU transfers its own data to a Smart Multi-Utility Gateway, (SMG). This unit collects data from all RMUs and transfers it to both the in-home display and the Data Concentrator (DCN). Furthermore the SMG can be integrated with devices for allocation of heating cost [6].

A key element of the proposal is the in-home display. As the described in Section I, it allows the user analysing in real time the energy consumption, comparing the actual energy consumption with the expected one, analysing the cost and the efficiency of each energy source and actuating decision about the home management.

The DCN collects data from groups of users (N users in Fig. 1) and transfers it to the Central Access System (SAC) through the network. Finally the SAC collects data from all the DCNs and applies all the required procedure to guarantee the efficiency of the system and to bill the consumed energy to all the users.

3.2. The Remote Measurement Units (RMU)

RMU perform the metering and the actuation for the considered energy system: the electrical, the gas and the heat. Each RMU has been developed according to the block diagram of Fig. 2. Each RMU is made up of: (i) an energy measurement section which contains sensors and processing to deal with the considered quantity; (ii) an actuator section to regulate (as for the electrical energy) or to turn off (as for the other quantities) the energy flow; (iii) a synchronization section to control the clock systems and to give reliable time reference to the performed measurement [7]; (iv) a local data storage and post-processing and, (v) a communication system over a TTL-based serial bus. The point (v) can be seen as a serial tunnelling that allows the RMU to communicate over different busses by the connection with suitable TTO-to-wired and TTL-to wireless interfaces. Some details about the communication system are given in the following subsection.

In Fig. 3 a block diagram and a photo of the realized RMU, incompliance with the MID requirements for the electrical energy are reported.

3.2. The Communication System

The implemented communication system plays a very important role in the proposed smart multi-meter architecture. It has been developed considering both the compliance with all requirements imposed by the Italian Regulatory Authority for Electricity, Gas and Water ("Autorità per l'Energia Elettrica, il Gas e il Sistema Idrico") and the maximum flexibility of user applications. It can be divided in two sides: the user and the administrator.

As for the user side, the implemented communication system is based on the availability for each RMU of a TTL serial port for communicating data. Then a number of TTL-to-wired and TTL-to-wireless bus interfaces have been

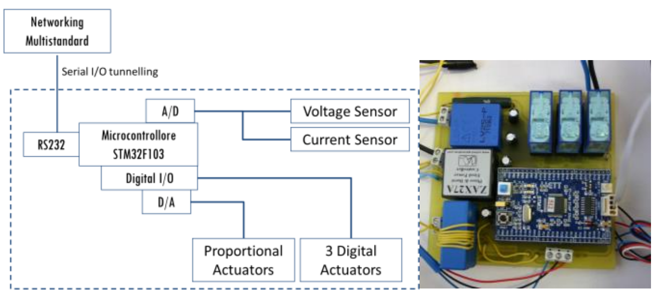

Fig 3: Block diagram and photo of the realized RMU for the electrical energy

developed to connect the RMUs to the desired wireless or wired bus. These interfaces can be considered as smart retrofit that do not require any additive function to be implemented in the meter [8].

In particular, the GAS RMU communicates with the SMG through a Radio Frequency (RF) bus with a central frequency of 169 MHz as requested by the national standards. This is the only RMU that operates with a single communication channel since this is the communication medium considered by the Italian authority for the natural gas remote metering.

The heat RMU is able to communicate on three wireless busses, namely the RF 169 MHz, the BT and the ZigBee. The WiFi communication was not implemented since the high power consumption of this communication media that is not compatible with the long battery duration requested for such meters.

The electrical energy RMU is able to communicate on both wired and wireless channels. In particular, as for the wired channel it communicates by using a Power Line Communication device (PLC). This is able to perform communication on AC and DC electrical network and allows full transparent communication without any need to do programming. This allows the electrical energy RMU to be inserted in the Italian automatic meter reading infrastructure. As for the wireless channels the on the RMU both the BT and WiFi retrofits can be connected. It is worth to noting that this RMU is the unique that is not powered by batteries but it is directly connected to the AC main.

Finally, the last element of the communication system at the user side is the SMG. It is a system able to fuse data coming from different media, to store this data and to communicate with the DCN over the wireless RF at 169 MHz and GPRS busses.

As for the manager side, the DCN and the SMG implement communications as recommended by the Italian Regulatory Authority for Electricity, Gas and Water. In particular, they implement the Device Language Message specification (DLMS) that is a generalised concept for abstract modelling of communication entities, and the COmpanion Specification for Energy Metering (COSEM) that sets the rules, based on existing standards, for data exchange with energy meters.

Key aspects of the realized communication infrastructure are the interoperability and the reliability.

4. CONCLUSIONS

A multi-utility smart metering architecture has been proposed in the paper. The proposed architecture is characterized by high flexibility, since it is able to integrate energy meters that communicate over different communication channels, and energy efficiency, since it gives to the user the possibility to analyse and regulate its consumptions.

To this aim, a key aspect of the proposed architecture is the availability of local intelligence at the Smart Multi-utility Gate stage. This functionality, together with the use of in-home displays, allows future implementations of energy diagnosis and Fault detection techniques. Another aspect that has to be underlined is the modularity of the remote metering units. This allows the integration of both commercial meters or ad-hoc ones with different wired or wireless busses. In addition, the availability of different wired and wireless communication systems, together with the described scalability and interoperability allows the compliance with the Open Meter systems.

Future research development will concern with the implementation on the considered architecture of techniques for the user energy efficiency and fault detection and the overall system energy efficiency and fault detection.

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