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Challenges in Monitoring Toward a new Multi-Utility Network for Energy Sustainability

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Abstract **–This paper deals with the large-scale use of monitoring systems which permits both an accurate check on the kilowatt-hour cost along the day and a more effective reward policy in favor of the users who produce energy in higher demand time slots. The development of modern supervisory control systems is necessary to manage the unpredictable nature of green energy power production. Moreover the suppliers of electricity, natural gas and water are able to provide more efficient and reliable tailor-made services through the widespread adoption of ICTs by consumers and industries. However the complex system which is emerging poses several challenges arising from the interaction among the many domains involved, the secure processing of large quantities of data and the deployment of a reliable and cost-effective sensor and metering networks.**

I. SMART CITIES TOWARD AN HOLISTIC PERSPECTIVE

During the last ten years, the rapid deployment of many green energy technologies has demonstrated their immense potential. Today, renewables are seen not only as a strategic sources of energy, but also as a way to address many other social needs (e.g. mitigating greenhouse gas emissions; creating job opportunities; reducing poverty and so on). An index of such trend is given by the power production market; for example, the average annual growth rate of photovoltaics (PVs) was about thirty-nine percent in 2013. Hydropower rose by 4% (approximately 1,000 GW) while other renewables collectively grew nearly 17%. Globally, hydropower and solar PV each accounted for about one-third of renewable power capacity added in 2013, followed closely by wind power (29%) [1].

Historically the electrical power companies had driven the scientific and technological development to found new solutions (e.g. devices, meters, architectures, protocols) to reduce the “distance” between themselves and their own customers enabling continuous real-time bidirectional information exchange. This allows each customer to “self-manage” his/her energy behavior depending on both power supply availability and price.

The possibilities revealed from a large-scale implementation of these technologies had encouraged other markets (e.g. water and gas distribution companies) to test similar solutions with the perspective of resources saving and sustainable development. Over time was born the idea to merge such independent networks into a big interconnected system. This vision means that many interacting parts, which behave according to simple and individual rules, have to produce a globally coherent behavior, i.e., properties and patterns.

Around the two-thousand it was faced the concept of “Smart City” (SC). It is an urban center, conceived as safe, secure, environmentally green, and efficient. This can be achieved if all infrastructures are designed, constructed, and maintained making use of advanced materials, sensors, electronics, and networks which are supervised by computerized systems, where decision-making algorithms and databases are implemented.

Nowadays, many research frameworks worldwide are founding projects on Advanced Metering Infrastructures (AMI) useful to manage efficiently energy, water, natural gas and transportation, so contributing to give concreteness to the SCs. A multi-utility network is approaching to offer customers and municipalities innovative solutions in reducing the consumption on energy, water and gas. These new platforms, joining green technologies, low-cost sensors and ICTs, will dramatically change the actual urban model giving bi-directionality to the information between utilities, customers and public entities. For this reason it was coined the definition of Urban Eco-System.

Probably, in a few years, we will find in our cities one or more Urban Control Centers (UCCs), which are concentrators where data from distributed sensors and home/building monitoring systems will convey in order to supply information about resources and energy consumption to all players, such as mangers, customers and city officers. These data, opportunely collected, processed and stored, will be useful in several ways. On one hand public entities will be able to define optimal strategic plans; on the other hand citizens will take conscience about their consumption and will care of the “health status” of their city. A first ambitious challenge is then to *harmonize the different evolution cycles*

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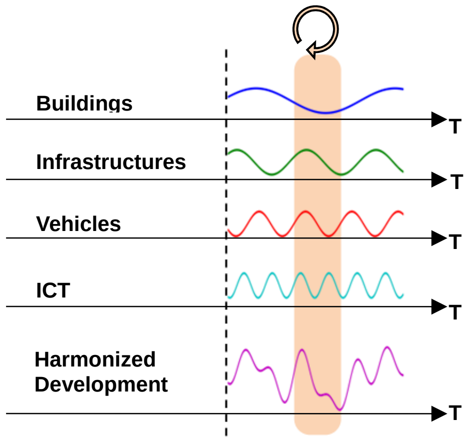

Fig. 1. Different evolution cycles. Adapted from [2].

(symbolically represented in Fig. 1), typical of each subsystem, to create a coherent control architecture. The ICTs evolve more and more rapidly than construction technologies: for example, actually it is difficult to think to replace the traditional mechanical water meter with the new electronic water meters without a heavy renovation of actual hydric infrastructure and huge investments.

II. EMERGING DOMAINS AND UCC ARCHITECTURE

Generally speaking, a SC can be viewed as a big IT-ecosystem in which different entities coexist (humans, infrastructures, devices, software) each with its own behavior. This is similar to a complex biological ecosystem [3], formed by a community of singular entities that change dynamically their needs and characteristics. Some entities, organic as well as not-organic, can be in competition to obtain more resources (energy resources, water, air etc.) or cooperate to achieve objectives. In this context, each SC should add innovative value to actual services in order to attract new entities and organisms into the community. At the same time it should avoid sustainability issues and the loss of the entities already in the community. The new technologies will operate within the physical context of a city (i.e. its buildings, spaces, and the networks) to support transport and utilities.

The needs of SCs are evolving and span a number of domains that include for example:

- Monitoring and management of the availability and quality of water and gas.
- Remote health care.
- Coordination and cooperation between municipalities, police, military, civil protection, to improve the response to emergency.
- Optimization in using the actual transportation and mobility infrastructures.
- Optimization in resources consumption.
- Climate change and price rising as factors affecting the status of customers.
- Creation and support of continuing vocational training for competences in specialized fields and management of technologies.
- Management of services for citizens and businesses that make the area attractive for them.
- Support to an environment that requires expertise and qualified services and, therefore, creates jobs for highly qualified professionals.

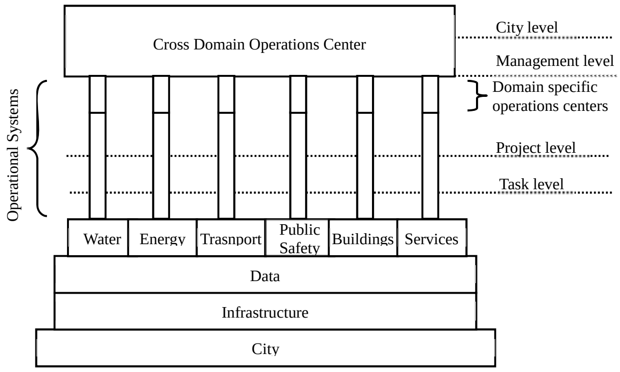

Fig. 2. UCC architecture. Adapted from [4].

It appears clear that to have a coherent response to these expectancies it is mandatory to supervise all cities activities and events as elements of a single process. An UCC is a “control room” used to survey and improve city operations by providing access to information. In Fig. 2. it is possible to get an idea about the UCC architecture. The proposed scheme considers two distinct types of operations centers: a cross-domain operations center (CDOC) and domain-specific operations centers (DSOC) [4]. The former permits access to information and data collected from a shared information space. This shared information space contains information from various sources and enables domains to contribute relevant data and analysis. A DSOC supports a specific city domain and provides access to applications and data related to that domain.

This approach ensures that all related information is provided to city management, giving a comprehensive view of problems. It also enables to understand and take action in a coordinated manner across city domains.

The lowest level in this architecture is the city layer where sensor networks give real-time information about the actual status of the infrastructures, making easily available new data resources that where too expensive to obtain until a few years ago. These data are then categorized by operational systems or event driven software that classifies them in the appropriate domain. Statistical tools and mathematical algorithms are used to extract further details about city events [5]. Results forecasting and scenario modelling could be useful to support risk management and decision-making. An example is the prediction of traffic congestion, which requires an estimation of the changes that occur in the different streams and the research for the patterns that explain the logical connections at different points in space and time.

III. BIG DATA: THE WHOLE IS GREATER THAN THE SUM OF ITS PARTS

The *extraction of knowledge from high volume data* between the city layer and the DSOC is a second challenge towards the implementation of a SC. The integration of a large amount of real-time data is a nontrivial task, but is essential in order to build models and patterns about performance, infrastructure usage, urban information, and human dynamics and take timely decisions...

A multi-utility approach puts in evidence the question of the interaction between different networks. As a matter of fact the behavior of a system as a whole cannot be predicted from the individual rules only. The potential of this flow of data from physical resources towards the utilities is the topic to engage.

We can consider surpassed the conception of the Internet as a "place" different from the real world “where” the content was defined by humans to be consumed by other humans. By now, with the Internet of Things (IoT) the content is defined by objects. Therefore, the interactions and influence over our lives is an open issue, and needs to be understood how the IoT will play a key role in our Smart Cities and Smart environments. Hence the challenge in the management of Big Data is also *to understand the interactions between smart devices and humans*.

The Smart Santander EU Project [6] is one of the major Smart Cities and IoT test bed in Europe. This test bed is providing data for noise, traffic, temperature, power consumption, parking pots, smart labels, and other environmental parameters. The correlations between traffic, temperature, season, and working day were analyzed and was demonstrated that the traffic distribution, aggregated by temperature bins, follows up a Poisson distribution model thus it is possible to predict complex behaviors based on simple measures such as the temperature.

Traditional mathematic methods cannot adapt to the analysis of uncertain, dynamic big data so it is mandatory to collaborate with mathematics and physics in order to develop new data analysis techniques for recognizing data regularity and statistical characteristics in different data and to develop new uncertainty models to represent results of processing.

The traditional way to acquire data cannot work easily with big data therefore new methods are facing in data acquisition:

- System log methods based on distributed architectures, to store hundreds of mega samples per second with an appropriate transmission speed.
- Techniques to extract information from unstructured data of the network by using web robots.

Cloud technologies can be considered as the interface to access the IoT [7]. Cloud computing is a well-known model for on-demand access to shared information; cloud based platforms help to connect to the objects around us so that we can access anything at any time and any place by using web applications..

To take useful information from these data researchers worldwide are developing Web-Based Knowledge Management Systems, integrating smart metering, historical consumption data, communication networks and data management systems in order to provide real-time information on how, when and where resources are being consumed.

IV. SMART METERING FOR AN AUGMENTED SENSING CAPABILITY

In recent years, thanks to the rapid grown of the computational capabilities of embedded systems, we are looking for the success of augmented reality hardware and applications which allow anyone with a smartphone or a tablet PC to extend its own perception of the real environment. In the same way Smart Meters or, more generally, smart objects, can be viewed as means to improve the limited human perception of usage, consumption and price of resources (energy, water and gas). Moreover, the advent of advanced metering, logging and wireless communication technologies has enabled the dynamic accurate measurement and data transfer of consumption information (e.g. time and quantity of water used for a shower). Real-time data like that would help planners and developers to understand daily resource usage and consumer behavior, and their spatial and temporal variability.

The implementation of smart metering involves two elements: meters that use the newest technology to acquire information on resources usage and communication systems that can transmit almost real-time data. A Smart Meter essentially performs three functions: it automatically acquires stores and communicates up-to-date water usage readings on a real-time (or nearly real time) basis. Through the use of communication interfaces such as power-line and wireless, and the introduction of gateways to several well deployed networks (GSP, UMTS, Ethernet, WiFi) it is possible to bring data readily to any computer and to a UCC for analysis or to a website for customers’ viewing.

As already said, power meters have actually received the majority of research attention and focus. However, smart gas and water meters will also play an important role in the emerging smart grid. Water metering using different approaches to disaggregate total usage has been proposed in the literature [8], [9], [10]. Non-intrusive

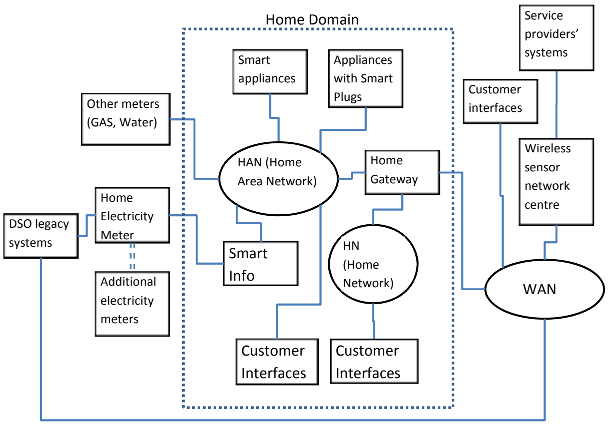

Fig. 3. Energy@home project global architecture. Adapted from [16].

loads monitor for gas meters [11], [12] was also studied. In [13] a technique utilizing the acoustic signature of gas meter pressure regulators was presented.

Several hardware implementations for supporting the SC paradigm can be found in the scientific and technical literature. For example in [5] and [14] ad-hoc plugs and cores have been developed in order to integrate reconfigurable hardware platforms such as FPGAs (Field Programmable Gate Arrays) in the SC middleware. FPGAs add high performance capabilities and permit to process huge amounts of data without a centralized infrastructure. Moreover, reconfigurable hardware make possible to replace and/or upgrade algorithms in the future [15].

Also big enterprises and medium/low voltage grid operators are investing on research projects about Smart Homes trying to add new functionalities to the actual metering infrastructure. This involves the collaboration for several players, as demonstrated by the interesting framework reported in [16]. The key elements of the framework are:

- The Power Meter, which is the core of this system, responsible for providing certified metering data. The Meter is interfaced with the telecommunication infrastructure and the household appliances.
- Smart Appliances, able to modify their behavior autonomously and to cooperate in order to adjust power consumption, under user defined constrains.
- Smart Plugs, which are able to collect metering data and to implement on/off control on the plugged energy loads.
- Home Residential Gateway, which, allows data exchange between the devices operating in the Home Network (HN), in the Home Area Network, and Internet.
- Human Interfaces, to monitor and configure user energy behavior.

An alternative approach for adding new functionalities is to retrofit an existing meter. An interesting application is given by real-time signals on water usage to estimate, for example, time and quantity of water used during a shower [17]. Mechanical water meters can be interfaced to digital data loggers by means pf magnetic pulses detection, so obtaining devices that can discern usage patterns and can play an important role in detecting leaks in existing houses [18]. A commercial wireless smart water meter is depicted in Fig. 4.

Fig. 4. A commercially available wireless smart water meter, LXS/SR series by MinSen Meter Co., Ltd.

Further real-time data of this nature would help planners and developers understand everyday water usage and consumer behavior, and their spatial and temporal variability.

In [12] a prototype to retrofit gas meters is presented. The designed module is based on a TRDA-SH360 optical encoder fitted to the index shaft of the old gas meter to record its rotation. A microcontroller captures the TTL pulse train from the encoder and process acquired samples. Data are subsequently sent to a personal computer for long-term data storage and post-processing.

Obviously, the technical challenge for engineers is *to design low cost and reliable instruments* that could easily take the place of the traditional meters.

The Open Source Hardware (OSH) is nowadays a movement that pushes scientist and engineers in new directions in the field of instrumentation. Choosing OSH equipment permits final users to reduce the costs, to have at their disposal a community of developers, a lot of technical resources and documentation to develop an instrument. An OSH meter could be based on the famous Arduino board [19] or similar projects and be an interesting method to develop low-cost instrumentation for renewable energy source monitoring, involving young scientists in this field of research [20].

V. SUPERVISORY SYSTEMS FOR INTERMITTENT AND PRECIOUS ENERGY SOURCES

Achieving the major production of renewable energy requires addressing key fundamental challenges in the control and reliability of intermittent resources like solar-based energy generation systems. Supervisory systems are needed in all kind of power generation source to control all the normal operations. They are used during start up, power operations, shutdowns, and plant upsets. The role of measurement and instrumentation is fundamental for the safety and efficiency, according to three types of functions: monitoring, control, and protection.

There are many reasons for which a system as expensive and long-term as a PV power supply should be monitored. For example if a system has been financed on the basis of its power output, the comparison between the expected output and the actual one could be interesting for the investors. An aspect not to be underestimated is the plant surveillance. While performance verification requires only the simple measurement of input and output signals, there are several variables that should be checked in case of both new technologies and pilot plant's characterization. The complexity and costs of metering systems depend on the number of measurements to be carried out and the desired accuracy. The development of a security policy for data-access is also a fundamental part of an on-line monitoring.

The control and supervisory tasks of private producers of energy distributed over wide areas require the use of sophisticated schemes that must be able to ensure access and exchange of great amounts of data which can be stored in a historical Data Base (DB), ready to be used for successive processing and analysis procedures. The advent of computer networks and web-based information technology offers opportunities to quickly upgrade manufacturing systems and implement advanced methods for the diagnosis or for parametric identification [21]**Errore. L'origine riferimento non è stata trovata.**.

For example, some of the most influential factors that affect PV performance include solar availability, array temperature, array soiling, solar spectral variation, and solar angle of incidence. A solar monitoring system can provide historical data to track these factors and determine the root cause of performance degradations.

Many PV inverter manufacturers offer hardware and software to implement a monitoring system. These have the advantage of being well tested and robust. Commonly available monitoring systems are based on data loggers and acquisition systems for digitizing the signals. Communication between the data logger and a data processing system can be based on several protocols, which have a different impact on the real-time performance of the monitoring system. Another relevant limitation of the most part of monitoring systems is that they are generally "closed" and in a very actual sense the user cannot easily manipulate the application interface or modify the implemented power quality indexes and often cannot meet the specifications required by some national founding programs. If an acquisition system is not available, the reading of the signals directly from inverters is possible, but often the communication protocol is not known and time consuming solutions, such as the reverse engineering of the protocol.

More general and adaptable monitoring systems are those based on a DAQ card as acquisition hardware, as illustrated in Fig. 5. By implementing the paradigm of synthetic instrumentation, these systems are real time and user-friendly, allowing a complete and easy re-

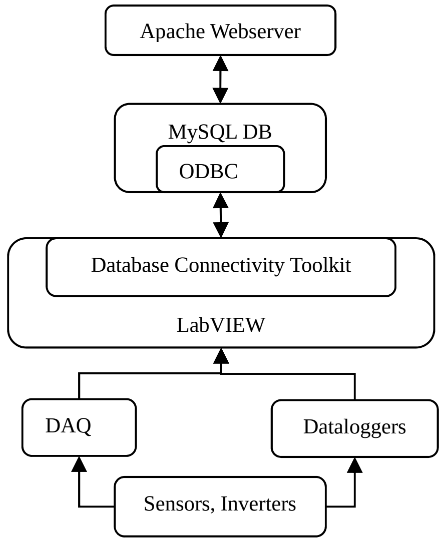

Fig. 5. Typical architecture of an open monitoring system.

configuration of the monitoring interface and the change of the way the performance and quality indexes are computed. All measured values, from different PV plants, are acquired by a DAQ board connected to a set of suitable sensors and stored in a single centralized DB. Other than local storage, a more "*open*" and fruitful approach is to share the acquired data, for example by using simple means such as a web page or smart phone apps, so that the user or a scientific community can easily access the data related to the renewable energy production and the environmental parameters. This allows on one hand the awareness of their own consumptions and on the other hand can boost both the study and the validation of the procedures and the algorithms so improving energy management in the distribution network.

VI. CONCLUSION

In order to fulfill the SC vision, governments have to consider investments in AMI as relevant as the ones for other public services such as road pavement, public lighting, supply networks etc. In this sense, AMIs infrastructures should be scheduled, designed and deployed as a fundamental service.

Measurement is Knowledge. For this reason, a not negligible aspect is the data sharing by means of the new communication platforms. The development of open and easily accessible architectures allows everyone to be aware of its resource consumption and be respectful of the environment.

The big challenge in urban sustainability is *to develop comprehensive and consistently applicable policies over different areas*. These policies need to be based on a broad and comprehensive understanding of the different factors that influence the relationship between cities operations and the environment. The integration of the various efforts in material and resource consumption, air quality, energy efficiency, urban planning and management should be an absolute priority of the political effort to make our cities smarter, in the ongoing battle for sustainability.

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