Architectural Criteria for a Distributed Energy Monitoring System

Luca Guido Mongiovì
Energy & ICT Consultant – Expert in Energy Management
Milan, Italy
luca.mongiovi@gmail.com

Franco Bua
ECD – Engineering Consulting and Design
Pavia, Italy
franco.bua@ecd.it

Luigi Aurelio Borghi
Didelme Sistemi srl
Castellanza (VA), Italy
l.borghi@didelmesistemi.it

Giacomo Grigis
Schneider Electric S.p.A.
Stezzano, Italy
giacomo.grigis@schneider-electric.com

Loredana Cristaldi, Enrico Tironi
Politecnico di Milano – DEIB Department
Milan, Italy
Loredana.Cristaldi@polimi.it

Michele Liziero, Giulia Frattini
EnergyTeam SpA
Milan, Italy
michele.liziero@energyteam.it

Cristina Lavecchia
Fondazione Osservatorio Meteorologico Milano Duomo
Milan, Italy
c.lavecchia@fondazioneomd.it

Luigi Martirano
Sapienza University – DIAEE Department
Rome, Italy
martirano@uniroma1.it

Abstract—The standards related to energy management emphasize the role of the measurement activity but no exhaustive guidelines have been published for outlining requirements and architecture of a comprehensive energy efficiency monitoring system that goes beyond a simple measuring system.

A Monitoring System for Energy Efficiency should transform several kinds of energetic and context data into actionable pieces of information for controlling energy performance, improving operations and maintenance as well as verifying the effectiveness and the continuity of corrective actions. Eventually the energy efficiency monitoring system should be modular to be upgraded over the time and to fit the needs of any organization.

This paper aims at contributing to the work of CEN-CENELEC JWG9 "Energy measurement plan for organizations" by providing background information for the development of its standards and for future work.

Keywords: Energy Management, Distributed Monitoring System, Achitecture, Susteinability, Technical standardization

I. INTRODUCTION

The role of energy efficiency in the global energy transition has been examined by the International Energy Agency (IEA) in the 2016 Energy Efficiency Market Report. The agency highlighted that, in addition to the energy source mix, it is also mandatory to consider the role of energy efficiency policy while evaluating the effects on climatic change; energy efficiency is defined in the report as a critical "fuel" in the transition to a low-carbon economy [1].

Energy Efficiency is a competitive issue for any organization. It can be pursued following either voluntary requirements and/or compulsory regulation. In either case, it should not be a one-shot activity but a continuous effort in a more comprehensive activity where the focus is to improve energy performance considering all the energy vectors and their significant uses [2]. In this scenario, IEC recommendations define measurement activity as a key parameter to determine the efficiency of a plant or process.

Starting from this consideration, an effective Energy Management requires the knowledge along the time of both the relevant energy uses and the main influencing factors such as operational requirements (e.g. production data) and environmental data (e.g. external temperature, humidity, etc.). This activity concerns all types of energy (electricity, gas, steam, chilled water, compressed air, etc.).

Measuring is just half of the journey. It takes to transform collected data into correlated and usable information by means of a sustainable, well designed, and upgradable energy efficiency monitoring system.

System definition requires a top down planning approach, starting from the identification of the minimum of relevant measuring/data collection points. Additional points can be

added after the first energy efficiency goals have been achieved.

Hence the need of distributing in a scalable and hierarchical architecture the measuring points, the data concentrators and the data processing and presentation subsystems.

II. Consideration on monitoring Activity

As indicated in ISO 50001 [2] a comprehensive approach for energy management requires several steps.

After the choices about the scope (sites, zones, energy flows and uses to be monitored, as well as the financial and human resources involved) it is required to identify and measure all the *relevant variables affecting significant energy use*, herein referred as "influencing factors" and classified as operational factors and environmental factors.

The above parameters must be considered to assess energy baseline and evaluate performances.

A. Identification of operational influencing factors

The knowledge of company's operations (e.g. processes and technologies of production and auxiliary plants) and objectives (e.g. volumes and mix of production) helps to identify operational influencing factors that must be monitored.

B. Identification of environmental influencing factors

Weather conditions (e.g. air temperature, humidity, atmospheric pressure, and solar radiation, wind speed) and indoor microclimate conditions influence energy consumption of many processes, such as in chemical and food industry, photovoltaic plants, and building climate control.

For instance uses of energy (gas, electricity, heat pumps) for Heating Ventilation and Air Conditioning (HVAC) in living and working environments [3] are strongly affected by environmental influencing factors such as Heating Degree Days (HDD) and Cooling Degree days (CDD), that must be related also to additional factors such as outside air temperature and relative humidity, as well as indoor thermal comfort index (function of indoor temperature, relative humidity, radiant heat, natural light, type of human activity).

Environmental measuring devices have to be appropriate in terms of technical specifications, positioning, reading frequency, metrological traceability [3] according to the targets of quality and reliability.

III. Achitectural Requirements

Monitoring can be considered as a strategy for investigation, detection, and policy decision in many fields. In literature, the solutions devoted to "Smart grid" pay attention to the definition of architecture devoted to protection, control, and monitoring functions using communications as a medium for implementing solutions [4, 5] but, unfortunately, present monitoring systems are commonly developed by different organizations using specific technologies and platforms.

Starting from this consideration, different examples of integrated monitoring architecture based on Web services have been presented [6-8].

To overcome the aforementioned problem and design a flexible monitoring system able to integrate - as much as possible - preexisting instruments, in the following will be presented and discussed the architecture proposed to the working group JWG9 "Energy measurement plan for organizations".

The layered and modular architecture model herein presented (see Fig. 1) is intended to provide a general framework to identify the Hardware and Software components required for designing a brand-new monitoring system for energy efficiency or integrating an already existing system. It provides a general interconnection and interworking scheme among these components, as well.

The list of functions and equipment indicated in this paper is not exhaustive neither it is required that all of them shall be adopted in a single implementation:

- Type and quantity of acquired data, and therefore of sensors and data acquisition interfaces, depend on the scope (covered areas and processes, and required depth of analysis) of the Monitoring System.
- Data Analysis functions, and Information Presentation interfaces and outputs should be limited to the real operational and control needs of the users.

Monitoring System Functions have been logically grouped in four layers that are presented with a top-down approach, starting from the end users' specifications to the low-level data acquisition requirements:

A. *Information Presentation*

B. *Data Correlation and Analysis*

C. *Data Classification, Transformation and Storage*

D. *Data Acquisition, Collection and Adaptation*

To facilitate the readability of the architecture scheme reported in Fig.1 logical components of the monitoring System are depicted in green, physical components in blue and legacy/different components (both logical and physical) in other colors. Main components of each layer are depicted in the following.

A. Information Presentation

A suitable Software Layer for Information Presentation is required on top to provide appropriate and value added information to several involved responsibility levels in the organization and even to external stakeholders.

Each involved person should be given reports and/or dashboards focused on his/her specific responsibilities; access and privilege control should be implemented as well for security reasons.

Some operators (such as Energy Manager or Responsible of Maintenance/Operations) should additionally be given specific Software tools and graphic interfaces for flexible analysis and "zoom-in / zoom-out" visualization of the monitored zones and entities.
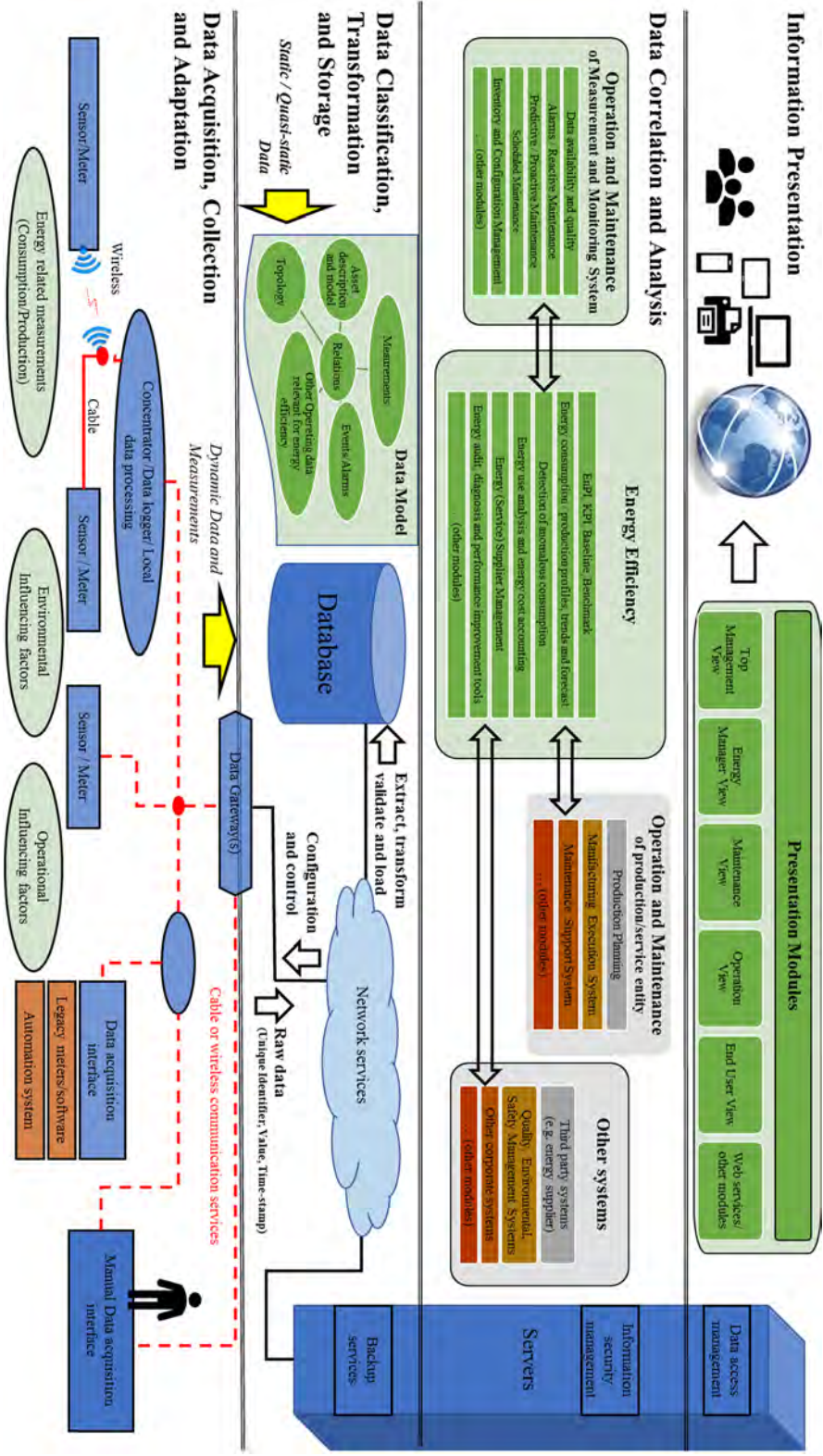
Fig. 1 Proposed Architecture for a Multi-Layer Energy Efficiency Monitoring System

Finally, in this layer can be also implemented additional modules such as:

- Supervisory Control Alarm and Data Acquisition (SCADA) modules to improve personnel awareness/reaction times;

- Digital Signage (e.g. modules to report to personnel or to external people live information on Energy Performance of the Organization).

Physically the Monitoring System Software for Information Presentation can be hosted on a Local Server or on a Remote server (either in another site of the same Organization or on third party cloud computing premises).

Use of web based interfaces for user device interconnection can additionally improve the accessibility and the use of reports, dashboards and flexible analysis tools, with adaptation to different fixed and mobile devices.

B. Data Correlation and Analysis

The Monitoring System Software for Data Correlation and Analysis, that feed the upper layer presentation software with value added information, should be modular and scalable to allow a progressive introduction of the needed functions in accordance with the priorities and the growing knowledge and awareness of the Organization.

Software modules should address both tools for energy efficiency analysis and the operation and maintenance of the monitoring system itself.

Examples of Energy Efficiency Software modules are:

- *Energy Performance Indicator (EnPI), Key Performance Indicator (KPI), Baseline, Benchmark:* absolute consumption figures alone are meaningless; to understand whether there is an efficient use of energy it takes to transform measured energy values into significant indicators of energy intensity for the monitored process (e.g. kJ/Ton of product) then to compare this figures to the target values (set by the organization) or to the reference values (from external benchmark) for the same processes.

- *Energy Consumption/Production Profiles, Trends and Forecast:* analysis of historical profiles, within the appropriate time frame and in comparison with targets, is used to detect main or most urgent areas for corrective actions and to verify the effectiveness of this actions. Trend analysis modules can early identify the onset of faults or bad operating conditions. Forecast modules can help to better quantify and address future purchasing of energy, as well as to create reference profiles to be compared with actual consumption measurements.

- *Detection of anomalous consumption:* violation of consumptions thresholds (static or time dependent) can generate alarms and activate a manual or automatic response to promptly limit over-consumption or under-performance and prevent more serious impacts on equipment and operations.

- Energy use analysis and energy cost accounting: Energy use analysis tools help to identify energy savings, maintaining the same quantity and quality of product/service, by adopting either better operating points or more efficient equipment. Energy cost accounting modules help to calculate indicators such as the impact of energy costs on product/service costs or the breakdown of energy costs by cost center.

The Monitoring System Software for Data Correlation and Analysis could also be integrated/interoperate with external Operation and Support System or Business Support System to create synergies.

C. Data Classification, Transformation and Storage

Correlation and Analysis functions described in the previous section B require a complex set of input data with different characteristics and origin:

- *Dynamic data from the field* (with automatic or manual acquisition): measurements, events, alarms;

- *Static or Quasi static data related to equipment*: e.g. asset description (type, model, nameplate data, and reference working parameters);

- *Metadata* (where and how devices are used): Topology, Inventory, Configuration;

- *Other Operating data relevant for energy efficiency* (typically imported from other systems)*:* e.g. production forecast, maintenance planning, energy costs, technical parameters (e.g. building/oven dimensions and thermal insulation);

An efficient and flexible management of these data requires the definition of a suitable data model, data adaptation and virtualization (to segregate Application Software from data acquisition/input), and possibly the use of an object oriented and relational data base to optimize data organization and maintenance.

Physically the Data Classification, Transformation and Storage can be hosted on a Local Server or on a Remote server (either in another site of the same Organization or on third party cloud computing premises).

D. Data Acquisition, Collection and Adaptation Layer

This layer includes all the "measuring devices" (meters, sensors, probes, gauges and in-field data interfaces) that are relevant for implementing an energy efficiency monitoring system in accordance with the scope defined by the interested Organization. A correct choice of measuring instruments must take into account also a suitable measuring accuracy, a periodic calibration plan and an evaluation of installation costs and burdens that may occur during deployment.

Additionally, there is the possibility of manual data acquisition and entry by a Human Operator through suitable manual data acquisition interfaces:

- sometimes the integration of a meter in a communication network is not easy or immediately convenient, although its data are mandatory for energy monitoring;

- sometimes important data or events of operational influencing factors (e.g. a long-lasting maintenance stop of a production line, or an extraordinary load factor for a given time period) can be input only by a Human Operator.

Dynamic data to be acquired from the field have been grouped in three main sets:

1. *Data directly related to energy, energy consumption and energy use of monitored processes,* energy production, storage and feed-in, for all the relevant energy vectors, usually WAGES (Water, Air, Gas, Electric, Steam). Examples of measuring devices for these data are Fiscal Meters (Electricity, Water, Gas), Energy Analyzers (for voltage, current, phase, distortion, etc.), Meters of physical quantities (temperature, pressure, flow rate, luminance, etc.).

2. *Data related to relevant variables as environmental factors* that significantly influence the energetic consumption of the monitored processes. Examples of measuring devices for these data are Meters of environmental physical quantities (temperature, pressure, solar energy rate, etc.).

3. *Data related to relevant variables as operational factors* that significantly influence the energetic consumption of the monitored processes, such as production mix and quantities, maintenance intervals and events, operational data of production and operational data of auxiliary services. Examples of data acquisition interfaces for these data are PLC controlling a line and the displays/keyboards for manual data entry by a Human Operator.

Data Concentrators

Data concentrators can be adopted to collect, process and log data from sets of measuring devices/data interfaces in order to optimize the overall structure of the LAN and the data traffic with Data Gateways.

They implement local data store and forward functions for data integrity in case of temporary communication fault.

They can have local displays and Human Machine Interfaces, as well, and can react locally to events or implement time based logics: for instance, they can generate alarms in case of meter fault/isolation or for anomalous measurements (e.g. out of scale or unexpected at a certain time).

Data Gateways

Data Gateways are dimensioned for a delimited area or plant section (i.e. they act as LAN Edge equipment), and perform the adaptation of data exchange protocols and data formats. Additionally, they can act as concentrators.

They handle the dialogue with higher layer elements (DB, Servers, etc.) either with direct LAN connections (fully local monitoring system) or via a long-distance TLC Network.

Eventually they can transfer configurations or commands from the higher-level elements to LAN components and connected equipment.

Local Area Network (LAN)

The LAN can be segmented into several physical wired or wireless sections.

Transmission media, transmission protocols, interconnection topology (tree, star, mesh, hybrid), routing and redundancies are to be chosen to fit the main requirements in terms of device interconnection, robustness, data retention/recovery, throughput, LAN implementation and maintenance costs.

IV. DESIGN AND IMPLEMENTATION OPTIONS

There are several architectural alternatives in terms of:

- HW and SW redundancy;
- Data Base and Software allocation (local, cloud, hybrid);
- Topology (star, mesh, hybrid), Type (wired, wireless, hybrid) and Communication Protocols of the LAN/WAN for data collection and transfer;
- Topology and number of levels for data acquisition, collection, adaptation and storage;
- Interworking with other Operation and Business Support Systems.

In any case the proposed general architecture is scalable to allow widening the scope of the system in subsequent sustainable implementation steps, adding modular components into the proper level.

It allows the implementation of both purely local systems (e.g. all HW and SW components installed within a single site) and distributed systems (e.g. multisite cases and/or cases with virtualization of the higher layer functions in a cloud infrastructure).

V. CASE STUDIES

In order to show the effectiveness and completeness of the proposed architecture, two case studies are presented in the following.

A. Case Study 1 (Data Centre)

A leading operator of data centers and internet exchanges leases out data center space to a wide variety of tenants. Its objectives are to reduce energy consumption by improving Power Usage Effectiveness (PUE) and Water Usage Effectiveness (WUE), to ensure power supply availability and reliability, monitoring and billing of individual tenant's energy consumption. The energy management solution (Fig. 2) provides web reports, customized graphics, dashboards, power quality waveform captures, alarming. It also allows to monitor circuit breaker status, Uninterruptible Power Sources (UPS), Static Transfer Switches (STS) and Building services.
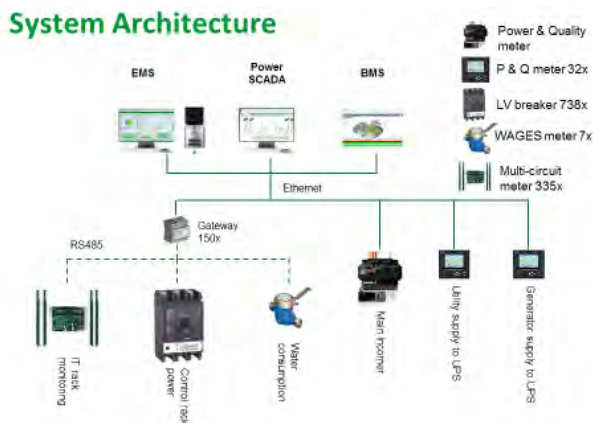

Fig. 2: Energy Management Solution – Main Interconnected Objects

In this case, the Energy Efficiency Monitoring System has been implemented to achieve the following organization goals:

- Generating PUE and WUE dashboards (Fig. 3) and reports for compliance and improvement;
- Monitoring power quality;
- Identifying over-drawing by any rack;
- Generating Energy cost report and Load profile report for each tenant;
- Capacity planning based on energy consumption reports.

Fig. 3: Example of EnPI and Power Consumption dashboards

B. Case Study 2 (multinational food company)

A worldwide food company, focused on continuous sustainable improvement, has environmental sustainability as a strategic goal, with the following requirements:

- reducing ecologic footprint (CO_2 emissions);
- improving energetic efficiency;
- optimizing use of other resources uses (especially water).

To reach these goals, the company invested in:

- Defining a measurement plan for any plant, to control any factor that influences energy consumption, for each energy vector;
- Equipping any plant with devices to measure and collect consumption figures;
- Implementing an Energy Efficiency Monitoring System to analyse and share information about costs and consumptions (Fig. 4, Fig. 5);
- Implementing an Energy Management System [2], based on a "Plan, Do, Check, Act" approach, and a corporate policy committed at every company level.
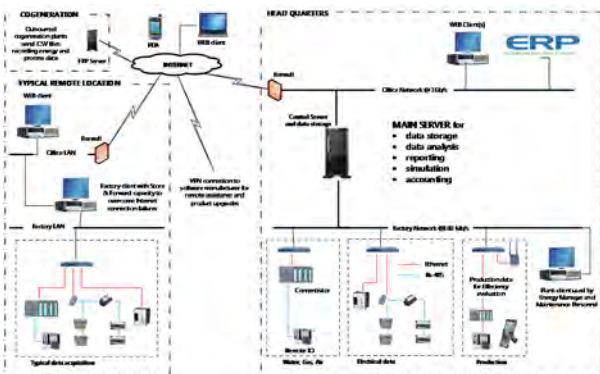

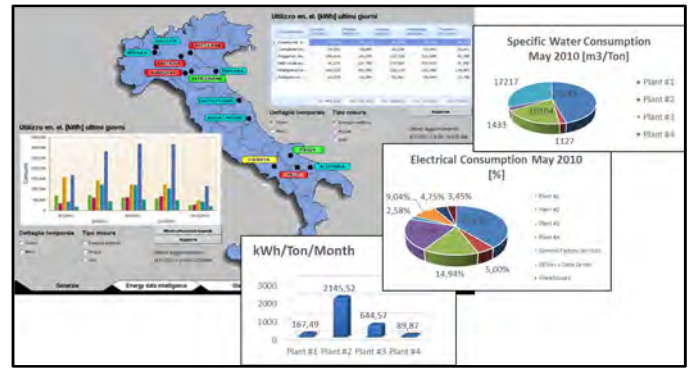Fig. 4: Energy Efficiency Monitoring System – Architecture

Fig. 5: Example of Presentation and Analysis modules

The implemented monitoring system increases knowledge and awareness, allowing to identify process improvements and sustainable upgrade of the plants (production and auxiliary systems) with more efficient equipment.

This continuous improvement process led to significant savings per ton of product starting from 2010: energy consumption -5%, water consumptions -19%, and CO_2 emissions -23%.

VI. CONCLUSIONS

This paper presents a monitoring architecture able to analyze the energy performance of an organization, improve operations and maintenance as well as verify the effectiveness and the continuity of corrective actions. It indicates the need of acquiring and process, in addition to energy measurement, other data such as influencing factors and context data. The scalability and effectiveness of the proposed architecture has been shown by means of the analysis of case studies.

REFERENCES

[1] https://www.iea.org/eemr16/files/medium-term-energy-efficiency-2016_WEB.PDF.

[2] UNI EN ISO 50001:2011 Energy management systems -- Requirements with guidance for use.

[3] WMO GUIDE TO METEOROLOGICAL INSTRUMENTS AND METHODS OF OBSERVATION - No. 8 (Seventh edition, 2010).

[4] Shengye Lu; Sami Repo; Davide Della Giustina; Felipe Alvarez-Cuevas Figuerola; Atte Löf; Marko Pikkarainen Real-Time Low Voltage Network Monitoring—ICT Architecture and Field Test Experience. IEEE Transactions on Smart Grid 2015, Vol: 6, Issue: 4 Pages: 2002 - 2012, DOI: 10.1109/TSG.2014.2371853.

[5] Ratan Das; Vahid Madani; Farrokh Aminifar; John McDonald; S. S. Venkata; Damir Novosel; Anjan Bose; Mohammad Shahidehpour Distribution Automation Strategies: Evolution of Technologies and the Business Case IEEE Transactions on Smart Grid Year: 2015, Vol: 6, Issue: 4. Pages: 2166 - 2175, DOI: 10.1109/TSG.2014.2368393.

[6] Zhongwen Guo; Pengpeng Chen; Hao Zhang; Mingxing Jiang; Chunrong Li : IMA: An Integrated Monitoring Architecture With Sensor Networks IEEE Transactions on Instrumentation and Measurement Year: 2012, Vol: 61, Issue: 5 Pages: 1287 - 1295, DOI: 10.1109/TIM.2012.2186395.

[7] Domenico Grimaldi, Mihail Marinov Distributed measurement systems - Measurement, Volume 30, Issue 4, December 2001, Pages 279-287

[8] Juan José González de la Rosa, Antonio Moreno Muñoz, Aurora Gil de Castro, Víctor Pallarés López, Jose Antonio Sánchez Castillejo A web-based distributed measurement system for electrical power quality assessment Original Research Article Measurement, Vol 43, Issue 6, July 2010, Pages 771-780.