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Power monitoring system for university buildings: Architecture and advanced analysis tools

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ABSTRACT

Nowadays, our dependence on electricity is strong because power consumption has increased considerably in the last years. For that reason, an efficient use of electricity is necessary, especially in public buildings. In order to manage the power consumption, it is vital to measure and monitor the electrical systems. Monitoring can provide advanced visualization and data analysis tools which can help us to achieve energy savings and peak power optimization. In this work, we present a power monitoring system developed for the campus buildings at the University of León (ULE) in Spain. This system is based on a three-layer structure. In the server layer, data are acquired from meters installed in the campus buildings. In the middle layer, data are stored and processed. In the client layer, monitoring interfaces, accessible remotely through the Internet, provide both traditional and advanced monitoring tools, based on statistical and data mining techniques. These techniques exploit data in order to find electrical patterns, detect faults and deviations, predict future power consumption, optimize peak power, etc. The data acquired by the monitoring system during 2010 are analyzed. The results from the visualization and data analysis tools, implemented in the monitoring system, are presented. The application of the proposed tools led to economic savings of around 15% and deeper knowledge about the electrical system.

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1. Introduction

In the last years, power consumption has experienced a significant increase. This trend is bound to continue in the future, so it is necessary to carry out actions that promote energy savings and efficiency to reach a more sustainable development [1]. Indeed, the European Union (EU) suggests that energy efficiency is the key to slow down the power consumption growth, reduce pollution and strengthen competitiveness [2,3]. Since buildings account for 40% of the power consumption in the EU [4], the reduction of their consumption is crucial to decrease the power dependence and comply with the Kyoto protocol. In that sense, public buildings, such as those in a university campus, should set an example [5]. Some authors argue that 20% of the electricity used by buildings could be saved just by repairing malfunctions and avoiding unnecessary operations, i.e., by achieving energy efficiency [1].

However, optimization and fault detection can only be possible if information about the relevant variables is available for analysis and monitoring. A detailed understanding of the electricity use allows us to find where it is wasted or to forecast power demand. This feedback has proven to be effective as a self-teaching tool for saving electricity and, consequently, money [6]. In large organizations, such as universities, it might result in a significant reduction of the electricity bill, especially under the current open market where tariffs can be negotiated [7]. Buildings must be provided with electrical measurement and monitoring systems to manage appropriately power consumption and improve their energy efficiency [8]. These systems must store historical data and exploit them to obtain the intrinsic information which must be displayed in a legible, understandable and innovative way [9]. However, monitoring systems are currently scarce and inefficient because they are usually focused only on few electrical variables, mainly those involved in billing, and the integration with other building systems and future expansions is difficult [10]. Furthermore, their storage capacity is often small and data are acquired at a low sampling period, which implies the loss of certain information about the system dynamics.

To overcome these drawbacks, modern power monitoring systems should be based on open, non-proprietary and modular architectures, cutting edge technologies and standard communication protocols to facilitate the integration, expansions and maintenance. Besides providing traditional monitoring tools, such as visualization of instantaneous, minimum and maximum values, trends, alarms and warnings, modern systems should include advanced monitoring tools that allow us to exploit the large amount of stored data. These tools could be based on statistical and data

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Table 1
Buildings and billing points of the electrical system.

Billing points	Buildings	Description
P1	B1	Data Center
P2	B3–B4	Engineering School I – Lecture Hall
	B5–B17	Engineering School II – School of Sports
	B18–B19	Sports Center – Sports Center II
P3	B6–B8	School of Arts – School of Education
	B7–B9	Law School – School of Labor Studies
P4	B10–B11	Veterinary Hospital – Veterinary School
	B12–B13	Cafeteria I – Biology School
	B14–B15	Service Center – Farm Development
	B16	Animal Facilities
P5	B20–B21	Central Library – Bank
	B22	Cafeteria II
P6	B2–B30	Radio – Business School
P7	B23	Molecular Biology Research Center
P8	B24	Agricultural Facilities
P9	B25	Dormitory
P10	B26	Administration Offices
P11	B27	Environmental Research Center
P12	B28	Mining Engineering School
P13	B29	Language Center

mining techniques [11] which provide a better understanding of the electrical system and improve decision making. In the future, monitoring systems should provide information about power quality and not only power quantity [12]. Another vital requirement in modern monitoring systems is the remote access through the Internet to visualize the electrical system from anywhere [13]. Some power monitoring systems which follow the aforementioned key lines have appeared recently in the literature [14,15].

In this work, an advanced monitoring system of electrical power for the campus buildings of the University of León (ULE) has been developed. The system has been designed using standard technologies and avoiding proprietary software as much as possible, in order to ensure its scalability, integrability and reliability. Several traditional and advanced monitoring tools have been added. These tools are used to know the power profiles, find voltage peaks or sags, determine the distribution of power consumption in different time periods, detect faults and electrical drops, predict future power consumption, verify bills and compare behaviors of different buildings.

This paper is organized as follows: Section 2 describes the measurement system of electrical power at the University of León. Section 3 describes the architecture of the monitoring system. Next, Section 4 presents the advanced monitoring tools included in the system. Experimental results are exposed in Section 5. Finally, conclusions are drawn in Section 6.

2. Measurement system of electrical power

The campus of the University of León is composed of a group of buildings used for teaching, research or miscellaneous support services (cafés, data centers, administrative tasks, etc.). The power consumption in these buildings, framed in the tertiary sector, corresponds basically to lighting systems, heating, ventilating and air-conditioning (HVAC) systems [4] and industrial equipment for researching. The buildings are located in three different zones of the town of León: north area or Campus de Vegazana, city center area and south area. The electrical company supplies power to university buildings from 13 electrical connection points (P1–P13), which, in turn, are billing points. According to the level of voltage, there are two types of connection points: low voltage (400 V) and medium voltage (21 kV). In the second case, an electrical transformer is needed to reduce the level of voltage. Table 1 lists the 30 campus buildings grouped into the 13 billing points.

A measurement system has been designed to capture electrical variables from each university building (see Fig. 1). This system is composed of electrical meters and a meter network for their communication. Electrical meters are from different manufacturers and models, depending on the technological requirements. The type of meter determines the number and accuracy of the captured variables as well as the communication interfaces and computing resources. The types of electrical meters are enumerated below:

- Nexus 1252 meters (Electro Industries/GaugeTech[1]): These meters not only measure the electrical variables but also allow an analysis of them. They store voltage sags, peak power and other transient effects, to make the analysis of the energy quality easier. The meter has RS-485 and RS-232 serial ports and an Ethernet port, so it can also work as a gateway between both interfaces.
- CM 4000 meters (Schneider Electric[2]): This equipment enables an assessment of the energy quality by means of an analysis of harmonics. As in the previous case, it has Ethernet and RS-485 network interfaces that let it work as a gateway between both of them.
- Shark 100 meters (Electro Industries/GaugeTech): This model only performs electrical measurement. Its main applications are invoicing and measurement in the secondary distribution level. One advantage is its low cost. As a communication interface, it has a RS-485 serial port.
- PM 800 meters (Schneider Electric): This model is useful to monitor an electrical installation at a low cost. It uses a RS-485 serial port.

Nexus 1252 and CM 4000 models are categorized as high-performance measurement devices, whereas Shark 100 and PM 800 models are included in the middle class. In any case, the captured variables are the basic ones, i.e., voltage and current, and other complementary ones, such as power, power factor, energy, total harmonic distortion (THD), harmonics in voltages and currents which are computed from the voltage and current sampled waves. The total number of captured variables is 53.

The geographic dispersion of the campus buildings, and therefore of the electrical meters, requires to establish a communication network to link all of them. This meter network comprises multiple network segments, which differ in the physical layer used to transmit the information. There are two types of network segments: Ethernet and serial RS-485. The serial RS-485 segments link close meters, i.e., buildings, while Ethernet segments connect widely separated buildings. The Shark 100 and PM 800 meters conform the serial RS-485 segments whereas Nexus 1252 and CM 4000 constitute the Ethernet ones. The last two meters are also used as a gateway between both types of segments. In this network architecture, which combines serial RS-485 and Ethernet segments, undesired bottlenecks can appear due to the simultaneous communication of several meters connected in the same serial RS-485 segment. However, this architecture leads to a significant cost saving, because it avoids the use of measurement devices of the high-performance class, which are quite more expensive.

The meter network uses the local area network (LAN) already available in the buildings of the University of León to minimize the network wiring. An independent virtual local area network (VLAN) has been created to communicate the electrical meters. The VLAN defines a logical segment, avoiding information exchange with other segments dedicated to different purposes such as administration and faculty. VLANs work on the third layer or network layer of the OSI (Open System Interconnection) model [16]. The

[1] www.electroind.com.
[2] www.schneider-electric.com.

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