Development of a real time energy monitoring platform user-friendly for buildings

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Abstract

This study introduces the development of a user-friendly and quite effective energy monitoring system installed in the building of School Engineering at the Universidad Autónoma de Querétaro since 2008. The metering and control software, that processes and analyzes the digitalized signals, has been developed in Integrated Development Environment (IDE) primarily MonoDevelop designed for C#, under the Linux embedded server operating system with a real time kernel. This system allows the measurement of the electric energy parameters of within a building, where the main power source has been divided into several sections for individual analysis. Measuring electric energy in sections allows the identification of higher consumption areas, the detection of abnormal conditions in voltage and current of the building. The consumption of electric energy parameters are displayed by means of an easily understood graphic interface which can be consulted via the Internet. Users who know exactly when energy consumption occurs and where it takes place are able to take more informed decisions about how to lower their energy consumption.

Keywords: Building, monitoring, electric energy, consumption;

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1. Introduction

Energy monitoring systems are used widely in industrial plants and buildings to observe the energy consumption. The residential sector, unlike the commercial and industrial sectors, is made up of multiple small energy users such as houses, mobile homes, and apartments. Research has shown that these residential energy consumers waste almost 41% of the power supplied to their homes [1]. Change of voltage, energy consumption, power factor, and current parameters must be measured for buildings. Fundamental understandings of how energy is consumed, monitored, and controlled are key prerequisites for an energy conservation process. Users that know exactly when energy consumption occurs and where it takes place are able to take more informed decisions about how to lower their building energy consumption rates [2]. Currently, however, millions of users are still largely in the dark about the amount of energy they consume [3]. In 2009 a study conducted by the Department of Energy on Energy consumption loads, found that miscellaneous electrical loads account for 45% of the electricity consumption in residential buildings and 34% in commercial buildings [4]. Studies have suggested that savings of over 35% of the miscellaneous electrical loads total energy use may be possible [5].

Several energy systems have been recently studied according to several demands as result of different needs. For example, companies generally have many different rate schedules and penalty policies for poor-power-factor loads. In order to cut down on electric bills and avoid penalties, companies involve themselves with the efficient use of electricity, result of fast growing developments in electronic and software technologies, the data acquisition systems and energy monitoring applications [6]. However some commercial systems currently available require a large investment due to the following reasons: The systems are sold separately; the systems use complex hardware solutions and the systems’ hardware solutions are not configured easily; besides not being adaptable for particular operative conditions. Also, the configuration and operation of the systems from remote locations are usually limited and the necessary system software is required for every application. The electric energy problem might be dealt by using new devices of low cost which may allow users to obtain greater benefits from electricity.

Over the last two decades, a plethora of intelligent components and products have been introduced. The term “intelligent” has been extensively applied to portray the ‘smart’ properties of the building system products. This concept is described as “one that creates an environment which maximizes the effectiveness of the building’s occupants, while at the same time enables efficient management of resources with minimum life-time costs of hardware and facilities” [7]. To improve efficient use of electricity, reduction must occur as a result of changing use habits [8]. Recent studies have focused in several directions with the purpose of saving energy, including direct feedback, home automation and smart homes and a new type of homes that are designed to be zero net energy homes. Buildings must be provided with electrical measurement and

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### Nomenclature

| Symbol | Description          |
|--------|----------------------|
| \( I_{ef} \) | effective current    |
| \( i_i \)   | instantaneous current|
| \( N \)    | number of samples in a complete period |
| \( V_{ef} \) | effective voltage    |
| \( v_v \)   | instantaneous voltage|
| \( \Delta t \) | sampling time        |
monitoring systems to manage appropriately power consumption and improve their energy efficiency [9]. 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 [10]. Another vital requirement in modern monitoring systems is the remote access through the Internet to visualize the electrical system from anywhere [11]. The work presented by Yary [12] shows the implementation details and results of a power measurement technique based on the Internet. In this particular research, voltage, current and watt-hour transducers were used to collect analog data and to send this information by Internet. In this manner, data could be accessed frequently through a web-site. However, this study presented some drawbacks: transducers were used to give a DC voltage proportional to AC signals; consequently, the error in the non-sinusoidal case is not taken into consideration. Bucci [13] presented a digital instrument for the power quality analysis where voltage or current waveforms are non-sinusoidal and it is possible to compare measured values with those obtained with a standard wattmeter. Daponte [14] presented a paper which describes the design and implementation of a monitoring system for the detection, classification and measurement of transient disturbances in electrical power systems which was implemented in LabView™. The system allows transferring the acquired data to a remote embedded computer server for post-elaboration and storage, using an existing local area network or wide-area network via TCP/IP protocols. Given these breakthroughs, the main objectives to be addressed in this work will be to develop an appropriate monitoring system with the following specifications: low cost instrumentation, having the capability to measure under non-sinusoidal conditions and a standard communication interface.

From June 2010 by American Council for an Energy-Efficient Economy (ACEEE) of 57 energy conservation projects from 1970 to 2010. It describes and summarizes past work, concluding with the fact that in the US, studies have reported 2-11% savings when users are presented with feedback on energy consumption [15]. Woods [16] energy monitored for a period of at least 12 months and this revealed an average daily consumption for electric cooking of 1.30 kWh. Subsequently across a minimum monitoring period of 2 months, 14 out of 31 households achieved energy savings greater than 10% and six of these achieved savings greater than 20%. The average reduction for households employing an ECI was 15%, whereas those given background information alone reduced their electricity consumption, on average, by only 3%.

In this paper, the development of a consumption monitoring system and quality electric energy is proposed. This system allows the measurement of all the electric energy parameters of within a building, where the main power source has been divided into several sections for individual analysis. Measuring electric energy in sections allows the identification of higher consumption areas, the detection of abnormal conditions in voltage and current of the building. The electrical consumption and parameters are displayed by means of an easily understood graphic interface which can be consulted via the Internet. The monitoring system was designed to be used in buildings; therefore, all data gathered can be used to take educated decisions for the utilization and efficient administration of the electric energy inside a building. In addition, this system is capable of sharing data measurements from the main embedded computer server via a local-area network or wide-area networks to another remote computer.

2. Materials and methods

This study develops a user-friendly and quite effectual energy monitoring system which has been installed in the building of the engineering department at the Universidad Autónoma de Querétaro in use since 2008. The system consists in: User Interface: the screen of the main menu shows the building in which the power monitor system was installed, Fig 1. At the bottom of the screen there are three buttons: Energy, Building Map and Data Base. The function of Energy, Building Map and Data Base options is described as follows:
• Energy: This screen shows the current and voltage signals in the two upper squares of the embedded system. Screen that shows in digital and analogical form the data from the different powers (active, reactive, apparent and power factor) in real time for every section of the building.

• Building Map: This screen shows a map of the building where the on/off function switches for the equipment can be seen in real time.

• Data Base: This screen shows the electric energy consumption on a daily or weekly basis for every section of the building.

The user has access to all the screens in every section of the building, to see or request any information related energy consumption and power at different hours on any day or a week. There is also a screen that asks the user which building section he or she wishes to look at, in order to check the electric consumption for an hour, day or week.

Fig. 1. Power monitoring user interface

2.1 Instrumentation description

A block diagram for the measuring equipment is shown in Fig 2. In order to obtain proper AC signals proportional to the voltage and current present in the load, a set of voltage and current transformers was used. The testing was done with a 0-10A current transformer that gives a linear output ratio of 100 mV/A, the voltage transformer used has a reduction relation of 20.

By using this, it was possible to obtain a 6 Vrms voltage from a 120 Vrms signal. Both current and voltage signals are conditioned to increase dynamic range and limit maximum outputs before A/D conversion. Once the current and voltage signals are adapted, they are introduced into a 16 bits resolution digital analog converter ADS8364. The sampling frequency was established at 60 Hz and the number of samplings in a cycle at 512. An external clock that establishes the frequency in which the voltage and current samples are recorded was also required. The acquired data was processed by the main embedded computer server that was programmed to do the mathematic calculations in order to obtain the power quality measurements and to process the requests of the remote equipment connected by means of a local-area network via TCP/IP protocol.
Due to the advantages of the TCP/IP protocol, the monitoring client or the control workstation can be connected to the intranet or the internet. Then, the server was set to handle the acquisition and control of the electrical energy data while at the same time, reserves a time space for the administration of the TCP/IP connections, which are useful for the monitoring and use of remote control over the system. The TCP/IP connections model used is shown in Fig 2. It consists of a server of Monitoring Workstation which can maintain 4 different states after receiving the data: Step 1, establish the connection with the client, to confirm the name of the user, the password and to determine if he or she belongs to control or monitoring. If the system does not recognize a legitimate user, it will automatically be disconnected. Step 2; listen to the TCP/IP port in search of new clients. Step 3; receive a command of controlling or monitoring according to the privileges of the client, and to process this command in order to perform the requested actions, handling small packets of data to avoid having only one client covering the whole process. Step 4, once the process has been completed, the connection with the client should be terminated.

The system only allows a remote station of control. If this station sends a control command, the resources blockade model is taken into account in order to avoid problems in the control resources handling. This function is more important in the Monitoring Workstation. In this manner, if the Monitoring Workstation is using a control resource, the Control Workstation will not have this resource. Although the process manages small data packets, it is important to avoid the limit of the information flow that is sent in the state 2, since the priority of the monitoring system is to focus on managing the system.

![Diagram of electric power monitoring](image)

The electric energy is measured in five different sections of the building, which are the following: classrooms 19-20, 21-22, and 23-24, perimeter lighting and sockets. The system allows sampling of the current signals and voltage at the same time. For this reason, there is no delay in the sampling time. The systems measured to accurately the power calculus in every section of the building and store the data in the embedded system for future consults. The main characteristic of the hardware system is flexibility. Through the development and application of the software, it is possible to have an electric energy monitoring system in real time, while showing the energy data in a comprehensible way on the screen. Consequently, this system is very versatile and powerful in monitoring energy parameters in buildings. The instrumentation and the embedded system are located in a control room in the north section of the building.
2.2 Discrete integration algorithm

This algorithm is based mainly on the simultaneous current signals and voltage sampling which has already been discussed by several authors [17]. The discrete integration method, calculates the current and voltages signals and active power through the digital version of each power source, in this order respectively. It also allows for the calculation of the effective values of the voltage, the current, and consequently, the apparent power and the power factor. The current and voltage samples must correspond, one by one, to identical points in time, and the total sampling time must be a whole number of times M, the fundamental period of entrance signals. The discrete integration provides both, apparent and active powers, and also the power factor in non-sinusoidal conditions with a null influence of the calculus method when measuring, if provided values M and N are properly chosen. First, it is necessary to calculate the effective values of voltage and current, as is indicated in the discrete integration method Eq. (1) y (2). In order to simplify the calculus and be more precise, the values \( i_0 \) and \( v_0 \) should be taken into account. To fulfill the previous conditions, it is necessary for the sampled data to be taken from the beginning to the end of the cycle of the sinusoidal wave. Consequently, the equation is reduced to:

\[
V_{ef} = \sqrt{ \frac{1}{N} \sum_{k=0}^{N-1} v^2 \Delta t}
\]

\[
I_{ef} = \sqrt{ \frac{1}{N} \sum_{k=0}^{N-1} i^2 \Delta t}
\]

Where \( N \) is the total number of samples in a complete period and \( \Delta t \) is equal to the sampling time; all the discrete powers to be implemented in the system.

2.3 Validation

To calculate the error percentage of the electric parameters of current, voltage active power, power reactivates, apparent and factor power, the next equation was defined according to Cox [18]:

\[
\% \text{errorEP} = 100 \left( \frac{X_{\text{Fluke}} - Y_{\text{System}}}{Y_{\text{System}}} \right)
\]

Where \( Y_{\text{System}} \) denotes the measure of the electric parameters by means of the system development, \( Y_{\text{Fluke}} \) denotes the electric parameters measured by the 435 power quality analyzer.

3. Results and discussion

The results of the electric energy monitoring system are displayed in both analog and digital form, in such way that the user can easily read the different electric energy variables. The bottom of energy in screen shows in digital and analogical form the data from the different power (s) (active, reactive, apparent and power factor) and voltage and current signal in real time for every section of the building (19-20, 21-22, 23-24, and sockets) Fig 3. The different power factors measured with the system were 0.95, 0.92, a power factor of zero in section 23-24 because there was no load connected, and in the sockets section was 0.73. Section 19-20 has
a better behavior with power factor 0.95. The worst case is presented in socket section with 0.73 power factor; this value needs to be improved to avoid fines imposed by the Supply Company in México (CFE). The power factors of 0.92 and 0.95 are in the range allowed by the energy Supply Company in México. Furthermore we noted that the section that demands more active and apparent power was section 21-22, with 667.54 Watts and 722.58 VA. The voltage level is kept between 123.06 and 126.44 Volts in each section of the building. Electric current varied from zero in section 23-24 (because there was no load connected) to 5.85 amperes in section 21-22. The energy monitoring system has a database that records the power consumption of each of the four sections of the building, which is displayed in the user-friendly interface Fig 4. This database allows the user to identify the area of greatest electricity consumption.

Fig. 3. (a), (b), (c) and (d) shows in a user-friendly electrical variables (Amperes, Volts, Watts, VAs, Vars and power factor) in each of the sections of the building.

In this case the section of increased energy consumption is the in sockets section, with approximately a weekly energy consumption of 39.7 kWh and 5.67KWh per day, average; section 19-20 is the lowest with
5.91 KWh. With the sum total KWh, you can calculate total amount of money to be paid to the company supplying electricity in Mexico. Eventually this information will allow the user to manage in a more efficient way the use of electric energy and implement energy saving practices in some areas of the building. After all, energy saved is, quite literally, energy found. The monitoring system is designed to perform long measurements where the data storage is important for future analysis. The information is stored paying special attention to consumption of KWh to maintain better administration of the electric energy in the building. The experimental results were compared with an energy analyzer, Fluke model 43B.

The different screens of the electric energy monitoring system implemented in the building and advantages of the system architecture are as follows:

- The use of the embedded system allows for expanded data conveyance, generating the basis for the low cost of the system that, when compared with other commercial energy analyzer systems, allows monitoring only one channel.
It is designed to work on the data collection as a centralized and/or distributed system. It allows monitoring the electric energy consumption in each section of the building. It stores the active power data measured per hour, day and week. Thus, it is possible to predict the energy consumption cost according to the tariff. The system also supervises the measuring variables limits, avoiding penalization, in case it exceeds the maximum demand or the power factor.

In the Table 1 shows the error rate between the embedded monitoring system and the Fluke, the result was 1.554 for a period of 105 minutes which is acceptable.

### Table 1. Percent error between the system developed and Fluke

| Time (min) | Fluke (KWh) | System embedded (KWh) | % Error EP | Time (min) | Fluke (KWh) | System embedded (KWh) | % Error EP |
|------------|-------------|-----------------------|------------|------------|-------------|-----------------------|------------|
| 1          | 0.016       | 0.017                 | 5.882      | 55         | 0.557       | 0.552                 | 0.905      |
| 5          | 0.037       | 0.038                 | 2.631      | 60         | 0.630       | 0.638                 | 1.253      |
| 10         | 0.059       | 0.058                 | 1.724      | 65         | 0.660       | 0.664                 | 0.602      |
| 15         | 0.100       | 0.101                 | 0.990      | 70         | 0.691       | 0.700                 | 1.285      |
| 20         | 0.195       | 0.197                 | 1.015      | 75         | 0.720       | 0.730                 | 1.369      |
| 25         | 0.257       | 0.255                 | 0.784      | 80         | 0.785       | 0.810                 | 3.086      |
| 30         | 0.297       | 0.295                 | 0.677      | 85         | 0.819       | 0.830                 | 1.325      |
| 35         | 0.327       | 0.324                 | 0.925      | 90         | 0.892       | 0.900                 | 0.888      |
| 40         | 0.370       | 0.365                 | 1.369      | 95         | 0.950       | 0.965                 | 1.554      |
| 45         | 0.428       | 0.424                 | 0.943      | 100        | 0.977       | 1.000                 | 2.300      |
| 50         | 0.490       | 0.486                 | 0.823      | 105        | 1.000       | 1.019                 | 1.864      |

% Mean error | 1.554

### 4. Conclusions

Power monitoring systems can provide information on voltage, current, power and waveforms. Using the information provided by these units, it is possible to do the pertinent changes in order to have a significant impact on energy savings. The current energy savings technology relies on conventional data logging systems which possess crucial drawbacks. More recently, power monitoring allows data to be accessed more frequently by means of data communication protocols such as Bluetooth or Internet. Former studies related to power monitoring presented results about particular topics, but they differed from each other. In this document a power monitoring system was presented. The main advantage of this system is that it gathers the most important information regarding an efficient power monitoring system. Also it records data such as measurement in non-sinusoidal conditions and stores data in such a way that it can be consulted by means of a network of local area by the TCP/IP protocol. Further, the instrumentation used is low cost and the software was designed using Linux embedded operating system in C# .NET language. The measurements gathered by the system were compared with a power quality analyzer (model Fluke 43B); the maximum margin of error was 0.15% in voltage, current and power. This application shows that a system of this kind could be applied based on electronic economic components without loss of accuracy. It can be beneficial in places where high energy consumptions are reported and where the resources to install complex equipment exist.
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