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A Survey of Devices for Analyzing Electricity Consumption

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Abstract

In this paper, a review of the devices used in collecting, measuring, analyzing and monitoring electric power consumption are presented. These devices are an integral part of embedded systems. The relevant concepts related to challenges in the energy sector are presented, and one method of identifying solution to these challenges is by using a reliable power meter for collecting and monitoring electricity consumption. To obtain recommended devices for data collection and monitoring of electricity consumption, an extensive review of relevant power meters used for data collection is conducted. The information compiled focuses on some of the characteristics of these meters. In carrying out a comprehensive study of these devices, the qualities and benefits of these devices (ease of operation and installation, ability to monitor appliance usage in the building all day, and the ability to reset during power outages) are clearly identified.

Keywords

Measurement, embedded systems, power meter, monitoring, installation, power outages.

1. INTRODUCTION

In determining the recommended technique for data collection and monitoring of electricity consumption, an extensive review of relevant power meters used for data collection was conducted. The information compiled focuses on some of the characteristics of these meters (“Home Of Energy”, 2018). There are two main types of devices used for monitoring household electricity consumption; the first focuses on monitoring a building’s electricity consumption, and the second allows monitoring at the individual appliance level. This study utilized both measurement techniques in collecting electricity consumption for modelling. Many devices have been developed for measuring whole building electricity consumption. Most of these devices use an inductive sensor design placed in the main power supply of the building through the electricity company supplied meter.

A simulation to model the electricity consumption of electric vehicles was discussed by Monigatti and Apperley (2012). The research utilized the distributed battery capacities of electric vehicles for storing energy. The paper discussed electricity consumption feedback to consumers of their appliance usage. Ozoh (2016) described the various power meters in use including measuring appliance usage, while determining its impact on total consumption in the building.The study reveals that huge potential for energy efficiency exists in appliance usage, with the collection and monitoring of electricity consumption. The use of appropriate devices for collecting and monitoring electricity consumption is important for planning and management, and as a result for improving efficiency in real world problems (Ozoh et al., 2018).

Electricity is a key energy resource in each country and an important condition for economic development. Ozoh et al. (2018) presented a technique that allows the real-time control of home appliances with the help of internet ready devices (IRD) and embedded systems. The aim of the study is to manage household electricity consumption more efficiently using the automated energy management system (EMS). To investigate the efficiency of the EMS, electric consumption measurements for electric bulbs utilizing EMS were collected and compared with the electric consumption for electric bulbs without using EMS. A study by Lee et al. (2012) showed that electricity consumers recognized and realized that efficiency in consumption is an important attribute in power usage and management, and its also an important differential between electric power distribution and consumption. The research concluded that industrialized countries have found ways of improving efficiency in electricity consumption which varies from the use of sensors; which regulates and control electric usage, to the efficient allocation and scheduling of electric power supply.

The contributions of this paper are summarized as follows:

1) The proposed use of a device for collecting and monitoring electricity consumption in buildings.
2) The use of a low cost and reliable device for energy automation systems in buildings.
3) The application of an embedded system to energy informatics.

2. DESCRIPTION OF ENERGY CONSUMPTION DEVICES

An in-depth study of devices applied in energy informatics is undertaken, with the aim of identifying a reliable device for collecting, measuring, and monitoring electricity consumption in buildings. These devices are discussed in details in the following sections.

2.1. Wattson Energy Monitor

The Wattson energy monitor is a device for measuring electricity consumption and is indicated in Figure 1. It shows how much electricity a building is using in watts, and has a transmitter attached to the consumer's electricity meter ("Wattson Energy", 2018). It displays both numbers and colors to provide feedback to the homeowners about their energy consumption. The device is very reliable. When the lights glow blue, less electricity than normal is being used; when it glows purple, average electricity is being used, and when it's red, more electricity than usual is being used. This device has LED display which can show electricity use in kilowatts or in different types of currency such as euro, or pound. Additionally, this device has a memory that can record up to four weeks of data and this data can show daily, weekly and monthly consumption with software included for connection to the computer for real-time data reading.

Figure 1: Wattson Personal Energy Monitor

2.2. OWL Wireless Electricity Monitor

The OWL Wireless Electricity Monitor is a device for monitoring the whole house electricity consumption and provides real-time information on the amount of electricity being consumed ("OWL Wireless", 2018). The OWL monitor is displayed in Figure 2. The device was designed to help reduce the power usage by showing unnecessary power used. The LCD screen of this device can display a large amount of information for customers, such as date, time, temperature, power consumption, current consumption and greenhouse gas emissions, which can help to reduce power usage. The user of OWL can set up a power usage limit and when the power goes above this limit, the alarm function in this device will alert the user. This device can store up to 30 days data and this data can be uploaded to a computer for analyzing and simulating electricity consumption.

Figure 2: OWL Wireless Electricity Monitor

2.3. Belkin Conserve Insight Device

The appliance to be measured is plugged into this measuring device, in order to record its electricity consumption, which is then connected to the main power outlet of a building ("Belkin Conserve", 2018). The Belkin conserve insight monitor has a LCD, which displays appliance usage measurements for 45 minutes, and after that, displays its average usage measurements. The LCD can display appliance usage in dollars, watts and the carbon dioxide emitted for electricity consumed by appliances in the building. This is indicated in Figure 3.

Figure 3: Belkin Conserve Insight Energy Monitor

2.4. Power Mate Digital Measuring Meter

This device was developed to show the running cost for individual appliances based on the behavior of these appliances ("Power Mate", 2018). The device shows the running cost for the appliance (per hour, per week, per quarter or per year), the greenhouse gas emissions, and the increasing and expected appliance power usage. The device utilizes the EnviR monitor as a measurement component, and can measure individual appliance usage. It consists of a sensor, the EnviR monitor, bridge, modem and the database in the server. The appliance which needs to be measured is plugged into the sensor socket. The sensor sends the power usage every six seconds to the EnviR monitor using the wireless connection between them. This device is shown in Figure 4.

Figure 4: Power Mate Digital Measuring Meter

2.5. Electricity Sensor using Pattern-Recognition

Farinaccio and Zmeureany (1999) dis-aggregated the total electricity consumption in a house into the major end-users through a single electricity sensor using a pattern-recognition approach. The research dis-aggregates the entire house's electricity consumption using an algorithm, which was tested with monitored data. For the measurement stage, the study used a monitor clipped onto the main electric breaker. Measurements were taken for three weeks in three different months. The first week was called the training period because it improved their algorithms by identifying and analyzing electric appliances' characteristics. The main aim of the research was the translation of appliances' signatures into pattern-recognition rules. Hence, the study is based on appliances' signatures.

2.6. Intelligent System of Electrical Appliances in Real-Time Processing

This approach focuses on intelligent system recognizing the activities of electrical appliance usage in real time (Ruzzelli et al., 2010). The objective of the study was to identify individual appliances' consumption to increase energy awareness. This is necessary in order to study behavioral pattern of consumers as it relates to using electricity in an efficient manner to reduce costs. The study analyzed the contribution of load signatures of appliances use. The study created a database that stored the signatures of appliances, where each appliance was assigned before decoding its signature. Afterwards, the system could recognize the appliances that were on by comparing them with data stored in the database. In concluding the research, the study was able to recognize appliance use by identifying their signatures.

2.7. Markovian Reference Model

A method for monitoring and data collection utilizes the stochastic Markovian reference model. It was used for monitoring and measuring household energy consumption for different periods of the day (Ardakanian et al., 2011). The research derived models by first obtaining real measurements of the electric load for household electric appliances. To obtain the load data set, a text-box to measure aggregate loads for 20 homes was built. Measurement nodes were deployed to houses covering a set of factors such as the space area of building, number of occupants and energy consumption patterns of the household (see Figure 5). The measurement node used in the research measured the power consumption (in Watts) of a house. This was measured through a secure network connection to a server. It was assumed that the homes selected for measurement were selected in random.

Figure 5: Markovian Measurement Node (reproduced from Ardakanian et al., 2011)

2.8. Smart Energy Monitor (SEM)

This method uses in-depth qualitative methods to explore the use of smart energy monitor (SEM) in households, and changes in its usage pattern over a 12-month period, and discusses collection of consumption data for households using smart monitors. The monitors are displayed in Figure 6, and consist of the solo, which has a single mono chromatic display that includes a 'speedometer' to indicate instantaneous levels of energy use (expressed in kWh, pounds sterling or carbon dioxide emissions). It includes a 'milometer' which shows the amount of energy used each day, and a 'fuel tank' allows householders to set a daily budget and indicates whether or not this is being met by displaying a tick or a cross symbol. The duet is exactly the same as the solo on its left-hand screen, but contains a right-hand screen that monitors boiler usage and, six 'plug bug' devices that wirelessly transmit data to the duet unit. The trio, which has a full-color display and can monitor heating, hot water use and all electrical circuits in the home. The trio is capable of displaying consumption for household appliances in graphical form over a twenty four-hour or monthly periods. Participants in the research were recruited in various ways including through newspaper and internet advertisements, at energy events and fairs, and through local authorities and housing associations. The follow-up interviews were conducted by telephone. All of the interviews were digitally recorded and transcribed verbatim. Results from this study indicated that electricity users perceive a lack of support from government and proposed the need for introduction of measures to reduce electricity consumption in households. The research also suggested the need for the provision of adequate feedback, through the use of the smart meter, to households in order to control their energy use.

Figure 6: Monitors showing the Solo, the Duet and the Trio (reproduced from Hargreaves et al., 2013)

2.9. PowerLogic Power Meter

The PowerLogic (Figure 7) is a device for measuring individual electricity consumption measurements for appliances in buildings. The PowerLogic power meter offers all the measurement capabilities required to monitor an electrical installation in a single 96 x 96 mm unit extending only 44 mm behind the mounting surface (“PowerLogic”, 2018). With its large display, all three phases and neutral can be monitored simultaneously. The bright, anti-glare display features large characters and powerful back lighting for easy reading even in extreme lighting conditions and viewing angles. The meter menus are understood by all, with the availability of two languages (English/Chinese) included standard in the power meter. Some of the main qualities of the PowerLogic are:

- Ability to measure electricity consumption for individual appliances.
- Easy to install: Mounts using two clips, no tools required. Ultra compact meter.
- Easy to operate: Intuitive navigation with self-guided, language selectable menus, six lines, four concurrent values. Two light-emitting diodes (LEDs) on the meter face help the user confirm normal operation (heartbeat/communications indicator LED: green and other LED orange, customized either for alarms or energy pulse outputs).
- Easy circuit breaker monitoring and control: The PowerLogic provides two relay outputs (high performance) with capability to command most of the circuit breaker coils directly. In addition, monitored switches can be wired directly to the meter without external power supply.
- System status at a glance: Bright, anti-glare, back lit display plus two LEDs; orange for energy pulse or alarm and green for heartbeat/communications indication.
- Accurate energy measurement for cost allocation.
- Power quality analysis: The PowerLogic offers total harmonic distortion (THD) and TDD measurements as standard. Total demand distortion is based on a point of common coupling (PCC), which is a common point that each user receives power from the power source. The TDD compares the contribution of harmonics versus the maximum demand load.
- Load management: Peak demands with time stamping are provided. Predicted demand values can be used in basic load shedding applications.

- Alarming with time stamping: Over 30 alarm conditions, such as under/over conditions, digital input changes, and phase unbalance inform you of events. A time-stamped log maintains a record of the last 40 alarm events.

- Load timer: Load timer set point adjustable to monitor and advise maintenance requirements.

The compact size and high performance of the PowerLogic makes it suitable for many applications. Some of the applications include:

- Panel instrumentation.
- Cost allocation or energy management.
- Electrical installation remote monitoring.
- Alarming with under/over, digital status, control power failure, meter reset, self diagnostic issue.
- Circuit Breaker monitoring and control with relay outputs and whetted digital inputs.

Figure 7: PowerLogic Power Meter

3. COMPARISON OF THE DEVICES

The inherent features of using the devices in buildings are summarized in Table 1. The features discussed in this section are examined to determine their strengths and weaknesses. As a result, challenges in applying these techniques discussed and analyzed.

Table 1. Positive and Negative Attributes of Devices for Electricity Consumption Data Collection and Monitoring

Device	Positive Attributes	Negative Attributes
Wattson Energy Monitor	1) Simple input data. 2) Displays colors. 3) Resembles regular meter. 4) Can store 4 weeks data. 5) Enables real-time processing.	1) Inability to reset during power outages. 2) Does not show graphical display. 3) Does not identify behavioral pattern of users.
OWL Wireless Electricity Monitor	1) Has ability to reduce unnecessary usage of power. 2) Enables real-time processing. 3) Can display such information as date, time, temperature, power consumption, current consumption and greenhouse gas emissions.	1) Inability to reset during power outages. 2) Does not display colors. 3) Does not show graphical display. 4) Does not identify behavioral pattern of users.
Belkin Conserve Insight Device	1) Displays individual appliance usage. 2) Displays carbon emissions. 3) Ease of use.	1) Can not store a large data set. 2) No circuit breaker for monitoring and control.
Power Mate Digital Measuring Meter	1) Shows running cost for appliances. 2) Shows greenhouse gas emissions. 3) Displays expected appliance usage.	1) Does not identify behavioral pattern of users. 2) Can not store a large data set. 3) No circuit breaker for monitoring and control.
Electricity Sensor using Pattern-Recognition	1) Uses a single electricity sensor. 2) Simple input data. 3) Identifies major electricity users.	1) Data collection period not enough. 2) Study based solely on appliances' characteristics. 3) Not easy to install.
Intelligent System in Real-Time Processing	1) Enables real-time processing. 2) Displays individual appliance usage. 3) Identifies behavioral pattern of consumers. 4) Utilizes customer database.	1) Not easy to install. 2) Does not show greenhouse emissions. 3) No explicit description of components of variables.
Markovian Reference Model	1) Utilizes a database. 2) Displays multiple variables as output. 3) Can handle large data set.	1) Its statistically based model. 2) Does not show greenhouse emissions. 3) No circuit breaker for monitoring and control.
Smart Energy Monitor (SEM)	1) Utilizes smart monitors. 2) Discusses trends. 3) Displays consumption in graphics. 4) Displays colors. 5) Identifies consumption limit for appliances.	1) Does not identify major electricity users. 2) Does not show greenhouse emissions. 3) No circuit breaker for monitoring and control.
PowerLogic Power Meter	1) Easy to install. 2) Easy to operate. 3) Ability to measure electricity consumption for individual appliances. 4) Easy circuit breaker monitoring and control. 5) Ability to reset during power outages.	1) Does not display colors. 2) Does not show graphical display.

4. SUMMARY AND CONCLUSION

This study carried out a comprehensive study of devices for collecting, measuring and monitoring appliance usage in buildings. The use of devices for electricity consumption data collection and monitoring in buildings will play an increasingly important role in the efficient usage of appliances in buildings. Thus, research on electronic devices is necessary. This paper discusses in details a comprehensive review of literature on the use of these devices for improving efficiency in electricity consumption. They provide a background about empirical research of improving efficiency in the energy sector.

There is a need to identify a power meter that will be easy to install, use and monitor appliance usage in the building. The devices for collecting electricity consumption measurements were described in this study. Each device has its unique characteristics and benefits. The Wattson energy meter uses an inductive sensor placed in the main power supply of the building. The OWL wireless energy monitor can set up power usage limit such that when power goes above this limit, an alarm function will alert the user. The Power Mate digital measuring meter shows the running cost for individual appliance usage. Some other devices display the carbon dioxide emissions to the environment during appliance usage. Such devices include the Belkin conserve insight, smart energy monitor and the in-home displays power meters. However, PowerLogic power meter was selected in this study to collect, measure and monitor electricity consumption data for individual appliance buildings. Some of the qualities and benefits of PowerLogic power meter over other devices (ease of operation and installation, ability to monitor appliance usage in the building all day, and the ability to reset during power outages) are clearly stated.

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