Measurement 51 (2014) 441–450

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Consumer load measurement in automated buildings

T. Kurczveil *, P. Diekhake, J. Liu, E. Schnieder

Institute for Traffic Safety and Automation Engineering, Technische Universität Braunschweig, Germany

ARTICLE INFO

Article history:
Available online 4 December 2013

Keywords:
Building automation
Energy metering
Decentralized system
Low cost field bus system

ABSTRACT

Diminishing fossil fuel supplies accompanied by rising prices is increasingly leading to consumer awareness regarding their energy consumption. With the intent to prepare for diminishing primary energy sources, sustainable alternatives (e.g. energy gained through wind or solar power and trends towards smart grids) have been introduced and found wide application. With the application of intelligent solutions, the energy consumption in buildings can be reduced significantly. One basis for these solutions, such as load and energy management for optimized energy distribution and saving, is the energy metering of components in electric systems. This contribution shall present a field bus system that, due to its local distribution and system architecture, is suitable for energy consumption measurement of its individual components. After presenting the SmallCAN bus system and its concept, a summary of the mathematic algorithm and an example application will be shown to exemplify the functionality.

1. Introduction

Being responsible for 72% of the United State's total electric energy consumption in 2006 (this number is expected to rise to 75% in 2025) [1], buildings offer great potentials and play a key role in the future development of energy efficient systems. The intelligent networking of electric appliances with building automation and control systems, along with technical building management has shown to bring energy savings of up to 20% [2–4]. These can not only be achieved by intelligent control of actors; the configuration of an automation system can be defined such that inefficient operation states are identified and automatically prevented. The basis of an intelligent load management system on the other hand is to provide information about the power consumption of a building or even individual consumers, which is particular challenge for locally distributed building automation systems: the acquisition of consumption data usually comes with high costs or inadequate measurement uncertainties. This contribution shall present a way of measuring the energy consumption of individual appliances within a building using a single calibrated and verified energy meter and the status information of all consumers collected by an intelligent building automation system. This will allow the determination of the current energy state of an electric system (e.g. building), representing a necessary condition for a local load and energy management. Whereas load monitoring in the context of smart grids is often presented to benefit local energy providers aiming to stabilize the power grid or to determine demand response [5], the determined energy state of a building can also benefit customers with the knowledge of the energy consumed by individual electric appliances.

Using the building automation system SmallCAN, a solution shall be presented to measure and monitor individual loads of interconnected electric appliances in a building.

2. State of the art

The topic of distributed load and energy measurement has occupied many research groups in the recent years.

* Corresponding author. Tel.: +49 5313917684.
E-mail addresses: kurczveil@iva.ing.tu-bs.de (T. Kurczveil), diekhake@iva.ing.tu-bs.de (P. Diekhake), liu@iva.ing.tu-bs.de (J. Liu), schnieder@iva.ing.tu-bs.de (E. Schnieder).

0263-2241/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.measurement.2013.11.052

Especially with the advent of smart grids, the trend increasingly grows towards a fully observed and monitored electric power grid.

Whereas the initial idea of making power intake of a phase available aimed to benefit energy providers who could actively communicate operation requests with buildings and their appliances [6], this information was soon found to be of additional use for not only energy providers but also customers. Among many others, Bergman et al. suggest that the information about the consumption of individual appliances could be used for user recommendations [7]. These recommendations do not only include the prevention of energy inefficient operation states, but also the identification of aging appliances, accompanied by higher energy intake.

The difficulty of this lies in the decomposition of the measured energy intake of all consumers to determine energy and power ratings for individual appliances with minimum overhead. One approach that has greatly evolved in this area is Non-Intrusive Load Monitoring [8–14]. The trend of consumed power is analyzed by means of signal processing. Methods such as genetic algorithms and frequency analysis can be used to detect changes and find patterns in the power intake, to calibrate consumer models in a learning phase, and to correlate the power intake to the characteristics of different electric appliances. While sophisticated publications go as far as identifying the viewed program from a television's energy consumption [15], the underlying algorithms require an increasing amount of computational power.

On the other hand, the optimal operation of appliances requires a change in user behavior, which is hard to achieve permanently. Works such as [16] show that with the distribution of information on how to reduce energy consumption alone is insufficient, since people tend to fall back into old habits that mostly conflict the goal of permanent reduced energy consumption [17]. Automation systems can assist building operators to reduce energy consumption permanently in buildings. Based on [18], more details and further developments shall be presented of the SmallCAN system, required components, and algorithms that allow the complete disaggregation of required power for all connected appliances, while eliminating the need for high computing powers.

3. Field bus system SmallCAN

With the goal of providing an optimized automation system applicable for households and buildings, the development of the SmallCAN bus system [4] was initiated at the Institute for Traffic Safety and Automation Engineering of the Technical University Braunschweig in 2003. The optimization and design of SmallCAN include the administration of up to 1000 participants (all connected by means of an identical and universal bus coupler) and an extent of the bus line of up to 1000 m [19]. One major goal of SmallCAN is a complete decentralization and thus the elimination of unnecessary or, as in many cases, even redundant wiring and costs for the design of a central unit. The pursuit of this decentralization means that each participating actor and sensor is equipped with its own (integrated) transceiver. For this purpose a low-cost, energy-saving, universally applicable, and uniform SmallCAN bus coupler has been developed. With this approach, isolated solutions can be avoided and each device can be adjusted and optimized for the prevailing situation. In addition to the universal expandability and clear arrangement, the decentralized structure has the advantage of detecting the operating state (on/off) of all individual devices in the corresponding building, e.g. consumers. Thus, SmallCAN represents a comprehensive system that next to interconnecting and operating electric appliances based on measurements and predefined functions, can act as a distributed sensor system, allowing for the load measurement of individual electric appliances.

3.1. Software

The software of each bus coupler consists of the following modular components:

1. Operating system.
2. Special function.
3. Freely located special function.

The operating system (OS) of the bus coupler contains all the necessary routines for bus communication, scheduling, and function execution. Special functions (SFs) control and monitor the hardware that is located on the application adapter. SFs represent the actual function of the bus node and/or application module. Freely located special functions (FSFs) are independent from the presiding hardware and perform further processing of data that is sent onto the bus. As hardware independent functions, FSFs can be outsourced locally onto any bus coupler with sufficient capacity for any required calculations that cannot be performed by a single FSF or an SF presiding at its respective hardware/appliance.

SmallCAN systems that are equipped with an optional compact PC can be connected to a client PC via conventional LAN or Wi-Fi and set up by the SmallCAN Tool. It was developed along with SmallCAN to allow for easy configuration, parameterization, visualization, programming, network management, and application management of any SmallCAN system. The configuration is performed by writing the sender and receiver addresses of bus messages into in the EEPROM memory of the respective bus couplers, by entering all relevant message IDs in a receiving and sending list of bus couplers.

3.2. Hardware

For the application on the hardware side, application modules are used, acting as a gateway between appliances and the communication bus. In combination with the bus coupler, any electric component can become a compatible participant on a SmallCAN bus system. The power consumption of a bus node, including application module and bus coupler, is strategically limited to 80 mW [4]. This way, participating application modules can be supplied with energy over the bus cable. Even with a high number