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Development of a user-friendly, low-cost home energy monitoring and recording system

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ABSTRACT

This paper reports research undertaken to develop a user-friendly home energy monitoring system which is capable of collecting, processing and displaying detailed usage data. The system allows users to monitor power usage and switch their electronic appliances remotely, using any web enabled device, including computers, phones and tablets. The system aims to raise awareness of consumer energy use by gathering data about usage habits, and displaying this information to support consumers when selecting energy tariffs or new appliances.

To achieve these aims, bespoke electrical hardware, or '*nodes*', have been designed and built to monitor power usage, switch devices on and off, and communicate via a Wi-Fi connection, with bespoke software, the '*server*'. The *server* hosts a webpage which allows users to see a real-time overview of how power is being used in the home as well as allowing scheduled tasks and triggered tasks (which respond to events) to be programmed. The *system* takes advantage of well standardised networking specifications, such as Wi-Fi and TCP, allowing access from within the home, or remotely through the internet. The *server* runs under Debian Linux on a Raspberry Pi computer and is written in Python, HTML and JavaScript. The *server* includes advanced functionality, such as *device* recognition which allows users to individually monitor several devices that share a single *node*. The openPicus Flyport is used to provide Wi-Fi connectivity and programmable logic control to *nodes*. The Flyport is programmed with code compiled from C.

1. Introduction

The management of electrical energy supply to meet the growing demand without contributing more to the green-house gas problem is a major task. To reduce green-house gases, more and more renewable sources of electrical energy are being added to networks. However, these new sources of supplies can be intermittent and variable. For example, analysis of the variability of wind power and how it could be integrated into electrical markets is detailed in Ref. [1]. This report discusses the main issues in terms of grid management and technological options required to address the variability of wind and other renewable sources and highlight the importance of developing technical solutions concomitant to the growth of intermittent renewables to ensure electricity system stability. Bass et al. [2], using measured data from a gas turbine power generation plant in the UK, have shown how intermittent and variable sources of energy could impact on traditional power generation. Future management of electricity supply networks thus requires energy storage systems, variable tariff systems and cooperation from electricity consumers to limit low-priority power usage in times of high demand on the grid. In this context smart grid technologies are likely to play a major role. An electricity system, that is efficient, reliable, resilient and responsive, is a smarter grid [3]. Such a system would include an advanced metering system with the ability to use electricity more efficiently [3]. Electricity smart grids can be part of an overall smart energy system that include flexible generation systems and fluctuating renewable sources [4]. Home energy management is an important part of the solution to reduce greenhouse gases and incorporation of renewable sources of energy. For the success of the smart grid, home energy management and modelling systems with data recording facilities are also required. A number of recent studies have considered systems, software and hardware for home energy management. In the context of smart grids, a DA-RTP (day-ahead real time pricing)

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model based on smart meter data has been discussed in Ref. [5] and the study shows that a flatter demand curve and lower losses can be achieved by using such a system. The study by Almos et al. [6] provides an analysis to illustrate the change of domestic load based on smart meter energy actions and the engagement of consumers is discussed in Ref. [6]. The development of an energy management system that incorporates consumer owned smart meters and distributor owned smart meters is described in Ref. [7] where applicable hardware and control systems have been demonstrated in a smart grid context. An approach that could be used to automatically analyse smart meter data to identify consumer characteristics has been presented in Ref. [8] where house hold characteristics could be used by suppliers to target energy efficiency campaigns. Depuru et al. [9] have discussed in detail various features and technologies that can be integrated with a smart meters with the emphasis on security issues required in smart meter communication networks. Vega et al. [10] have reviewed the most relevant literature and summarised infrastructure, communication media – protocols and variables managed by a system. Their study also analysed a large range of energy management models associated hardware and software and emphasised the need to incorporate monitoring, control and supervision of home appliances as well as the need to incorporate communication protocols to ensure the reliability of real time information collection through modern sampling tools and advanced algorithms. In other studies published in the literature, smart meter techniques have been discussed in details. For example, various features and technologies that can be integrated with a smart meters has been discussed by Depuru et al. [9]. Vessileva et al. [11] have discussed the need the need for providing energy consumers with required information about their energy usage and studied the consumer categories and how it could be used to develop effective demand response measures. Further relevant studies include the work of Beckel [8], Pereira et al. [7] and Zhao et al. [12]. At a higher level (supplier or distributer), the smart grid concepts appear be a good solution for integrating variable and distributed energy sources. An overview of the emerging smart grid and the potential for the smart grid to act as an enabling technology for renewable energy integration, price-responsive electricity demand, electrified transportation and distributed energy production is discussed in Ref. [13]. User mode distributed energy management via smart grids [14] and potential use of ICT (information and communication technologies) with regards to smart grids are discussed in Ref. [15]. At a domestic and consumer level smart meters have emerged as the technological solution providing necessary data for the incorporation of renewable energy systems, monitoring and control of metering technologies and demand management (Batista [16]). Availability of reliable, low cost flexible hardware and software solutions capable of metering, data collection, data analysis, storing and transmission are required for the success of the smart grid. Kim et al. [17] have discussed the overall structure of a smart grid and the role of UPnP (Universal Plug and Play) devices for HEMS (Home Energy Management Systems). Most other studies relevant to the present study have used IEEE 801.15.4 and ZigBee technologies for device control and energy management (Han and Lim [18], Batista et al. [16]). Jang and Healy [19] in their studies have discussed in detail the challenges and obstacles in the implementation of wireless sensor networks in buildings. The main challenges are building structure, reliability degradation, security, battery life time, initial cost and ease of use. Some energy management systems have explored the use of PLC (Power Line Communication) technologies for data collection and recording in home energy management. These include the work of Han et al. [20], Papagiannis et al. [21], Al-Mulla and ElSherbini [22]. Further details are available in the review of powerline technologies for smart grid applications by Yigit et al. [23].

At consumer level various forms of smart meters have been introduced by electricity suppliers to inform customers of their energy usage profiles and these have enabled the suppliers to obtain useful demand profiles. However some smart meters do not provide a breakdown of which appliances contribute to the overall demand profile. This has been a problem and smart meters are already termed to be 'not so smart meters' [24]. There is great interest in developing useful, secure, low-cost technologies to monitor and record domestic energy usage and allow users to have more control over their energy usage. Perhaps in the future such systems may even be able to automatically switch energy provider on their owners behalf, depending on which companies offer the cheapest, greenest energy. The technology could also be used to deliver targeted advertising to users supported by savings estimates based on the real usage data that the system collects.

None of the existing 'smart meter' solutions offered by energy suppliers to private homes in the UK are able to control devices around the home. Input into the National Grid in the UK is almost entirely comprised of plants which are unable to quickly change their rate of supply, (for example, gas, coal, nuclear) or worse, have an unreliable rate of supply e.g. wind. Since mass produced electricity is not easily stored, the grid must attempt to balance supply with demand by forecasting demand. Demand trends typically follow the day/night, weekday/weekend and summer/winter cycles, but are also affected by social events, such as breaks during soap operas and sport events. If the grid could temporarily enable and disable high-power, non-time critical devices around the home, such as water heaters and air conditioners then they would be more effectively able to balance supply with demand, whilst avoiding resorting to inefficient energy storage or 'brown-outs'.

Appliance monitoring and control systems have the potential to reduce costs, energy consumption and carbon emissions [25]. They can achieve this by providing sophisticated control functionality, and by collecting useful data that can be used to inform appliance purchase decisions and select more economical energy providers. Energy providers can use the data to provide low cost tariffs and in an ideally open market-place for electricity-supply, users should be allowed to switch suppliers at a short-notice to take advantage of low cost tariffs and change their usage profile to minimise their energy costs.

As mentioned above most currently available 'smart meters' are able to collect data but consumers could not identify elements of their energy usage or analyse data to make useful interventions to change their behaviour. In many cases smart meters show a cost at a particular time but do not provide information on which appliances are responsible for the cost or collect item specific data and present them in a useful manner to understand their energy profiles. There is a requirement to develop low-cost smart meters which can collect detailed data, communicate with simple devices such as mobile phones, tablets and computers at home and consumers should be able to see energy usage, broken down by appliances and time of use so that they can make changes in their behaviour to use energy more efficiently or buy new and energy efficient appliances to save energy on long-term. This project aims to develop a low cost secure hardware and software solution, making as much use of existing hardware as possible, which can be used to monitor and control mains electrical *device*s, at the same time collecting information about the way energy is used in the home. The information collected aims to be of sufficient quality to help users make informed decisions about potential appliance purchases and energy tariffs based on the user's actual usage habits.