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Overview of non-intrusive load monitoring and identification techniques

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Abstract: Load monitoring and identification is a method of determining electrical energy consumption and operation condition of individual appliances based on the analysis of composite load measured from the main power meter in a building. They can supply information such as type of load, electricity consumption detail and the running conditions of the appliances to both the consumer and the utility. The information can be used to formulate load plan strategies for optimal energy utilization. Load monitoring techniques can generally be grouped into intrusive and non-intrusive load monitoring. Intrusive load monitoring provides accurate results and would allow each individual appliance's energy consumption to be communicated to a central hub. However, this method is costly because of the number of equipment to be manufactured and installed. This has prompted the introduction of non-intrusive load monitoring system. Non-intrusive load monitoring is cost effective and convenient means of load monitoring since it requires lower equipment due to fewer components to install and smaller space requirements. This paper is concerned with the overview of different load identification and monitoring techniques for energy management focusing on non-intrusive load monitoring.

Keywords: Energy management, intrusive load monitoring, load identification, non-intrusive load monitoring.

1. INTRODUCTION

Intrusive load monitoring technique monitor appliances based on supervisory control and data acquisition (SCADA). To adequately monitor appliances, sensors are installed at each appliance to be monitored, and once the appliance recorder receives a sensor message, it immediately records the load data and delivers them to the data centre for further analyses. The intrusive load monitoring system is comprehensive, systematic, and convenient method of monitoring load. However, the cost of installation and maintenance of measuring devices such as meters or sensors may be a too expensive. In addition, the intrusive load monitoring technique is too complicated to implement in an ordinary household without a two-way communication device such as smart meter. Also, customer acceptance is another issue that could hinder the effective implementation of feedback programs, since some customers will not allow the intrusion in their privacy (Du *et al.*, 2010). Future load-monitoring systems should be based on the strategies for minimizing the number of monitoring devices and cost effectiveness of the monitoring systems. This has led to the introduction of non-intrusive load monitoring system (NILM) (Zoha *et al.*, 2012), (Du *et al.*, 2010), (Ehrhardt-Martinez, *et al,* 2010). Non-intrusive load monitoring techniques make use of a single recording meter that is installed at the electrical service entrance from where the whole household energy consumption and time of use of each appliance are monitored. Besides, NILM is low cost (in terms implementation and maintenance), it does not require an intrusion into the customer's premises when monitoring energy consumption of different appliances (Zoha *et al.*, 2012). In this paper, different load identification and monitoring techniques for energy management are reviewed and analysed focusing on non-intrusive load monitoring.

2. OVERVIEW OF LOAD MONITORING TECHNIQUES

2.1 Intrusive Load Monitoring (ILM)

The Intrusive load monitoring system is a common metering system that measures the energy consumption of an appliance by connecting power meters to each appliance in the household. Therefore, it requires entering the house, thus the system is referred to as intrusive. It provides accurate results, however, imposing high costs and a complex installation which usually requires wiring and data storage units for the house households concerned. Intrusive load monitoring techniques can be direct or indirect monitoring techniques (Yoshimoto, 2000), (Zeifman, and Roth, 2011). Direct monitoring techniques which are also known as physical intrusive signatures measure the electrical characteristics of each appliance's power demand (Marceau, and Zmeureanu, 2000), (Breed, and Delport, 2001). The physical intrusive signatures can be generated by a small device attached to the power cord of an appliance for measuring the energy consumption by the appliances. Whenever the appliance is switched on, the device sends signal to the data collector indicating the operating state of the appliances. The power drawn by the appliance can be calculated by measuring the electromagnetic field generated by the flow of current through the wire. This technique provides accurate measurement, but it is not cost effective (Zeifman, and Roth,

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2011). On the other hand, indirect intrusive load monitoring (IILM) techniques measure non-electrical characteristics, from which each appliance's power demand is inferred. There are three forms of indirect intrusive load monitoring technique: appliance tagging, ambient sensors and conditional demand analysis. Appliance tagging is the modification of smart appliance such that a tag displays a unique signal when the appliance turns on or off.

2.2 Non- intrusive Load Monitoring (NILM)

Non-intrusive load monitoring is a convenient means of determining the energy consumption and the state of operation of individual appliances based on analysis of the aggregate load measured by the main power meter in a building. NILM is a process of analysing changes in the voltage and current going into a building and deducing what appliances are used in the building as well as their individual energy consumption. It is called non-intrusive because it does not require intruding into the house or consumer premises when measuring the power consumption of different appliances. Smart meters with NILM technology are used by utility companies to survey the specific uses of electric power in different homes. NILM is considered a low cost alternative to intrusive monitoring techniques. The idea of analysing the power flow to determine household appliances and report on their operating condition started when George W. Hart was collecting and analysing load data as part of a residential photo-voltaic system studied (Ehrhardt-Martinez, 2010). The basic monitoring principle is to recognize a step change in active and reactive power in the total load produced by altering the operating state of the different customer's appliances. Recently, Électricité de France (EDF) developed a new approach which consists of Hidden Markov Model (HMM) in an attempt to recognize the logical and chronological switch-on and off of different appliances. An HMM consists of states and transitions between appliances switched on and off (Phial, 1998). Monitoring of individual utility customers for the purpose of energy audit is an important application of NILM system. A NILM can be installed temporarily at the customer's request in order to analyse the characteristic of the appliances which can be used in suggesting ways of reducing consumption and costs. A second audit is often valuable to confirm the savings resulting from conservation measures. Another application of NILM is a power monitoring for appliance failure analysis or security purposes. Faulty appliances can be detected by their unusual power consumption or duty cycles. For instance, irregularity in power consumption of refrigerator which was ON almost all of the time can easily be detected and replaced. In terms of security, a vacation home which is unoccupied for a long period of time can be monitored at a single point. The monitor could be programmed to automatically generate and report appliances usage above or below the specified thresholds and send notification to the owner automatically via phone message. Furthermore, application of NILM involves the verification of demand side management control. Many electric utilities install appliance controller on deferrable load throughout their customer base to shed them during the period of peak power usage. NILM can verify that the system is in operation and has not been overcome by radio or customer inference. Apart from the aforementioned applications, NILM system applications include load forecasting and rate forecasting (Ehrhardt-Martinez, 2010).

The main idea behind the NILM system is to determine the energy consumption of individual appliances in a building based on the analysis of the aggregated data measured from a single meter outside the building (Zoha *et al.*, 2012). The total aggregated measurement of the household energy consumption of the individual appliance from the main meter can be estimated according to equation (1) (Zoha et al., 2012), (Wang and Zheng, 2012):

$$p_t = \sum_{i=1}^{n} p_i(t) + e_t \qquad (1)$$

where;

p_t is the aggregated household energy consumption, $p_i(t)$ is the individual appliance energy consumption of at a given period of time and e_t is the measurement errors and line loss. Electrical appliances display a specific or unique characteristic during the normal working cycle. This characteristic is known as appliances signatures, which may contain information about values of electrical parameters during steady-state or transient states. This information enables proper monitoring and identification of a specific appliance from the aggregated household energy consumption measurement. The power signal from active appliances aggregate on the main meter is shown in Figure 1. Domestic appliances can be classified into the following categories based on the operational state or working principal of the appliances: two-state appliances, multi-state appliances; continuously-varying power appliances; permanent consumer appliances (Zoha et al., 2012), (Zeifman, and Roth, 2011), (Baranski, and Voss, 2003), (Norford, and Leeb, 1996), single measurement (Zeifman, and Roth, 2011).

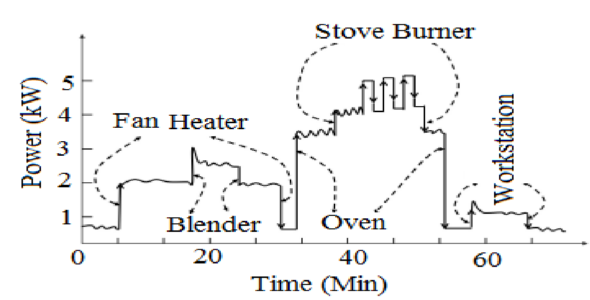

Fig.1: Power vs time plot of the total appliance data from

Two-state appliances are those appliances that have only two states of operations either ON or OFF at a given point in time. Examples of such appliances are table lamp, light bulb, toaster and water pump. Multi-state appliances are the appliances that have more than two operating states. For instance, the appliances with on, off and standby modes are multi-state appliances. They are also known as a Finite State Machine (FSM). Examples of appliances include washing machine, stove burner and dishwasher. Continuously-varying power appliances are the appliances that do not consume a