Exploration on Load Signatures

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Abstract

Knowledge of electric load signatures is the foundation of practical technologies for load monitoring, which involves the identification of an electric appliance and the determination of its operating state. Such knowledge can provide benefits to utilities, customers, appliance manufacturers and other stakeholders. Many approaches can help to understand the load characteristics of electrical appliances and equipment. This research focuses on the two core components of these approaches: (1) methods to measure and represent load characteristics, and (2) the development of signal processing techniques and estimation algorithms for signal filtering, signal disaggregation and load recognition. This paper presents the methodology and observations of the load signatures in their operation modes. The current and voltage of typical appliances are measured, and characteristics of the waveform signatures so obtained are analyzed. By studying the collected data, it is planned to develop an algorithm that can provide a basis of a taxonomy of electrical loads and an archive for stakeholders' reference.

Keywords: Load signatures, load monitoring, signal processing, customer interface, load management

1 PREAMBLE

Recently developed technologies promise to strengthen the link between utility companies and their customers by providing a better understanding of the usage and consumption of electric power [1]. Smart meters can analyze electrical load signatures (either passively or using probe signals) to monitor usage and relay this information to the utility. Future appliances and equipment may be smart enough to communicate with the meter, describe their power needs (quantity, quality, etc.) and negotiate tariffs automatically. We believe that knowledge of electric load signatures is the foundation of practical technologies for load monitoring, and that such knowledge can provide benefits to utilities, customers, regulators, appliance manufacturers and other stakeholders. A utility can improve planning and operations and develop new products and services, such as enhanced building audits and operation and other energy services. Customers benefit from reduced costs and improvements in power quality and reliability. Regulators can produce better policies and rules. Manufacturers of appliances and equipment can improve quality and compliance, while anticipating market demands and providing more effective and efficient products. Everyone benefits from the increased overall efficiencies.

Previously, different application-specific methods have been used to understand different aspects of loads: power quality and efficiency, reactive power compensation, system planning, load shedding, etc. At the core of these approaches is the need to understand the load characteristic – load signatures – of electrical appliances and equipment. This research explores existing and new methods to measure and represent load characteristics, eventually aimed at the creation and use of a library of load signature information – a very useful proposition, given that most load monitoring approaches and appliance design and deployment require *a priori* knowledge of load signature characteristics. Furthermore, this research will develop several signal processing techniques – for disaggregation of signals ("signal separation") and load recognition; systems involved in electrical load monitoring rely heavily on these types of signal processing algorithms.

Many approaches may be useful to understanding load signatures, including (a) non-intrusive load monitoring (NILM) [2 – 15]; (b) echo-resonance load monitoring (ERLM) [16]; (c) sign-up load registration (SULR) [17]. In a NILM system, it is not necessary to install sensors in individual load. A past example of NILM system (MIT 1980s) [2] measured aggregate current and voltage at the metering panels and processed these signals to differentiate and identify individual loads. Approaches involving echo-resonance have wide application in medicine, engineering, security and defense. They rely on injecting a well chosen probe signal and studying on the invoked response of the

medium (load) of interest. A sign-up SULR system requires collaboration among equipment manufacturers, electricity suppliers, and consumers. It allows electrical appliances to handshake and communicate directly with utilities and other stakeholders.

The complex electrical loads of today (and tomorrow) have signatures that vary with time, depending on their state and mode of use. Common appliances have increasingly non-linear load characteristics. Nonetheless, regardless of approach, signatures formulated by actual operation of the appliance in the system are fundamental for application development. An archive of appliance operation signatures shall provide invaluable operation history and stability analysis for all types of buildings.

2 OBJECTIVES

In this project, the actual operational currents and voltages of typical appliances are measured, and characteristics of the waveform signatures so obtained are analyzed. Through studying the data collected, it is planned to develop an algorithm that can provide a basis of taxonomy of electrical loads and also an archive for stakeholders' reference.

The main goal of the project is to develop and investigate technology related to electrical load signatures, and it aims at the following objectives:

(a) Apply filtering algorithms to polish possibly noisy measurements of aggregate current, with voltage regulation being taken into account.
(b) Develop signal estimation algorithms for extracting event-related signal components corresponding to individual loads.
(c) Develop an archive, then a multi-feature classifier or load taxonomy for precise classification of diverse type of appliances.

This paper presents the methods for and observations of the load signatures in their operation modes. The study shall extend to cover load characteristics under many conditions, including passive and probe approaches, guided by our desire to eventually use such knowledge and methods to benefit stakeholders and the rest of society.

3 CONCEPTUAL MODELLING

Figure 1 shows the formulation of load signatures from actual operations of an appliance. We consider each appliance to consist of a number of elements (components); the elements can be physical or logical or both. Three sets of signatures are extracted from the appliance: steady state, transient state and operational pattern. The steady state and transient state signatures are depended on each strategic operable and standalone element of the appliance. The operational pattern signature is the continuous changes in its mode of operation compressed along the time axis. It is obtained by integrating and superposing all its operable elements in actual action in the time domain.
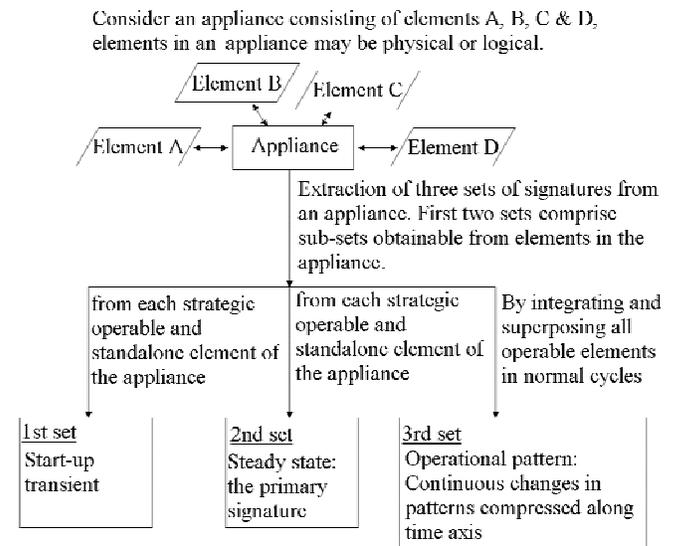
Figure 1. Formulation of signature components

Each signature is further divided into smaller components. Each of the three signatures of an appliance has the components of waveform shapes and patterns. Characteristics of the waveforms – shapes, patterns, magnitudes, power factor, change in power and harmonic contents – are extracted, and then archived along with the signatures.

The concept of using load signatures to identify loads from load monitoring signal is shown in Figure 2. To improve effectiveness of the method, taxonomy of load is to be constructed. The loads are classified according to the characteristics obtained from the measurements. Next, the processed data in the archive are transduced and scaled to uniform sizes, and then structured to form a load signatures database in a block. In a typical load monitoring system, when a new aggregate signal is measured, a signal separation is used to differentiate the aggregate signal into signals of

individual loads. The separated signals of individual loads are then compared with the load signatures retrievable in the database, and the loads are identified.
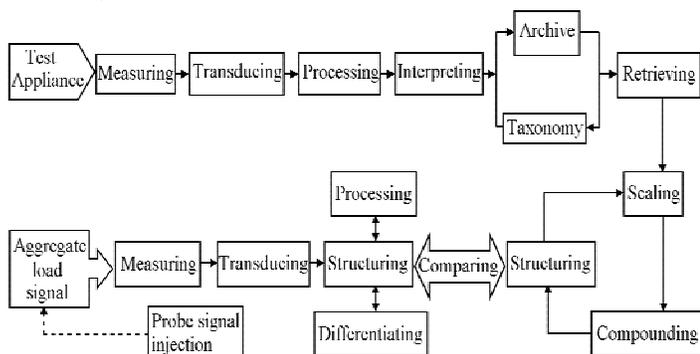
Figure 2 Concept of load signature

In the SULR system, the archive is used for prediction of load magnitudes, characteristics, and patterns. Each sign-up retrieves its operational signatures from the archive and the computer shall then superpose them with signatures of the on-going loads. The predicted patterns shall be useful in regulating system performance as well as energy & tariff management.

4 IMPLEMENTATION

The initial stage of the project consists of three main parts:

1. Measure the current and voltage of a number of appliances. The appliances are measured individually and in a combination of several appliances. The data obtained in the measurement is stored into a computer for further study.
2. Classify the data to obtain electrical loads taxonomy and archive. These are used to build up a database of load signatures for identifying individual loads.
3. Develop a method to differentiate and identify individual loads from the aggregate current and voltage measured at the meter panels.

At the current stage of the project, the experiment is set up for the measurement of appliances. First, the current and voltage of individual appliances are measured to observe their current and voltage waveforms individually, and then several appliances are measured together to observe their combined waveforms. A number of appliances are connected for measurement, some of them may be installed with timers to control their operation time, as shown in Figure 3. The combination plus its variation provide superposition of signals as well as patterns for studying appliance load recognition and their signal separation.
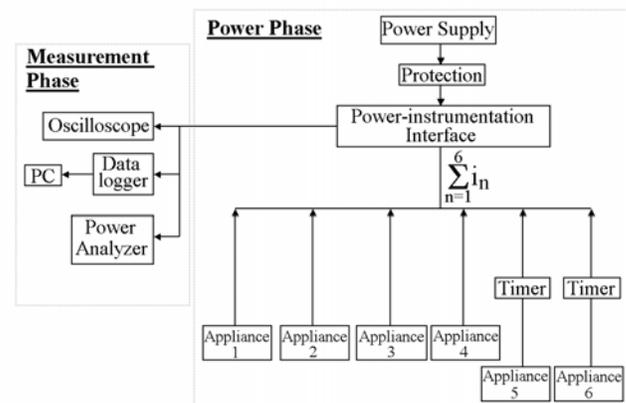
Figure 3. The connection of appliances and equipment

5 OBSERVATIONS

At this stage, a number of appliances are tested; they include

- Light bulb
- Energy-saving light bulb
- Fluorescent lamps with conventional ballast
- Fluorescent lamps with electronic ballast
- Computer and CRT (cathode ray tube) monitor
- Laser printer
- CD player
- Refrigerator
- Hair dryer with an energy-saving switch
- Vacuum cleaner
- Fan

The current and voltage waveforms in their steady states are observed on the oscilloscope. Figure 4 shows some examples of waveform of the tested appliances. From the observation, the voltage waveform, as shown in Figure 4(a), is unchanged for different appliances; the disturbance by the loads is insignificant. However, the current waveforms, Figures 4(b)-(g), are distinctive for different appliances, and represent the load signatures.

The current waveforms of different kinds of lights are shown in Figure 4(b) – (d). The lights are nonlinear appliances: the current waveforms are not purely 50-Hz sinusoidal (like the voltage). The current of the energy-saving light bulb is not conducted continuously; the light bulb is switching on and off at a constant time interval due to the power electronic devices inside the lamp. The energy-saving light bulb is an example of a switching power electronic appliance. The physical appearances of the two kinds of fluorescent lamps are identical, but their electrical characteristics are very different due to their different ballasts. The fluorescent lamps with conventional ballast

have a current waveform that is rich in third harmonic, but the fluorescent lamps with electronic (switching) ballast have a current waveform that contains many more harmonics; it is an example of a time-invariant power electronic appliance.   Whereas all the appliances used for (b) to (d) were lighting fittings, their signatures were observed to be quite different. Thus, load taxonomy classification shall not focus primarily on the purpose of the appliance, but also on its signature characteristics.

Figure 4(e) and (f) show the current waveforms of a laser printer when in stand-by and printing modes.   The printer is another nonlinear appliance. Clearly, the same appliance has different current waveforms in different operation states: when the laser printer changes to printing mode, its current waveform shape changes – a good example of the characteristic operational patterns in the current waveform of some appliances. Figure 4(f) shows a portion of the current waveform when the printer is printing.   The section with smaller amplitude has the same shape and amplitude as the current waveform when the printer is in stand-by.   The section with larger amplitude is the superposition of the small waveform of stand-by mode and a large sinusoidal wave.   In the whole process of printing, the current waveform is continuously switching between the two different shapes mentioned above. The printer is an example of an appliance with several operation states, an appliance with different current waveforms at different operation states. The operational patterns of current waveform form a part of the load signature.

The current of the above appliances operating at the same time are also measured, and the current waveform is shown in Figure 4(g). The combined waveform is the superposition of the waveforms of individual appliances from Figure 4(b) to (e), and some characteristics of individual appliances such as the spikes from the energy-saving light bulb current waveform and the triangular waveform shape of the fluorescent lamps with conventional ballast are still observable in the combined waveform. In the later stage of the project, algorithms for extracting the signals of individual loads will be developed, then the type and the quantity of appliances can be estimated from the aggregate signal obtained from measurement.

6 CONCLUSIONS

The project is currently in its first phase, the current and voltage of individual appliances are measured and the characteristics of the appliances are observed.   More appliances including commercial and industrial appliances will be measured to obtain a full database of load signature and taxonomy. Finally, a load identification method will be developed to identify loads from aggregate signals. When

an appropriate approach is adopted, stakeholders shall benefit through load management.
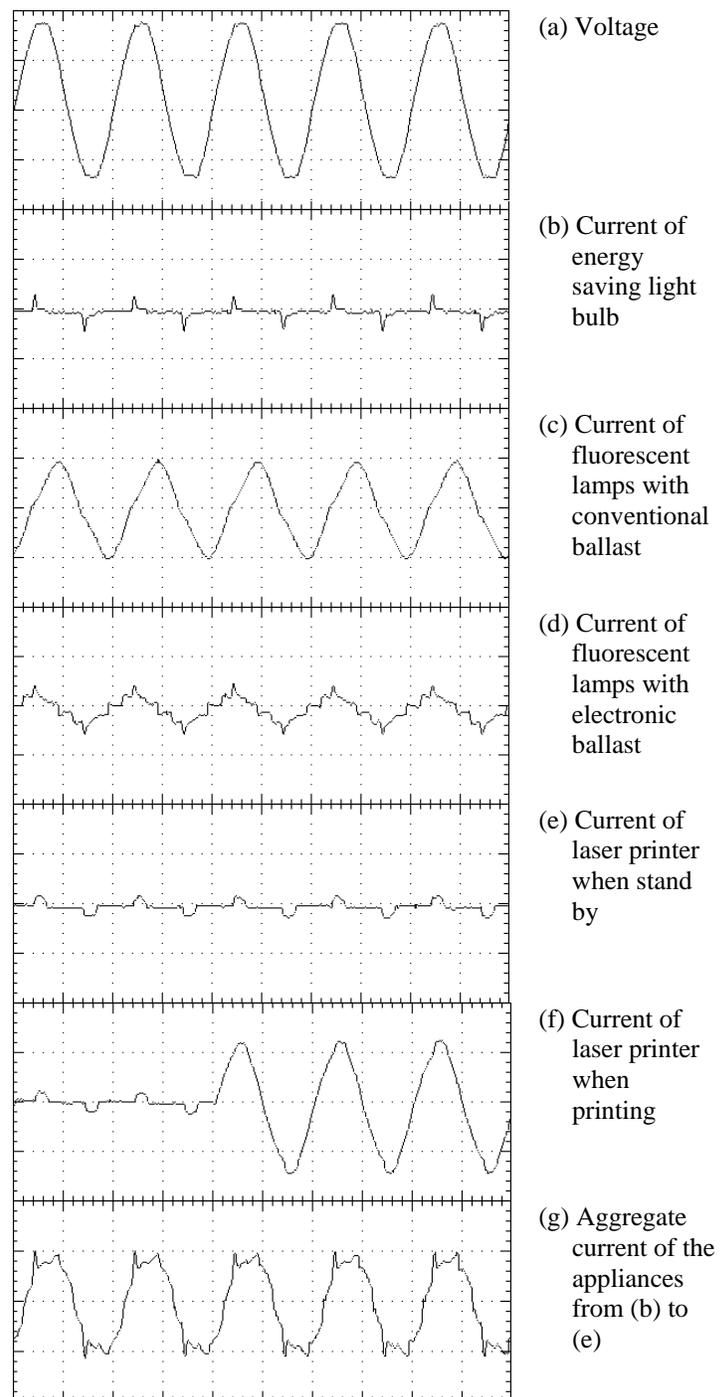
Figure 4. Examples of waveforms of some appliances. (a) Voltage waveform of all appliances, the scale is 200V/Division. (b) – (g) Individual appliance current waveforms and aggregate current waveform, the scale is 2A/Division.

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