A Model-Driven Taxonomy of Appliance Loads: Database Construction, Bi-Level Structures Definition, and Hierarchical Modeling Proposition

Dawei He, Liang Du, Yi Yang, Ronald Harley and Thomas G Habetler

Problem Statements

ELECTRICITY consumption in buildings sector accounts for about 75% of the total electricity generation in U.S. Of the primary electricity used by commercial buildings, about 37% is consumed by miscellaneous electric loads (MELs), and the MELs end-use is anticipated to grow by 78% between 2008 and 2030. MELs are defined as all non-main electrical loads in building, including a variety of electric devices such as refrigerators, computers, cooking devices, and space heaters/fans, etc. The energy consumption of MELs is often overlooked. Several MELs studies have suggested that an effective management of MELs could potentially improve energy savings of buildings up to about 10% to 30% of total MELs usage. However, the development of widely applicable energy saving solutions for MELs is difficult because of their diverse nature. This difficulty is compounded by the limited visibility of MELs' usage conditions in today's buildings. Thus, developing a cost-effective, nonintrusive appliance load monitoring and identification technology is probably one of the most promising solutions.

Database Construction

For every load type, four areas of research have been conducted in order to capture a complete space of the type, including market share study, available internal working types, front-end electronic circuit topologies, and load operating states. One of the main outcomes of the load research is to help construct a database for every load under study. The database describes every load type in five categories: 1) Load Type; 2) Brands (with top five market share); 3) operating characteristics; 4) Front-end Circuit Topologies; and 5) operating states.

So far, a total of 42 load types, and 5 to 7 brands per type, have been selected and studied. To obtain a more generalized load space, several standards including 80 PLUS, Energy Star, CECAER, and IEC 61000-3-2 are also considered when loads were selected The constructed database covers over 90% of electric appliances used in commercial and residential buildings.

The raw voltage and current (V/I) waveforms of all the load models selected have been collected under all the applicable operating states. This includes startup, steady, standby (or other low power states), and particular working states for some loads (e.g., printing states for printers). Each set of V/I waveform are sampled at 30.72 kHz sampling rate for one minute. A total of 627 sets of data have been recorded. A data-preprocessing-engine has been developed in MATLAB environment to process and analyze all the collected data, including V/I waveforms plot, V-I trajectory, FFT analysis, power factor, real power, reactive power, and apparent power calculation. This engine provides a user-friendly interface to access the database, as well as to display the signal analysis results, as shown in Fig. 1.

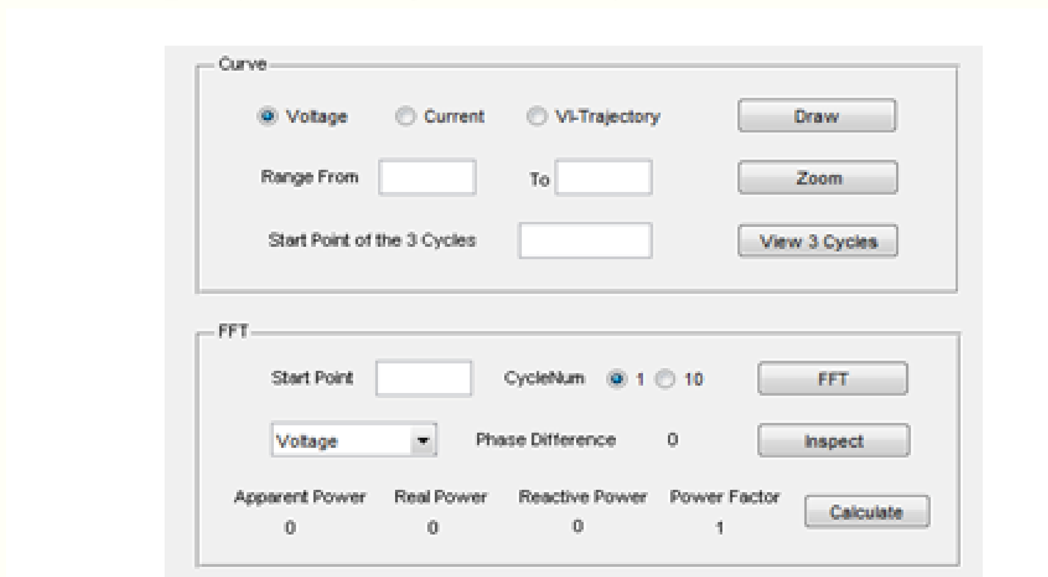

Fig. 1. User interface of loads database for non-intrusive appliance load identification system.

Bi-Level Structure and Hierarchical Load Modeling

Another major or more important outcome of the power supply market study is a purely model-driven taxonomy of typical MELs in buildings. This bi-level structured taxonomy is presented in Table I.

Load Category - Level 1	Load Category - Level 2
R: Resistive Loads	R1: Incandescent lamps (<100W)
	R2: Space heater
	R3: Bread Toaster
	R4: Coffee Machines - Other Kitchen Appliances
X: Reactive Predominant Loads	X1: Fans
	X2: Refrigerator (any with chiller)
	X3: Vending machine
	X4: Shredder
P: E-load w/ PFC	P1: PC (Desktop/Laptop) (>75W)
	P2: Projectors
	P3: Big TVs (LCD/LED) (>75 W)
	P4: Home Theater/Game Consoles (70-80W)
NP: E-load w/o PFC	nP1: PC (Laptop) (<75 W)
	nP2: Charger (any with battery)
	nP3: Other small electronic devices
	nP4: FL/CFL
	nP5: Portable MFD/Printer/Scanner
	nP6: PC Monitors
T: Linear Loads	T1: Small electronics (e.g. stapler)
	T2: AA battery charger
PAC: Phase Angle Controlled Loads	PAC1: Dimmer
	PAC2: Others with Thyristor Controlled Rectifier
M: Complex Structure	M1: Microwave oven
	M2: Printer/Copier/Fax Machine/MFD

The MELs taxonomy shown in Table I provides a guideline to load modeling, feature extraction, and load identification. The concept of a hierarchical load classification and identification system is illustrated in Fig. 2.

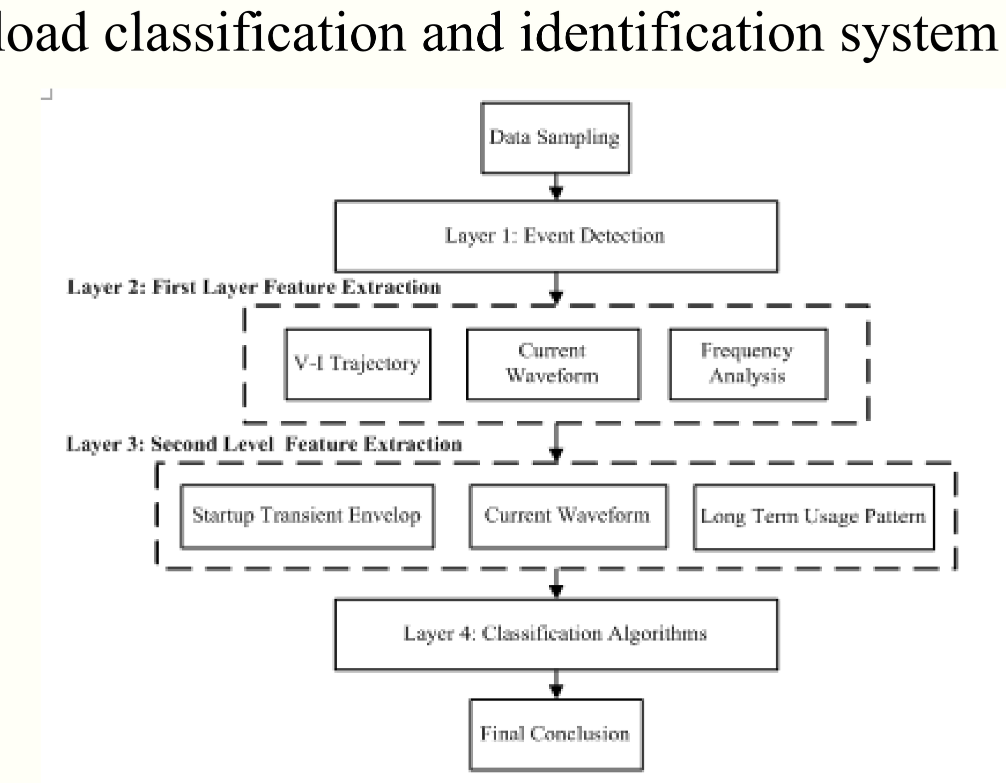

Fig. 2. A hierarchical structure of non-intrusive appliance load identification system.

Potential Application and Advantage

Typically, the dimension of traditional feature spaces in literatures is often on a scale of 10 to 15 to ensure a satisfactory result. There is no guideline to drive an optimized feature selection. However based on this multilevel structure, a new feature space is specified below. It proved to reduce the computing complexity significantly.

Category [n]	$5^{th}/1^{st}$ [%]	High Frequency [0/1]	Phase Angle [º]
1	0	0	0
2	0	0	[45,90]
3	[60,100]	1	[0,10]
4	[0,10]	0	[0,10]
5	[10,60]	0	[45,90]
6	[10,60]	1	0
7	[10,60]	1	x

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