A New Power Signature for Nonintrusive Appliance Load Monitoring

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***Abstract*—Nonintrusive appliance load monitoring (NIALM) method requires only one set of voltage and current sensors to be installed at the electrical service entry for load disaggregation and has attracted considerable research interests. NIALM's identity accuracy is closely related to power signatures (PSs) of loads. The current waveform (CW) is a PS which is frequently used. In order to improve CW's discrimination, this letter uses power theory to decompose CW to active and nonactive current. The experimental results indicate that the similarity between different appliances of the proposed PS is lower, compared with the CW and other PSs, leading to better load disaggregation.**

***Index Terms*—Current waveform (CW), nonintrusive appliance load monitoring (NIALM), power signatures (PSs), power theory, similarity.**

I. Introduction

NONINTRUSIVE appliance load monitoring (NIALM) method can drastically reduce the hardware and maintenance costs because only one set of voltage and current sensors need to be installed at the electrical service entry (ESE). However, the challenge of an NIALM is to accurately analyze data from the ESE and determines the electrical consumption of each appliance. The detection accuracy rate of an NIALM algorithm is closely related to its established power signatures (PSs). Failure to establish a strong and unique PS may lead to unsatisfactory load disaggregation.

Among many existing steady-state PSs, the steady-state current waveform (CW) is regarded as one of the most complete feature because it can reflect detailed characteristics of the appliance [2]. Thus, it is frequently used [1]–[3]. Nevertheless, when different appliances exhibit similar CW, a new steady-state PS is needed, able to magnify the unobservable difference, to discriminate them. Although some researchers use transient features such as transient CWs [2] and transient power spectra [4], the sampling rates required to capture these transient features are usually exceptionally high, leading to high cost.

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This letter proposes to decompose the CW into active and nonactive current based on the power theory developed by Fryze [5]. As demonstrated in this letter, compared with CW, the proposed method can easily discriminate different loads even though their similarity indices of CWs are high. Two experimental case studies demonstrate the validity of the proposed method.

II. Proposed Method

According to [5], ESE current $i(t)$ can be decomposed into active current $i_a(t)$ and nonactive (or useless) current $i_f(t)$

$$i(t) = i_a(t) + i_f(t) \tag{1}$$

$i_a(t)$ is the current, resulted from an orthogonal projection in the direction of the source voltage, and is expressed as (2). It is responsible for the transference of average energy to the load. These definitions are generally valid under periodical condition, and $i_a(t)$ is responsible for the same active power (P) as the CW

$$i_a(t) = \frac{P}{V_{\text{rms}}^2} v(t) \tag{2}$$

where

$$P = \frac{1}{T} \int_0^T \text{IPW} dt \tag{3}$$

$$\text{IPW} = i(t) * v(t) \tag{4}$$

V_{rms} is the root-mean-square voltage of the ESE voltage $v(t)$ and instantaneous power waveform (IPW). The nonactive current $i_f(t)$ is defined to be orthogonal to the source voltage, and is associated to any type of disturbance and oscillation that affect the instantaneous power, but does not transfer average energy to the load.

III. Test Result

To achieve load disaggregation, it is important for an NIALM algorithm to evaluate the likeliness of any two loads. One of the commonly used criteria for evaluating the likeliness of any two loads is based on the similarity index [2]

$$S_{(a,b)} = \frac{\sum_{k=1}^{N} y_{k|a}^2}{\left[\sum_{k=1}^{N} y_{k|a}^2 + \sum_{k=1}^{N} \left(y_{k|a} - y_{k|b}\right)^2\right]}, \tag{5}$$

where a and b corresponds to any two appliance combination in the database, $y_{k|a}$ is the kth measured sample from appliance combination a, and N is the total number of samples.

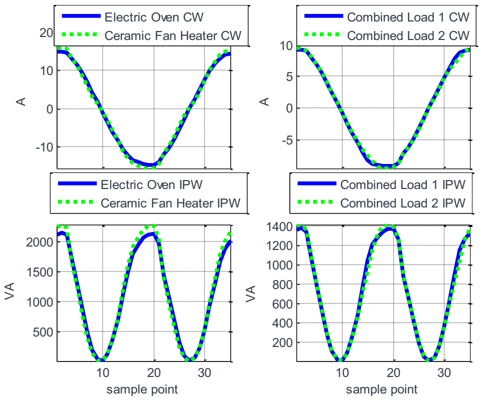

Fig. 1. Comparison of CW and IPW for scenarios 1 and 2.

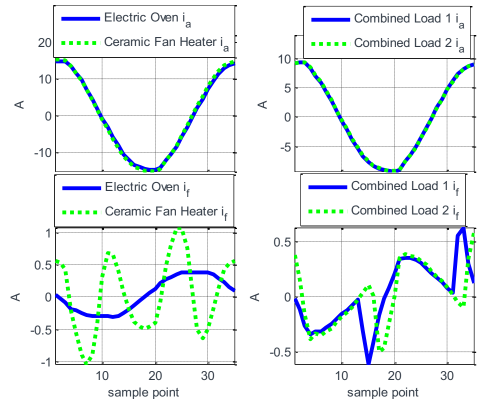

Fig. 2. Comparison of i_a and i_f for scenarios 1 and 2.

Note that depending on the type of the PSs, some of them such as IPW, Har, CW, and the proposed decomposed currents are vectors, whereas some of them such as P and Q are single values. Equation (5) can be evaluated for both types of PS, as done in [2].

Recently, there have been trends in applying NIALM to miscellaneous and electronic loads (MELs) [1], [6]–[7]. This is because they consume about 20% of the primary energy use in buildings and this share is predicted to increase more than 30% in the next 20 years [6]. Thus, being able to distinguish these loads is also of concerns. In this letter, both major loads and MELs are studied to investigate the effectiveness of the proposed method.

A. Electric Oven With Ceramic Fan Heater

In scenario 1, two major loads, an electric oven and a ceramic fan heater having the same rated power of 1.2 kW are studied.

B. Combination Loads

In scenario 2, two combination loads are investigated. The first consists of an electric kettle and a table lamp (fluorescent lamp with electronic ballast). The second involves an electric kettle and a DVD player. The electric kettle's rated power is 750 W. The table lamp's and DVD player's rated powers are 25 W.

Fig. 1 shows the PSs of CWs and IPWs [2] for scenarios 1 and 2. As seen from the figures, CWs and IPWs of the loads in both scenarios are very similar, resulting in poor PSs in terms of discriminating loads.

Fig. 2 shows the proposed decomposed currents, i_a and i_f. The figure indicates that although the active currents i_a also exhibit similar trends for the two loads in both scenarios, the nonactive current i_f is a good PS for discriminating various loads. The proposed current decomposition is able to unmask the subtle difference in nonactive currents between any two loads due to inherent nonlinearity, parasitic reactive elements, and switching circuits.

Table I shows the similarity indices of various PSs. As seen from the table, all the conventional PSs (CW, IPW, Har, P, and Q) yield high values of similarities, leading to poor load identification in both scenarios. On the other hand, proposed nonactive current, resulted from Fryze [5] current decomposition, is able to discriminate the loads effectively in both scenarios.

TABLE I
SIMILARITY OF PSS

Similarity index	CW	IPW	Har	P	Q	i_a	i_f
Scenario1	>0.99	>0.99	>0.99	>0.99	0.88	>0.99	0.18
Scenario2	>0.99	>0.99	>0.99	>0.99	0.95	>0.99	0.52

IV. CONCLUSION

This letter presents new PSs that can reduce the similarity of similar appliances. The experimental results demonstrate the validity of the proposed method. The proposed PSs can potentially aid current NILM algorithms to enhance load identification.

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