Appliance Characterization Based on Spectral Components Analysis

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Abstract—**Appliance detection within the total load can offer the user a better understanding of how the energy is used and can help him find solutions to reduce consumption and costs. The detection can be made based on the specific electrical signature each one has. This paper presents a new algorithm which characterize the appliances by making use of some parameters obtained from the spectral analysis of the electrical current. The obtained electrical signature is characterized by a large number of parameters which help distinguish similar appliances from each other.**

Keywords: electrical signature; nonintrusive load monitoring; appliance detection; spectral analysis

I. INTRODUCTION

The disaggregation of energy consumption into individual appliances represents an important research direction as it can provide solutions that can be used to reduce the energy consumption. Information regarding the consumption of electrical devices helps reducing the energy consumption by providing customized solutions for different locations or situations (householding or maintaining a business): it can be used to identify which appliances (HVAC systems or electronics) could most effectively reduce the consumption of energy[1]. According to some studies, the consumption of energy can be reduced up to 12% by using the appliance feedback [2-3]. The appliance feedback can provide users useful information which could help them identify solutions to reduce the energy consumption [4]: they can detect appliances with the biggest percentage of the total energy consumption, making them think about replacing those appliances with more effective ones, or seize opportunities to shift different activities to off-peak hours when the energy costs are lower. Virtual instruments, which are used in various areas [5-7], can be implemented to provide a more user-friendly interface.

The techniques used to disaggregate the energy consumption into individual appliances can be classified into two categories: intrusive and nonintrusive. The first ones use monitoring devices, connected to each appliance, which send information about the consumption to a central unit, while the second one uses a single monitoring device which, by analyzing different electrical parameters, can detect and monitor the consumption of the appliances connected to the power network. The second technique, also known as nonintrusive load monitoring (NILM), presents the advantage of a simple architecture which doesn’t require high costs. In spite of that, a complex software component is needed. Usually it monitors the voltage and current signals at the entrance point of the electrical network and it extracts different parameters, whose variations can be correlated to the operating status of the appliances connected to the network. These parameters, which can describe the status of and appliance, represent the electrical signature. Depending on when are these parameters detected, there can be three types of signatures distinguished: steady-state signatures [8-13], transient signatures [14-17] or a combination of both [18-20].

Over the years different parameters were used by the researchers to characterize an appliance’s electrical signature. The most common analyzed parameters are the active and reactive powers that underlie the NILM technique. Their step changes were first used by G.W. Hart to observe what was happening in a house in terms of appliance using [21]. Using finite state machines an appliance could be characterized through its whole operating cycle. Besides the step changes, the transient profiles of the two powers generated when an appliance is switched from one state to another, were also used for detection [17]. The transient profiles were characterized by a series of parameters, such as duration, number of transitions and total power change.

The non linear loads draw currents of harmonics frequencies, whose values can also be used to characterize the electrical signature [13],[22-23]. The harmonic content can also be used to detect and extract those consumers with a variable consumption from the total load. It was found that certain correspondences can be obtained between fundamental and different harmonic components [24-25].

Most of the modern electronics use switched mode power supplies to achieve a higher efficiency. This however comes with a cost which is the high frequency electromagnetic interferences generated by these power supplies. A group of researchers exploited this issue and used these interferences (noises) to detect the presence of an appliance [14],[16]. The method consisted in performing a spectral analysis on the detected noises and comparing the results with the ones recorded in a database in order to identify an appliance. These signals can be analyzed using different techniques such as wavelet or Wigner functions [26-27].

A different approach of detecting the operating status of an appliance consisted in using different types of sensors. For example, in [28], electromagnetic field sensors were used to detect the operating status of the appliances, by sensing the electric and magnetic fields generated by those appliances. This information, correlated with the total power consumption can help a NILM system to improve the detection process. In [29], a combination of magnetic, light and acoustic sensors was used to detect the electrical consumers. The magnetic sensor, placed near the power cord, was used to monitor the current which would be further used to determine the power consumption, while the acoustic and light sensors were used to detect the internal power state of the appliances.

In this paper we present an algorithm which characterizes the appliance's electrical signatures based on a steady-state analysis of the current's harmonics and phases. The algorithm detects the events generated by the appliances switching from one state to another. When the steady-state occurs, it extracts a segment of the electrical current signal. This segment is subtracted from the segment characteristic to the previous steady-state and the resulting signal is the subject of a spectral analysis in order to determine the parameters of interest.

II. ALGORITHM DESCRIPTION

The algorithm uses the voltage and current signals to continuously monitor the active and reactive powers which will be used to detect events that can be assigned to an appliance switching from one state to another. The detection of an event occurs when the active power's variation exceeds a certain threshold. When this happens, the algorithm will extract the voltage and current waveforms of the appliance that determined the event, by subtracting the waveforms acquiered before and after the event. The resulted data segment (current waveform) will be further processed in order to compute the electrical signature's parameters.

Since the electrical signature is consisted of current's harmonics and phases, which depend on the shape and phase of the acquired segment, it is therefore essential to bring the data segment to a predefined state. This is achieved by subtracting a sub-segment whose phase is as close as possible to a predefined value. The procedure by which the sub-segment is extracted is performed in two stages which are presented below.

In the first stage, the phase resolution $d\phi$ is determined, depending on the current's frequency and the sampling frequency. This parameter indicate us how many degrees correspond to the interval between two successive samples. Knowing the signal's frequency f_s and the sampling frequency f_e, the number of samples N_{per} corresponding to a period of the signal is:

$$N_{per} = \frac{f_e}{f_s}. \quad (1)$$

Since a period has 360°, the phase resolution is given by:

$$d\phi = \frac{360}{N_{per}}. \quad (2)$$

Knowing the phase resolution and the initial phase of the data segment, the number of samples after which the signal's phase is in the vicinity of the imposed value is estimated. begining with this estimation the algorithm passes on to the second stage, which aims to improve the accuracy of estimating the imposed phase. The algorithm determines the phases of a sub-segment estimated in the first stage (ϕ_e) and for other two sub-segments obtained by adding (ϕ_{e+1}) respectively extracting (ϕ_{e-1}) one sample. The phase estimation is achieved by using the DFT algorithm based on variable frequency resolution, concept presented in [30-31]. After that, the values of the estimated phases are compared with the imposed one and the closest one is selected. If the selected phase is ϕ_e, then is considered that the required precision is achieved. Otherwise, the process is repeated by adding or extracting one sample from the selected sub-segment, until a minimum difference is obtained between the imposed phase and the estimated one.

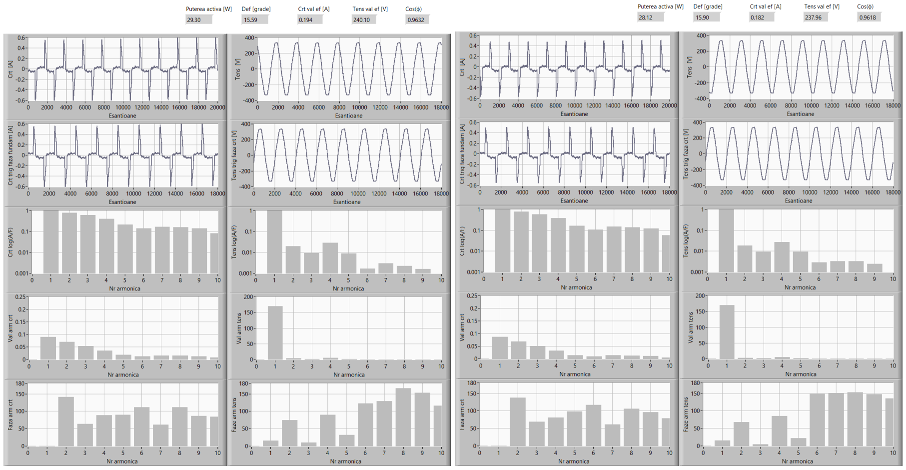
Once the sub-segment whose phase is in the vicinity of the imposed one is extracted, the current's signal corresponding to the detected event is determined. This is achieved by subtracting the sub-segments recorded before and after the event. The difference thus obtained will represent the signal which corresponds to the appliance that generated the event. Using the extracted signal, the phases and magnitudes of the current's harmonics are estimated and, together with the active power, will represent the electrical signature of an appliance. These values will be recorded in a database which will be further used to detect the appliances present in a house.

III. RESULTS AND DISCUSSIONS

Using the algorithm presented in the previous section, a number of 47 appliances which are usually found in a house were investigated to determine their electrical signatures. The signatures were recorded in a database which contains resistive, inductive loads or appliances that use switched mode power supplies. Depending on the availability, different batches for the same product were analyzed in order to observe the repeatability of the electrical signatures.

There can be appliances with different operating states, a category that includes consumers with a variable load (a drilling machine has a different consumption depending on the composition of the material which is drilled) or consumers that perform different functions (the washing machine: water pumping, water heating, drum rotation and centrifugation). For these consumers the electrical signatures for different loads and functions were determined. This way the operating states of these consumers could be detected.

In the figures bellow, the electrical signatures of a number of representative appliances will be presented, considering 0° the value of the imposed phase. In the left column the current's characteristics are presented while in the right column the voltage characteristics.



a. b.

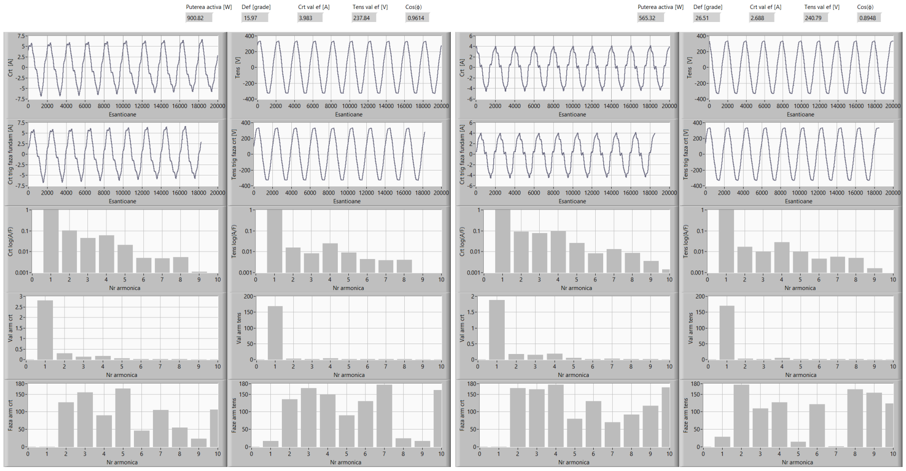
Figure 1. Electrical signatures of a 17 inch LCD monitor: a. lot I, b. lot II

In the first line are presented the data segments acquired when an event is detected, in the second line the extracted sub-segments with the imposed phase, in the third line the values of the odd harmonics (A, up to 19th order) normalized to the fundamental F in a logarithmic scale, in the fourth line the harmonics in a linear scale and in the fifth line the values of the harmonics' phases. Also in the upper part can be observed the active power, phase shift, current and voltage values and $\cos\phi$.

In Fig. 1 is presented a comparison between the electrical signatures of two lots of the same appliance, a 17 inch LCD monitor. It can be observed from the two signatures that the harmonics' amplitudes and phases present similar values for both of the lots. The harmonics' amplitude presents a descending trend for both lots, starting from a 0.09 A value of the first order harmonic and ending with a value of 0.02 A of the 19th harmonics. The phase of the first order harmonic (fundamental) takes the value of the imposed phase, 0°. The values of the rest of the phases vary between 60° and 140°, and are similar for both lots. Also the active powers are 29.3 W for the first lot and 28.12 W for the second.

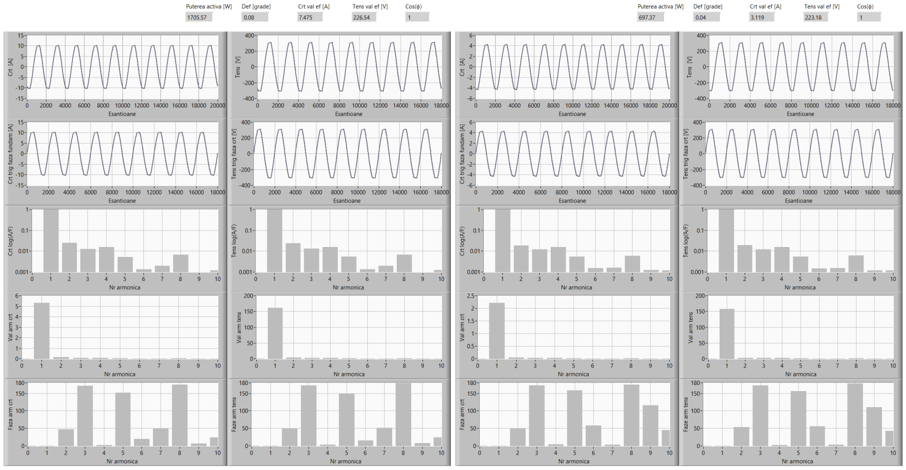
In Fig. 2 is presented the electrical signature of the two operating states of an air conditioner unit (AC), heating and cooling. By comparing the harmonics' amplitudes for the two states it can be observed that the fundamental component has a value of 2.7 A for the heating state and 1.8 A for the cooling state. Differences can also be observed when the phases are compared. The active power for the heating state is 900.82 W while the one of the cooling state is 565.32 W.

In Fig. 3 we observe the electrical signatures of two resistive appliances, an iron and a toaster. The fact that the two appliances are resistive can be observed by analyzing the normalized harmonics and their phases. As it is known, resistive loads will draw a current with the same waveform as the voltage. In the case presented in Fig. 3, it can be seen that the normalized values of the current harmonics have the same values as the ones of voltage harmonics – the proportions between the fundamental and harmonics is the same both for current and voltage.



a. b.

Figure 2. Electrical signatures of the states of an AC unit: a. heating, b. cooling.



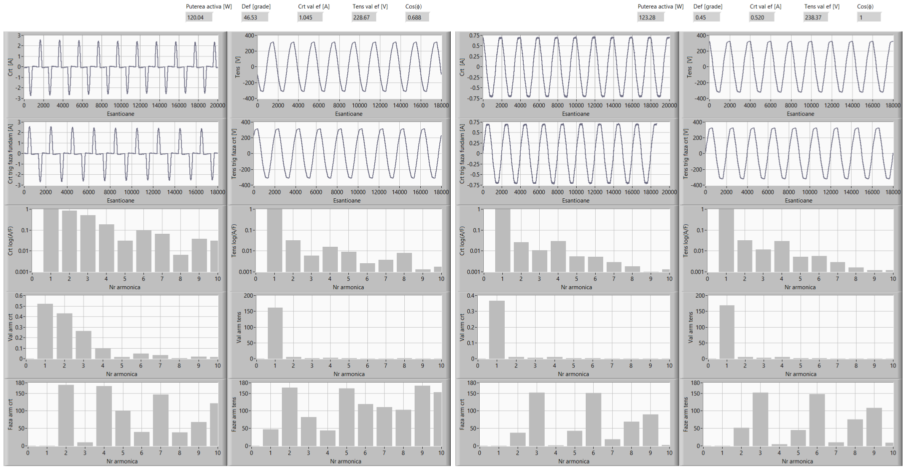
Puterea activa [W] 1705.57 Def [grade] 0.08 Crt val ef [A] 7.475 Tens val ef [V] 226.54 Cos(ϕ) 1

Puterea activa [W] 697.37 Def [grade] 0.04 Crt val ef [A] 3.119 Tens val ef [V] 223.18 Cos(ϕ) 1

a.

b.

Figure 3. Electrical signatures of: a. iron, b. toaster



Puterea activa [W] 120.04 Def [grade] 46.53 Crt val ef [A] 1.045 Tens val ef [V] 228.67 Cos(ϕ) 0.688

Puterea activa [W] 123.28 Def [grade] 0.45 Crt val ef [A] 0.520 Tens val ef [V] 238.37 Cos(ϕ) 1

a.

b.

Figure 4. Electrical signatures of: a. juicer, b. incandescent light bulb

Also, it can be observed that the phases of current harmonics and voltage harmonics are the same. The difference between the two appliances can be seized when the values of the harmonics represented in a linear scale are compared. Since the two appliances are of different powers, the current's fundamental will also have different values: 5.2 A for the iron and 2.2 A for the toaster. The active powers are 1705.57 W for iron and 697.37 for toaster.

In Fig. 4 is presented a comparison between two appliances of similar powers, juicer (120.04 W) and incandescent light bulb (123.28 W). Although they could be considered as a single appliance when comparing the active powers, when the amplitudes and phases of the harmonics are compared, a clear difference can be observed.

IV. CONCLUSIONS

The information about the consumption of an individual appliance offers a new perspective on how the energy is used and helps the consumer find solutions in order to reduce and the energy consumption and to improve its management. Considering these, a new algorithm that characterizes the appliances based on their electrical signatures was presented. The parameters which form the signatures are the amplitudes and phases of the current harmonics and the active and reactive powers determined by a consumer switching from one state to another. It was shown that these parameters can be used to differentiate between appliances of similar power or different operating states of the same appliance.

Using the amplitudes and phases of current harmonics up to the 19th order, there can be determined a complex electrical signatures with a large number of monitored parameters which can provide a high degree of granularity for the appliances in a house. In other words, by monitoring a number of 20 parameters one can made a better classification of the appliances than when using a smaller number – 2 for example: active and reactive powers.

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REFERENCES

[1] K. C. Armel, A. Gupta, G. Shrimali, and A. Albert, “Is disaggregation the holy grail of energy efficiency? The case of electricity”, Energy Policy, vol. 52, pp.213-234, 2013.

[2] B. Neenan and J. Robinson, “Residential Electricity use Feedback: A Research Synthesis and Economic Framework”, EPRI Technical Update 1016844, Electric Power Research Institute, Palo Alto, CA, 2009.

[3] K. Ehrhardt-Martinez, K. A. Donnelly, and J. A. Laitner, “Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities”, Technical ReportsE105, American Council for an Energy-Efficient Economy, Washington, DC, 2010.

[4] A. S. Ardeleanu, M. Cretu, and C. Donciu, “Electrical signature – a means of improving the management of electricity consumers,” Proceedings of the 7th International Conference on Management of Technological Changes, vol. 2, pp. 553-556, 2011.

[5] Branzila M., Alexandru C., Donciu C., et. al., “Virtual environmental measurement center based on remote instrumentation”, Environmental Engineering and Management Journal, vol. 6, issue 6, pp. 517-520, 2007.

[6] Branzila M., Alexandru C., Ciobanu C., et. al., “New DAQB and associated virtual library included in LabVIEW for environmental parameters monitoring”, 2008 IEEE International Conference on Virtual Environments, Human-Computer Interfaces and Measurement Systems, pp. 121-124, 2008.

[7] Branzila M., Mariut F., Petrisor D., “Virtual Instrument Developed for Adcon Weather Station”, Proceedings of the 2012 International Conference and Exposition on Electrical and Power Engineering, pp. 853-856, 2012.

[8] S. Rahimi, A. D. C. Chan, and R. A. Goubran, “Usage monitoring of electrical devices in a smart home”, 33rd Annual International Conference of the IEEE EMBS, pp. 5307–5310, 30 Aug - 3 Sep 2011.

[9] A. S. Ardeleanu and C. Donciu, “Nonintrusive Load Detection Algorithm Based on Variations in Power Consumption”, 2012 International Conference and Exposition on Electrical and Power Engineering (EPE), pp. 309-313, 25-27 Oct. 2012.

[10] M. Figueiredo, A. Almeida, and B. Ribeiro, “Home electrical signal disaggregation for non-intrusive load monitoring (NILM) systems”, Neurocomputing, vol. 96, pp. 66-73, 2012.

[11] C. Belley, S. Gaboury, B. Bouchard, and A. Bouzouane, “An efficient and inexpensive method for activity recognition within a smart home based on load signatures of appliances”, Pervasive and Mobile Computing, vol. 12, pp. 58-78, 2014.

[12] M. Temneanu and A.S. Ardeleanu, “Hardware and software architecture of a smart meter based on electrical signature analysis”, 2013 8th International Symposium on Advanced Topisc in Electrical Engineering (ATEE), pp. 1-6, 23-25 May 2013.

[13] M. Temneanu and A. Ardeleanu, “Non-intrusive Hybrid Energy Monitoring System”, Advanced Materials Research, vol. 837, pp. 495-499, 2014.

[14] S. Patel, T. Robertson, J. Kientz, M. Reynolds, and G. Abowd, “At the flick of a switch: detecting and classifying unique electrical events on the residential power line”, UbiComp 2007: Ubiquitous Computing, pp. 271-288, 2007.

[15] M. S. Tsai and Y. H. Lin, “Modern development of an Adaptive Non-Intrusive Appliance Load Monitoring system in electricity energy conservation”, Applied Energy, vol. 96, pp. 55-73, 2012.

[16] S. Gupta, M. S. Reynolds, and S. N. Patel, “ElectriSense: single-point sensing using EMI for electrical event detection and classification in the home”, Proceedings of the 12th International Conference on Ubiquitous Computing (Ubicomp 2010), pp. 139-148, 2010.

[17] C. Donciu, A.S. Ardeleanu, and M. Temneanu, “Multi-feature Load Detection Algorithm”, Advanced Material Research, vol. 772, pp. 448-454, 2013.

[18] H. H. Chang, C. L. Lin, and J. K. Lee, “Load identification in nonintrusive load monitoring using steady-state and turn-on transient energy algorithms”, 2010 14th International Conference on Computer Supported Cooperative Work in Design (CSCWD), pp. 27-32, 2010.

[19] Y. H. Lin and M. S. Tsai, “A novel feature extraction method for the development of nonintrusive load monitoring system basen on BP-ANN”, International Symposium on Computer, Communication, Control and Automation, pp. 215-218, 2010.

[20] H. H. Chang, K. L. Chen, Y. P. Tsai, and W. J. Lee, “A new measurement method for power signatures of nonintrusive demand monitoring and load identification”, IEEE Transactions on Industry Applications, vol. 48, issue 2, pp. 764-771, 2012.

[21] G.W. Hart, “Nonintrusive appliance load monitoring”, Proceedings of the IEEE, vol. 80, pp. 1870-1891, 1992.

[22] A. Cole and A. Albicki, “Nonintrusive identification of electrical loads in a three-phase environment based on harmonic content”, Proceedings of the IEEE Conference on Instrumentation and Measurement Technology, pp. 24-29, 2000.

[23] M. Berges, E. Goldman, H. S. Matthews, and L. Soibelman, “Learning systems for electric consumption of buildings”, Proceedings of ASCE International Workshop on Computing in Civil Engineering, 2009.

[24] K. D. Lee, S. B. Leeb, L. K. Norford, P. R. Armstrong, J. Holloway, et al., “Estimation of variable-speed-drive power consumption from harmonic content”, IEEE Transactions on Energy Conversion, vol. 20, pp. 566-574, 2005.

[25] W. Wichakool, A. T. Avestruz, R. W. Cox, and S. B. Leeb, “Modeling and Estimating Current Harmonics of Variable Electronic Loads”, IEEE Transaction on Power Electronics, vol. 24, pp. 2803-2811, 2009.

[26] Branzila M., David V., “Real Time Electrocardiogram Signal Processing for R Peak Detection Using Wigner and Wavelet Functions”, Environmental Engineering and Management Journal, vol. 12, issue 6, pp. 1207-1214, 2013.

[27] Branzila M., David V., Padole C., “ECG Signal Processing Using Wigner Function”, Proceedings of the 2012 International Conference and Exposition on Electrical and Power Engineering, pp. 601-604, 2012.

[28] S. Giri, M. Bergés, and A. Rowe, “Towards automated appliance recognition using an EMF sensor in NILM platforms”, Advanced Engineering Informatics, vol. 27, issue 4, pp. 477-485, 2013.

[29] Y. Kim, T. Schmid, Z. Charbiwala, and M. Srivastava, “ViridiScope: design and implementation of a fine grained power monitoring system for homes”, Proceedings of the 11th International Conference on Ubiquitous Computing, pp. 245-254, 2009.

[30] A. S. Ardeleanu and C. Donciu, “Frequency Estimation Based on Variable Frequency Resolution Concept”, 2012 International Conference and Exposition on Electrical and Power Engineering (EPE), pp. 792-797, 25-27 Oct. 2012.

[31] C. Donciu and O. Costea, “Intelligent system for precision irrigation of greenhouse vegetables”, 6th International Conference on the Management of Technological Changes, pp. 669-672, 2009.