State of art on load monitoring methods

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***Abstract*— This paper deals with a state of art about the most Non-Intrusive Load Monitoring (NILM) methods. These methods allow identifying consumption of the electrical loads. In the context of sustainable development, this is of growing interest and rapid evolution subject in recent years. The objective is to manage energy consumption by the determination of the operating schedule of individual appliances. These approaches have been developed to simplify the collection of energy consumption data. This technique for gathering appliance load information doesn't require placing sensors on individual appliances, and hence an intrusion into the energy consumer's property. This paper proposes an overview of the most popular methods and describes their advantages and disadvantages. It opens new perspectives which are under development in our laboratory. Our goal is to reduce the complexity of monitoring appliances and to find the most efficient method for identification.**

***Keywords*— sustainable development, load monitoring, Non-Intrusive, active power, appliance identification.**

I. INTRODUCTION

Sustainable development is a concept that can be summarized in a simple sentence: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." To achieve this, companies, governments and civil society must work altogether in order to reconcile three worlds which have long been ignored: economy, ecology and social issues. Controlling power consumption can contribute to materializing the abstract concept of sustainable development. For this purpose, energy market players and network operators are looking for financially viable, implantable and easily applicable solutions to all uses.

The NILM is a way to determine the energy consumption of individual appliances and the operating schedule of all of the major loads on an electrical service. One of the earliest approaches to Non-Intrusive monitoring was developed in the 1980s at MIT by George Hart, which had its origins in load monitoring for residential buildings. This process is described in [1].

In 1990, a NILM system was developed in the US with a very high cost of $2,500. A similar system was also developed in France by Electricité De France (EDF) using the power signatures of appliances [4]. Since, several other more or less intrusive methods have been developed [2]. These methods will be detailed hereafter. It is important to say that the load monitoring is classified as a subject of a high difficulty level [3] and requires even more investigation. For monitoring systems, it is possible to analyze measured data in the steady state and in the transient state.

In the steady state analysis, each individual load or group of loads are determined by identifying times at which electrical power measurement changes from a steady state value to another. The variations related to the current [4], the active and reactive power [1, 5], the admittance [1] related to either turning ON or OFF of loads. For transient analysis, loads are identified by their spectral analysis [7] or by their high frequency responses [8].

Fig. 1 illustrates the different methods used in the field of "load monitoring" for identification.

II. STEADY STATE ANALYSIS

A. Fundamental analysis

The operating schedules of an individual load or a group of loads are determined by identifying times at which electrical power measurements change from one nearly constant (steady-state) value to another. The steady states correspond to the load either turning on or turning off and are characterized by their magnitude and sign in active and reactive power. The identification of loads begins by the detection of the edge which separates the

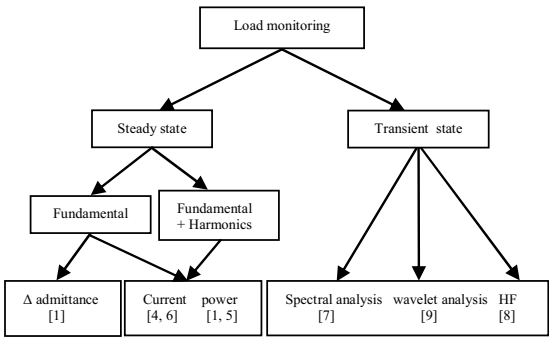

Figure 1. Classification of most popular NILM methods

steady state and the transient state. The transient state should be eliminated in a steady state analysis. Many methods treat this approach as in [4]. Recorded events of changing states constitute a library of operating cycles and the energy consumption of each load: ΔP-ΔQ variations [1, 6], ΔI variations [4], and ΔZ variations [1]. For example, Fig. 2 illustrates the variation of (t-P) and (t-Q) of four switching on and off of two loads A and B.

The identification is based on the matching of positive and negative variations adjusted according to the measured voltage. Sometimes, it is compared with a table of references. Each reference corresponds to a consumer apparatus (oven, refrigerator, etc). This method is not able to identify loads in several cases:

- Non linear loads that overlap ambiguously in the ΔP-ΔQ plane,
- Linear loads that overlap ambiguously in the ΔP-ΔQ plane,
- Unmatched events which correspond to simultaneous load activation,
- Rapid sequences of load activation,
- Long steady state for specific variable loads,
- New types of residential appliances not referenced in the data base.

B. Harmonic analysis

The harmonic analysis can be used in case of ambiguous overlapping in the ΔP-ΔQ plane; it is suitable to complete the identification [6], especially for non-linear loads.

The harmonic content can be calculated by using the Fast Fourier Transform (FFT) of the input current. The use of ΔP, ΔQ, and Harmonics makes the identification easier. Other approaches complete this information by using phase shift between the fundamental input current and the source voltage [6].

Fig. 3 illustrates an example of harmonic pattern.

This method is more efficient but still incomplete to identify loads in the following cases:

- Linear loads that overlap ambiguously in the ΔP-ΔQ plane,
- Unmatched events which corresponds to simultaneous load activation,
- Rapid sequences of load activation,
- Long steady state for specific variable loads,
- New types of residential appliances not referenced in the data base.

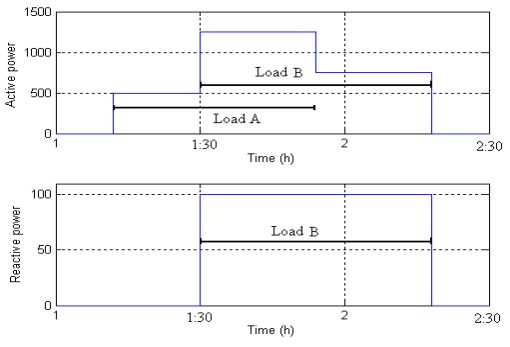

Figure 2. Time domain variation of active and reactive power

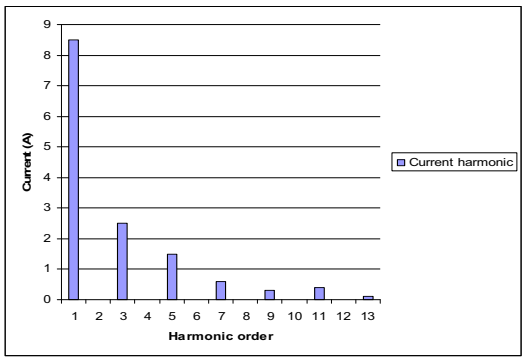

Figure 3. Harmonic pattern

III. TRANSIENT ANALYSIS

The transient behaviour of major appliances is a reliable indicator of load identification. The shape of the transient represents a class of loads and corresponds to its electrical behaviour. For efficient identification, each detected transient is compared to a data base by using a least squares criterion [7]. Fig. 4 shows in time domain, the power consumption of four parallel loads activated simultaneously, the elliptical shapes (A, B, C and D) contain the transient events.

Another method of transient detection has been proposed [8]. It consists of using an emitter of high frequency pulses (4 MHz) connected to each load of the residential network. The detection of these pulses allows thereafter the load identification. Since the pulses are influenced by the network and the load position, it is necessary to measure the pulses at the network input and to reference them in the data base.

The transient analysis presents several shortcomings:

- Necessity to use a high sampling frequency,
- Transient patterns need to be relatively unique and reasonably repeatable,
- A data base is complex and expensive regarding to the number of residential appliances,
- Measured pulses depend on the network geometry.

IV. LOAD MONITORING AND INTRUSION DEGREE

In general, loads are classified into two groups: two state loads (on / off) [4] and multi state loads [1, 5]. To create their data base, it is possible to carry out a number of initial tests in real situations. We can classify the data by using (ΔP, ΔQ) plane [1, 4, 7] or current variation ΔI [4]. Neural network is used in case of a continuous monitoring [6].

In case of transient analysis, the data base is formed by the following information: rise time, fall time, frequency, [7], then one uses signal processing [8] or wavelet transform [9] to identify the transient.

All these existing techniques claim to be Non-Intrusive, but the question is: are they really Non-Intrusive techniques?

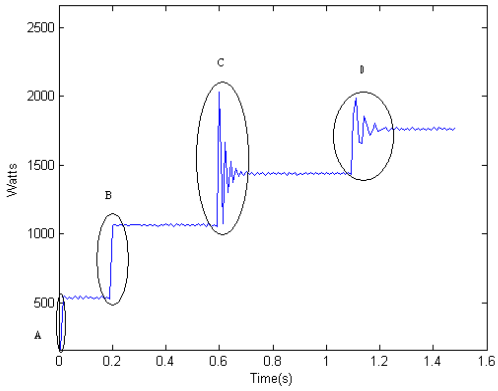

Figure 4. Active power and transient delimitation

NILM reveal several degrees of Non-Intrusive, they can be classified in two classes:

- MS-NILM (Manuel Setup) whose intrusion level is too high to setup the data base [1, 4, 5, 8]). It requires a manual turning on and off of each appliance in the residence. Thereafter, each signature is observed, classified then named in the data base.
- AS-NILM (Automatic Setup) which is less intrusive ([1, 5, 7]). It sets itself up as it measures the load, using prior information (gathered in laboratory or by opinion poll) about the characteristics of possible appliances.

MS-NILM is more precise than AS-NILM. Unfortunately, they require gathered a data base of the signatures of each residential appliance in various states; this semi-intrusion remains however awkward for the customer.

V. NEW METHOD OF ANALYSIS IN INVESTIGATION

A new methodology in load monitoring is under study. A new signal processing approach is proposed, which represents input current and voltage directly on base.

The majority of the methods use the Fast Fourier Transformation (FFT) in signal processing. Our signals are not stationary and by consequently the use of the FFT is not judicious. Moreover the moment of the beginning of the treatment window is lost by the FFT and raises difficulties to look at for changing loads to ON and OFF.

This method presents the following advantages:

- The extracted data for the identification is less than the other methods.
- The method applies on windows in transient stage as well as steady stage.
- The changing states are easily identified.
- The method remains effective in spite of the noise measurements.
- The method is implemented advantageously on embarked systems.
- There is no more ambiguous overlap with similar loads.
- The method is a real Non-Intrusive method: no more sensors on individual appliances and doesn't require gathering information about the appliances.

VI. CONCLUSION AND PERSPECTIVES

We have detailed most popular methods of load monitoring to determine the operating schedule of electrical appliances. Each method presents its own advantages and disadvantages, and opens the opportunity to propose a new approach which can be more efficient.

We are developing a really new Non-Intrusive method which will be presented in details in a forthcoming article. Clearly, only simple cases have been studied, but the results thus far are very promising.

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