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Load Disaggregation Development Project: A NILM Proposal for Energy Usage Changes

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Abstract— This article approaches the consumption disaggregation methodologies for electricity bill breakdown, that aims to promote the user's conscious consumption. That is, by accessing information about equipment use and consumption, consumers will become active agents in residential energy efficiency. The electric charges monitoring can be performed in several ways, however, regardless the used model, by analyzing the load curves of each equipment, through direct or disaggregated measurement (NILM), it is possible to understand the consumers and equipment behavior. This is, their electrical signatures, when compared to a standard, may indicate inefficient use or malfunction, by obsolescence or by default. Therefore, this paper concludes that the use of load disaggregation may go beyond its initial proposal to electricity bill breakdown, but to study behaviors of people and equipment in order to improve energy efficiency.

Keywords—NILM, user behavior, load disaggregation

I. Introduction

According to [1], we can say that consumers who have real-time feedback on their energy consumption, with automated and customized recommendations, will be 12% more efficient than those who only pay the bills, as in many countries around the world.

On this path, in 1992, Hart, G.W. published an article titled "Nonintrusive Appliance Load Monitoring" [2], which began the load disaggregation discussion for residential consumers. Following this article, much research has emerged along this path, looking for a way to achieve the electricity consumption division as in [3], [4] and [5], with different breakdown methods.

However, this kind of research does not occur in a simple way. As discussed in [6], there are three ways to measure and detail the electricity bill, with a large range complexity for hardware and software. The first, called Intrusive Load Monitoring (ILM) is made up of measurement devices, such as smart plugs, measuring any equipment individually. The second, called Non-Intrusive Load Monitoring (NILM), is composed by a unique meter at the residence entrance branch, with consumption disaggregation through software implementation. The third one would be a mixture between the two previous ones, called Semi-Intrusive Load Monitoring. The Fig. 1 exemplifies these models.

Currently, various research studies the different types of measurement and disaggregation, especially with the emergence of devices for smart homes, the Internet of things and data science. As can be seen in [8], [9] and [10], with the emergence of a toolkit that allows studies replicability on the subject, through several databases in a same structure and some data analysis algorithms.

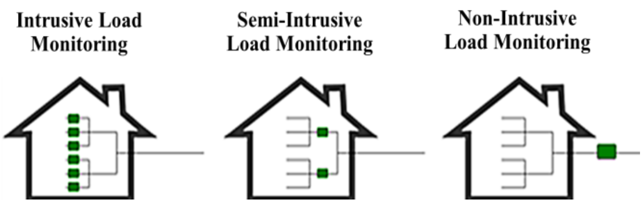

Fig. 1. Load Monitoring Methods. [7]

Therefore, this article presents one of the studies conducted on NILM methodologies, in the "Load Disaggregation Project", to be applied in consumption behavior analysis for residential consumers. The first topic (II) introduces the project, with its context and methodology. In the second (III), has the benefits in user behavior analysis and its consumption changes. And the last item, (IV) the conclusion and results.

II. The Load Disaggregation Development Project

A. Context

From the year 2,000, through the Law No. 9,991, the concessionaires and public server permits of electric power distribution should apply, annually, the percentage of 1% of its net operating revenue - NOR in R&D projects and in efficiency. energy, according to regulations established by ANEEL (national regulatory energy agency). [11]

Through this law and the need for innovation in the Brazilian electricity sector, UNICAMP, with its expertise and capacity in research and development, has partnered with several electricity distribution companies. Thus, projects that improve and contribute to the electricity supply security, low tariffs improvement, environmental impact reduction and technological development, bringing national expertise independence, have been emerging since the last 10 years.

Together with the R&D team of the CPFL Brazil company, an electricity distributor in Campinas City region (state of São Paulo), both involved in the Law 9,991 scenario, the project "Development of intelligent systems for monitoring, disaggregation and consumption analysis using modern sensing technologies" was created in December 2016. Thus, in order to analyze, test and develop three monitoring technologies of electric energy consumption that allow to split the residential energy bill per appliance, as mentioned in [6], this project found and studied the possibility of exploring user behavior through NILM methods.

B. *The Project*

The three metering architectures studies for consumption breakdown, as studied in [6], allowed to expand the national hardware and software development, as seen in next topics. The same study mentions that using non-intrusive load disaggregation, known as NILM, has great academic and commercial potential. Adding statistical tools on disaggregated results, using non-electrical characteristics, as usage pattern and appliance standard consumption improves load recognition assertiveness and reveals user behavior that is not energy efficient.

Ten homes were selected to install the three monitoring typologies, generating real data in real time. This dataset is distributed by measuring equipment, which can be a concentrated meter or sensors distributed by circuit or equipment.

C. *Methodologies*

This project was built based on a clean architecture model, upon three pillars: interface, interface adapter and entities (Fig. 2). The Interface is the user's requisitions, which "display model" is the visualization requirement from user and "database" is the real data from measurement sensors. The Interface Adapter is the data and results translation. In "database interface" the data is translated into the Architecture format, the "presenter" interprets the users visually requirements and "controller" translates user searches, interacting with 'Entities. The last one, Entities, is the NILM functions and execution which the "agent" module command the others and integrates them with the "Interface Adapters".

Thus, each layer becomes independent during its development, paying attention only to the input and output values of each module. Another advantage is that each load disaggregation module, such as event detection, event recognition and consumption estimation, is not unique to a single method. That is, users simply specify the method to be performed, which the block will execute as selected, again considering the pre-specified inputs and outputs in the architecture.

D. *Products*

During the project development, another partnership was formed with a startup company (Time Energy) to develop hardware for the three measurement types: intrusive monitoring, non-intrusive monitoring and semi-intrusive monitoring; known as Neras solution [14].

For measurement in the project residences, only the concentrated meter, Neras Pro which has a one second sampling time, was used.

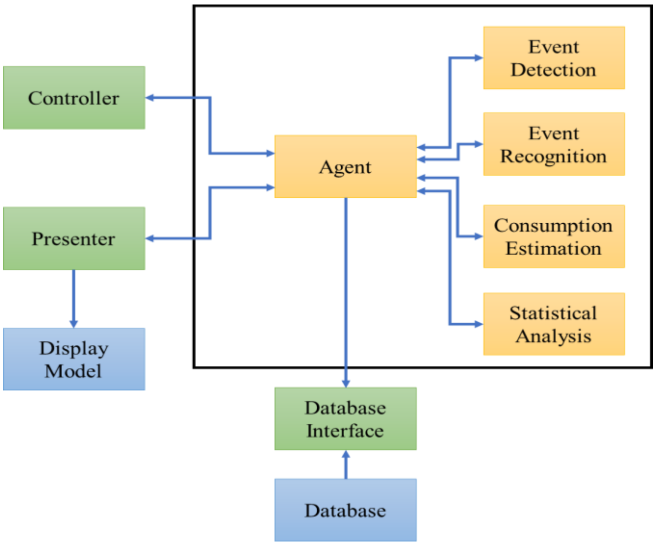

Fig. 2. Architecture model for NILM development.

This product development is an important result for the country research, showing that in addition to methodologies and simulations we can guarantee the application in products and market.

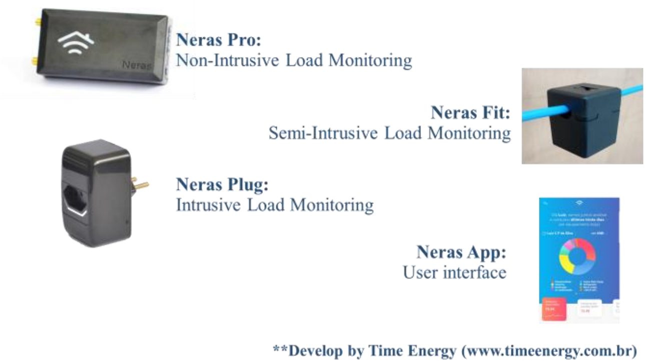

Fig. 3. Example of a figure caption. (figure caption)

III. Energy Usage Benefits

With NILM results and non-electric information it is possible to identify abnormalizes in equipment operations, such as activity periods at peak consumption times, malfunctions and low efficiency, due to technology obsolescence.

A. Project Results

The primary results of the project are accurate to disaggregate consumption by 60 to 80% (Fig. 4), depending on the day and load type used. To achieve this result, around 120 devices of various types and models were measured in order to create an electrical signatures base, with active and reactive power, power factor and electric current harmonics data.

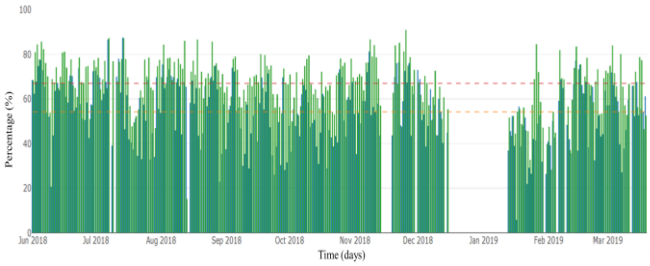

Fig. 4. Percentage hit by the daily residential consumption disaggregation from June 2018 to April 2019, for a residence.

Another major result of this project is the residential electricity consumption database. That is, 10 households with concentrated, semi-distributed and distributed measurement were monitored over periods of 6 months to 2 years, depending on the residence.

B. Consumer Behavior

Through the database and analyzing the consumption profile of each household, it was possible to identify consumption patterns and user behavior, such as: time of use of finished equipment, for example the electric shower time on; malfunctioning in refrigerators, with different behavior than expected; even the day of cleaning a house or the arrival and departure times of people through the electric gate operation.

All of this can be verified through various pattern recognition methodologies over the disaggregated data.

C. Equipment Efficiency

By analyzing the behavior of users and equipment, it is possible to apply energy efficiency models. That is, when analyzing that high consumption depends on user behavior, changes and good usage practices should be recommended. In the case of equipment with strange behavior, it should be examined whether it is due to obsolete (old equipment) or malfunction (broken equipment).

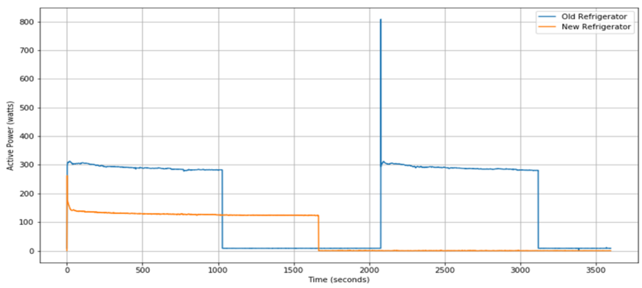

Fig. 5. One hour load curve from two refrigerator type.

Through a load curves analysis (active power graph) of similar equipments, such as an electric refrigerator, it is possible to observe differences in their behavior. As an example, in Fig. 5, with two refrigerator types, old (more than 10 years) and new one. In one hour period, the oldest refrigerator has two operating cycles, as well as a much higher power usage than the new refrigerator, which in only one hour runs for half the time.

Its exchange generates energy efficiency in a residence electricity consumption, as shown in Fig. 6, that presents a home's electricity consumption graph before and after changing an oldest refrigerator to a new one. After the equipment change, between days 3 and 4, the total electricity consumption fell by 65.5%. This shows that the main load installed and in use in the home was the refrigerator and that it was old, with low efficiency in its operation.

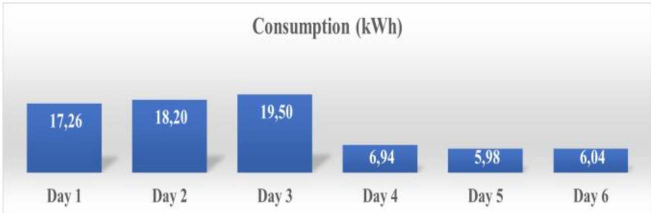

Fig. 6. Energy consumption for an old refrigerator (days 1 to 3) and a new one (days 4 to 6).

D. Maintenance

Another way to promote energy efficiency is to analyze equipment malfunctions. Fig. 7 shows the load curve of a refrigerator with differences in its operating cycle. It is observed that between the point 20,000 and 40,000 several times the equipment remained in on mode. Unlike what we see in Fig. 5, this refrigerator's duty cycle is not as expected, with one on and off per hour.

Analyzing this equipment in the physical place, it was observed that the insulation of the door was inefficient, causing the refrigerator's internal to exchange heat with the external environment, that is, heating faster. So your compressor needed to stay on to maintain the internal temperature as specified. The simplest and cheapest solution was to change the insulation rubber, bringing the refrigerator back to its normal operating condition.

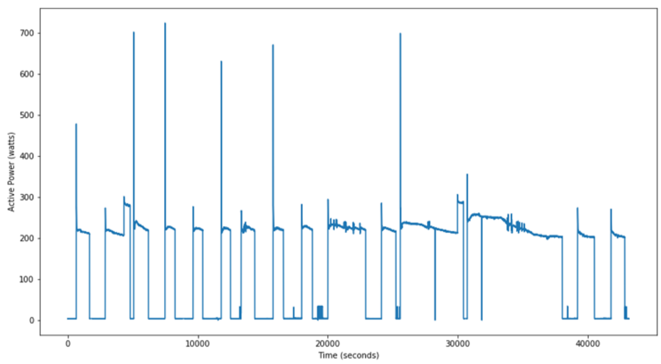

Fig. 7. Refrigerator load curve with bad door sealing.

IV. Conclusion

Despite the various studies on load disaggregation methodologies for electricity consumption breakdown and the monitoring methods for electric measurement, in order to obtain individual consumption information for each equipment, this project presented the gains of using this final material in new data for patterns recognition. Thus, allowing to find inefficient behaviors of users and equipment during its operation.

For users, it is enough to present real-time information about equipment consumption, usage time and usage behavior improvements, so that it can take efficient actions. Subsequently, presenting to the consumer the operating situation of each equipment, such as the retrofit to more efficient equipment or performing improvements and maintenance, can further ensure the energy efficiency of the home.

For this, it is necessary to analyze the individual behavior of each equipment, comparing it with similar or with its operation pattern, in order to find variations in your operation.

Acknowledgment

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