# Optimizing the Inspection Routine for the Detection of Electrical Energy Theft in AES Eletropaulo in São Paulo, Brazil

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*Abstract:* - This work describes the development of a non-invasive and low-cost process that allows for the improvement of the energy theft inspection routine, increasing the field inspection team productivity and reducing the customer's embarrassment in cases where no irregularity is found. This new process is based on the development of an electronic Ah meter device that can be installed on the customer's pole input connections to the power lines. Using the recorded Ah value in the device, it is possible to estimate, within a margin of error, the energy consumption of the customer during a small period, typically one week. This energy value is compared to the customer's regular energy meter reading for the same period. A comprehensive statistical study performed with a database of more than 80000 customers in distribution area of the utility company AES Eletropaulo in São Paulo, Brazil concludes that the comparison between these readings can clearly indicate when tampered or defective meters are found.

*Key-Words: Electrical energy theft, fraud inspection routine, electricity tariffs, sustainable development, emergent countries, energy efficiency, illegal energy consumers.*

## 1 Introduction

A major problem that electricity utilities companies in emergent countries face is the loss of revenue caused by non-technical losses, which are originated mainly by fraud or theft of electricity [1]. These figures are extremely high in Brazil, and in 2007 represented a loss of approximately 20 billion US dollars, or about 15% of total energy distributed in the country, which is equivalent to the energy generated by the biggest Brazilian hydroelectric power plant, Itaipu [2]. This problem is a common issue in other emergent countries, and finding solutions to this problem is of fundamental importance to achieve a sustainable development growth in these economies [3].

The economic losses caused by energy theft impacts drastically in the company's capacity to improve the quality of the electrical energy supply or for extending the electrification process in low income and rural areas. Due to the large number of illegal consumers, the cost of electricity becomes very high and both genuine customers and the utility companies are responsible for paying for this energy theft [4,5,6,7].

Also, the techniques used to illegal tapping of electricity lead to electric shocks and is not unusual to have people killed in these attempts of making an illegal connection [8]. To reduce these non-technical losses, the electrical utility companies have been investing heavily in efforts to control and combat tampered and illegal connections, using estimation techniques or performing incessant inspection of their wire networks [9, 10, 11]. However, the practical results are still very modest, despite the enormous effort [12].

To illustrate this scenario, even though AES Eletropaulo, the largest electricity utility in Brazil [2], has done a tremendous effort in this area, investing about 65 million US dollars per year, the level of its non-technical losses had a modest reduction, from 5.0% to 4.9%, when comparing the year of 2007 with the first quarter of 2008. Increasing the efficiency of the combat actions against non-technical losses and optimizing the relation between inspection costs versus the revenue recovered through these actions is a major challenge for power distribution companies [12]. The traditional tools of information technology (IT), although very helpful in order to identify potential situations of energy theft, do not offer an efficient solution to the problem.

Even the most sophisticated available software based on databases analysis provide only a marginal return, since the success ratio (number of irregularities detected to number of inspection realized) by this kind of analysis is still very low. Nowadays, in the city of São Paulo, only 12% of the executed inspections selected by the IT are of customers who actually present any problem of tampering or anomaly in their installations.

The current procedure to investigate a customer is to send a well experienced electrician unit to the destination provided by the IT-based smart system to perform a physical check of the installation. These conventional inspections take a long time, are expensive and difficult to perform, since the operation requires high skilled professionals, sophisticated tools (like flexible fiber optics bore scopes), and also require permission from the customers to access the local of inspection.

The typical procedure of installing a regular energy meter before the customer's meter is generally not effective because the customer can easily notice that its installation is under investigation and, thus, take the necessary actions to disable the theft scheme.

Therefore, it is necessary to evaluate solutions which involve development of new technologies and equipment as well as new techniques to review the working procedures in order to increase the system effectiveness and the feasibility of the inspection process.

## 2 Requirements for developing a pre-inspection routine procedure

Part of this work was dedicated to perform a statistic analysis of parameters which will allow for the establishment of a low-cost non-invasive pre-inspection routine procedure capable of substantially increasing the success rate of conventional inspections. This pre-inspection routine will precede the conventional inspection and it shall indicate if there is a potential electric energy theft or an anomaly in the meter of the customer under investigation. Then it is decided if a conventional inspection is likely to be successful and justified in that particular case which has already been selected by the regular IT software.

A very small electronic device estimates the customer energy consumption during a sample period, by measuring the electric current consumption in Ah. Based on the statistics of previous found frauds and the average values measured on each type of technical installation (Delta, single phase, 2 phases, 3 phases, etc.), and comparing the estimated energy consumption to the real consumption read for the same period in the utility regular energy meter, it is proposed a procedure to decide if the customers deserves to be physically inspected.

For the success of the pre-inspection process, the equipment must attend the following characteristics:

1. Easy installation and removal using an appropriated tool, allowing for a high productivity and a low-cost process;
2. Precision current measurement, considering that only the electric current will be measured and the reference voltage will be assumed according to the type of the client network circuit;
3. Fast download of measured data and performing the analysis and comparisons by an automated process;
4. Operation in temperatures from -5°C to 65°C;
5. Robustness, with hard-duty structure (to avoid violation) and reduced dimensions in order to be barely noticed by the customers;
6. Has to be transported in lots of at least 30 pieces in a motorcycle (in an appropriated box);
7. Low production cost, allowing massive use;
8. Desirable battery lifetime of one year.

## 3 Current Status of Inspections

To analyze the consumption behavior of detected energy theft and irregularities before and after the field regularization, a database from AES Eletropaulo containing 97833 customers selected by the IT software to be inspected, during the period of January 5th, 2009 to May 31st, 2010.

This database includes the six months energy consumptions that occurred before the inspection, the consumption for the month of the inspection, and the next six months consumptions in kWh after the inspection. The database also shows the classification of inspections according to their results, as:

a) HIT A = Anomaly;
b) HIT F = Fraud;
c) HIT O = in order;
d) HIT N = Not inspected.

The “Anomaly” is characterized by a defect in the meter, for example a worn-out part or a burn-out caused by a lightning falling on the power line. “Fraud” is characterized when any action of tampering with the meter is found, for example by blocking the meter moving parts or with a partial bypass of the meter. If after an inspection it was not found any kind of irregularity, it is classified as “in order”.

From the 97833 cases, only 81195 could be effectively inspected during this 16 months period. In the universe of inspected cases, 4976 (which represent approximately 6.13% of the database) were identified as frauds (some kind of tampering) and were regularized by the utility technicians. The anomalies represent 6946 cases, that is, approximately 8.56% of the data base.

Therefore, approximately only 14.69% of inspections generate energy recovery or energy addition to the billing, and almost 70000 unnecessary inspections were realized. With more than 5000 inspections per month and only circa of 70 being successful, the cost/benefit ratio of the inspection activity is very low. However, the utility company cannot stop the inspection activity because it would send a wrong signal to the customers, who would feel more comfortable to practice the tampering. A summary of the results is presented in Table 1.

Table 1: Current status of inspection activities

| Situation | No. of cases | Percentage |
|---|---|---|
| Fraud | 4976 | 6.13 % |
| Anomaly | 6946 | 8.56 % |
| in order | 69273 | 85.31 % |
| Total | 81195 | 100.00 % |

## 4 Establishing parameters to detect energy theft

In order to create a pre-inspection process using a measurement device which allows for the identification of differences in the expected consumption, it is necessary to statistically identify the behavior of the energy consumption of the customers who were caught with a fraudulent installation. To obtain the data that represents the behavior of consumption before and after the field inspection, it was considered the cases in which there were three or more registers of energy consumption before and after the inspection.

The database has 80601 cases that meet these conditions. For these cases, the mean and the median of the monthly energy consumption before and after the inspection were calculated. Plots of these variables are shown in Fig. 1 and Fig. 2. In these plots M0 is the month of the inspection and M-6 and M6 are, respectively, the 6th month before and after the inspection.

The plots clearly show that, in cases of anomalies and fraud, an increase of consumption occurs after the inspection and meter regularization. In cases that were inspected and found “in order”, there were no significant differences before and after the inspection. However, in cases that were not yet inspected, there is a slight variation (tendency of consumption increase), probably indicating that in this group can be found other cases of fraud or anomaly.

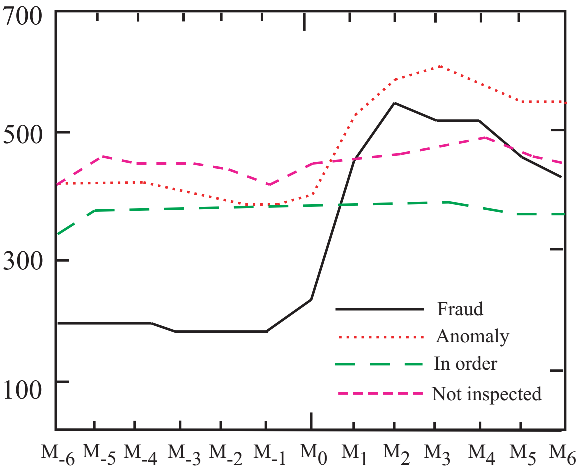


Fig. 1 Mean of the energy consumption for a period of six months before and six months after the inspection.

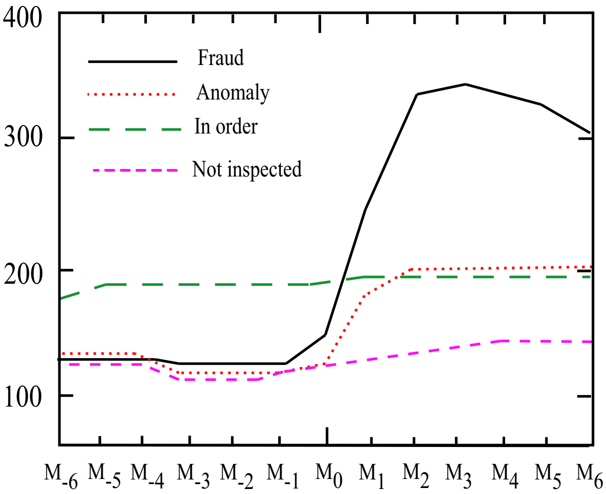


Fig. 2 Median of the energy consumption for a period of six months before and six months after the inspection.

It is also important to notice that in cases of fraud or anomaly, the consumption tends to decrease with time, but remains higher than during the period prior to the inspection. One of possible explanations for this phenomenon is that once the fraud or anomaly is regularized, the consumption starts to be read correctly and consequently the energy bill will be more expensive, stimulating the consumer to adopt energy efficiency habits and even changing the home's appliances to reduce the consumption.

To clearly identify the change in power consumption behavior, three different methodologies were used: a) the step analysis; b) the comparison of consumption behavior before and after field regularization and c) the standard deviation analysis.

The most common methodology for fraud or anomalies identification used by the utilities is the analysis of consumer behavior by seeking a variation to a lower consumption during a given period. Once identified this step, it is done a local inspection to measure the consumption, in parallel to the current measurement equipment, in order to confirm the anomaly or energy theft.

This method, although very used and easily applied, has serious limitations, since the step of consumption can be masked by variation of the consumption behavior due to:

- Climate seasonality which change consumption patterns;
- Consumers life-cycle such as children leaving their parents homes;
- Companies reducing production capacity;
- Consumers adopting energy efficiency mechanisms such as changing incandescent light bulbs to compact fluorescent and acquiring new appliances that consume less energy, as it was seen during the Brazilian electricity rationing in the years of 2000 and 2001.

All these variations make it difficult to identify with precision a threshold for the step of consumption, and many of the inspections that occur in the field will not confirm the suspected fraud. For example, if a step decrease of 10% in the consumption is adopted as the threshold value for deciding to perform a physical inspection, 17.45% of the cases would have been missed.

Observing the six months before the inspection which detected the fraud, it is found that none of the customers who were stealing energy showed consumption variations of more than 9.9%. Within the universe of anomalies found, a greater percentage of cases (23.91%) would be detected if the same criterion (step of 10%) was used. Thus, it is very difficult to identify fraud or anomalies simply by using the consumption step method.

The second method to analyze changes in the consumptions behavior involves the creation of variables which compares the consumptions before and after the field regularization. In this study, four variables were created, considering the data of 3448 cases of anomalies and 5170 cases of fraud with a consumption history of at least three months before and after field regularization:

a) DELTAA16 - division of the consumption registered at the 6th month after the regularization by the consumption registered in the month which immediately precedes the inspection;

b) DELTAA116 - division of the consumption mean of the period of six months posterior to the inspection to the consumption registered in the month immediately preceding the inspection;

c) DELTAA123- division of the consumption mean of the second and third months after the inspection (months of highest consumption) to the consumption registered in the month which immediately precedes the inspection;

d) DELTAA12323 - division of consumption mean of the second and third months after the inspection to the consumption mean of the three months immediately prior to the inspection.

The different divisions shows that, in cases of fraud, when comparing the month before the inspection with the 6th month after the inspection, the change in consumption patterns occurs with minor differences. However, when comparing the month prior to the inspection with the average of the six months after the inspection, 95% of cases show a variation greater than 14%. For the cases of anomalies, by comparing the month prior to the inspection with the 6th month after the inspection, 90% of cases show a variation of at least 10%. In the other cases this variation is less than 7.5%.

The third method used to identify changes in the consumption behavior was performing an analysis using the standard deviation. For each six months history of consumption prior to the inspection, it was calculated the average consumption (MEANA61) and the associated standard deviation (SDVA61). From these two variables, it was created a new variable called VAR that is the ratio between SDVA61 and MEANA61

It was observed that the mean of the consumption average for cases of fraud is 191 kWh and the mean of standard deviations is 53 kWh, resulting in a VAR of 30%, for higher or lower, which would represent a potential fraud.

Following the same methodology of analysis, but taking the median as a parameter, it reveals that the median of the average consumption of fraud cases is 132 kWh and the median of standard deviations is 27 kWh, referring to a variation median of 20%. The mean for the consumption average of anomaly situations is 418 kWh and the mean of standard deviation is 106 kWh, resulting in a VAR of 30%.

Adopting the median as a parameter, the median of the averaged consumption for anomaly cases is 136 kWh and the median of the standard deviations is 26 kWh, referring to a median variation of 17%.

In cases that are "in order", the mean of average consumption is 385 kWh and the mean of the standard deviation is 71 kWh, what results in a VAR of 23%. Using the median as a parameter, it shows that the median of the average consumption of "in order´´ cases is 191 kWh and the median of the standard deviations is 28 kWh, referring to a VAR median of 13%.

Those analysis show that in situations of fraud and anomalies, the existence of a step of consumption, contributes significantly to a greater variation in the calculated standard deviations, which are up to 30% to 50% higher compared to cases that are "in order".

Thus, considering the three analyses for detection of potential tampering or anomaly, the recommended threshold in this methodology for deciding to perform a physical inspection was set as difference of 15% between the regular energy meter reading and the calculated energy consumption using the developed electronic device.

## 5 Methodology of the pre-inspection activity

The following steps were established for the pre-inspection activity in the theft combat process:

1. Definition of customers' installations where the electronic device will be used, according to a list generated by the fraud intelligence analysis software and the programmed installation optimized route;
2. Identification of the electronic device that will be associated (by the serial number) to each customer ID number;
3. Organize the electronic devices according to the optimized route, prepare the vehicle (motorcycle or small car) with the safety signalization and equipment;
4. Park the vehicle near the customer house and install the safety signalization (if necessary);
5. Install the corresponding device(s) to the customer with the appropriated tool (a standard insulated hot stick) on the customer external wires;
6. Take the customer initial customer meter reading (on the regular meter) just after the electronic device installation;
7. Remove the electronic device after the defined sample period (one week) with the appropriated too;
8. Take the customer final meter reading (on the regular meter);
9. Download the electronic device data and compare them to the initial and final regular meter readings;

The computer analysis of the results will generate a new list, with the suggested customers who deserve to receive a conventional inspection, since suggestions these cases indicate high probability of frauds or anomalies. To verify the feasibility of the proposed pre-inspection activity, the AES Eletropaulo connections standards and real field situations were analyzed.

It was verified that the customers connections poles have lengths between 3.5 m to 5.5 m and the distance between the phases wires are in the range of 10 cm to 15 cm. Extensive field tests were done and documented on tape by the linesmen of AES Eletropaulo and submitted for approval by the engineers of the safety committee of the utility company. The conclusions indicated that the installation/removal of the electronic metering device is safe and can be performed in less than 30 s per device, using an appropriated tool, as shown in Fig. 3.

Fig. 3 A linesman installing the electronics device in a wiring connection of AES Eletropaulo.

## 6 The Ah meter electronic device

Composed by a hermetically sealed mini-clamp current transformer connected to a small polycarbonate box, the prototype was designed in black to avoid catching the attention of the customers. It is known that if a customer who is stealing energy notices a new device on his installation, there is a great probability that the tampering will be temporarily disable to avoid being detected. Sometimes the installed equipment can be seriously damaged or even destroyed.

In order to attend the requirements presented in Section 2, the electronic device was developed to fit a small box (50 mm x 85 mm x 22 mm). This housing also allows the device to be easily applied (and removed) in the wires near the pole connectors, without using a ladder, and by only one person. It is worth to notice that the wiring in some poor regions is chaotic and the access to the input connections of a customer can be difficult, as shown in Fig. 4, where a photograph of the wiring around a distribution pole is presented.

Fig. 4 Wiring of a typical pole connection in a poor region of the AES Eletropaulo concession area in the city of São Paulo.

A photograph of the assembled printed circuit board of the electronic device inside the plastic package with the mini-clamp meter is presented in Fig. 5.

Fig._5 Photo of the complete meter, with the mini-clamp and circuit housed in its final package.

The standard hot stick used by the AES linesmen receives a customs tool. In this tool, when the mini clamp is inserted, it arms a mechanical trigger which is released by the contact of the clamp with the wire where it will be installed. Several field tests were conducted and this tool transformed an operation which was initially imagined to be troublesome into a quick, reliable and safe operation. The complete device attached to the insulated hot stick, ready for being installed, is shown in Fig. 6.

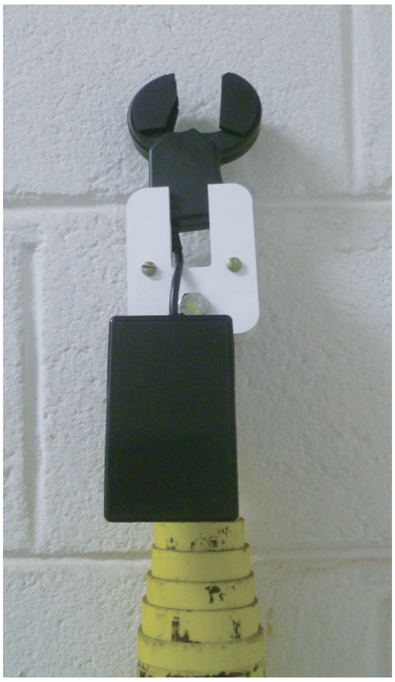

Fig.6 The mini-clamp meter ready to be installed, in the tip of an insulated hot stick used by AES.

The mini-clamp current transformer has a ratio of 2500:1, and can measure currents up to 100 $A_{rms}$. It meets the requirements of the international standard IEC 60044-1 Class 1 (error of ± 1.0%). At room temperature, the worst case error measured in laboratory tests was only ± 0.25%.

Based on these errors, it is expected that the developed measuring device will contribute with a typical error of less than ± 0.5%, and a worst case error of ± 1.25%, which is more than one order of magnitude lower than the value of the trigger threshold for indicating theft/anomaly.

The electric current meter device is based on the extremely low power MSP430 microcontroller from Texas Instruments with 24 bits Sigma-Delta Analogue to Digital Converter (ADC), 512 bytes of RAM and 8KB of flash [14].

This microcontroller is responsible of the reading and also for communication. A crystal driven timer in the microcontroller precisely activates the measuring process every second. This trigger awakes the ADC that operates at 4096 samples per second.

Next, the microcontroller starts reading the values of the analogue-to-digital conversion, looking for a zero-crossing of the signal.

As soon as a zero-crossing is found, the microcontroller starts to integrate in time the square of the voltage in the output of the ADC. The microcontroller continues this integration until the seventh zero-crossing is found, what means that three whole electrical network cycles have been measured.

At that point, the microcontroller calculates the square root of the integration result and multiplies the result of the square root by a calibration factor, obtained during the calibration of the device.

The result is the measured electric current in RMS. Assuming that this value is the RMS electric current for a one second period, this value is then integrated every second to obtain the electric current consumption in Ampere-seconds.

The communication between the measuring devices and the computer host, which will store the data and process the calculations to check for a potential fraud or anomaly, is done through a 2.4 GHz radio, operating at 0 dBm, using a customized protocol to guarantee that the radio is kept inactive most of the time, which minimizes power consumption [15]. A detailed description of the hardware is presented in [16].

## 7 Analysis of the voltage errors in the evaluation of the energy

As mentioned before, because the measuring electronic device will use only the electric current to calculate the power consumption, it is necessary to assume a reference line voltage to calculate the energy consumption, and this is done according to the type of the client network circuit. To identify a reference voltage for the power line, an extensive analysis of voltage measurements conducted in all concession area of AES Eletropaulo was performed, with 9474 measurements of voltages taken between the years of 2002 to 2009.

The analysis was conducted separately for all types of connection in the transformer, since there are six different types of connections in the network of AES Eletropaulo: Delta, Open Delta (lead), Open Delta (lag), Closed Delta, Single Phase, Two Phases, and Three Phases. The results of the statistical analysis showed that the maximum deviation from the average value in all cases was only ± 3.86% (for the Single Phase connections). The worst case standard deviations was $\sigma = 7.0$ for the average voltage value of 204.9 V in the Open Delta (lead) connections, and for the Single Phase connections with average voltage value of 117.5 V a value of $\sigma = 4.5$ was found for the standard deviation.

Therefore, taking into account that the maximum error in all types of connections is ± 3.86%, it is possible to use the average voltage value of each type of connection to calculate the electrical energy using the Ah values measured by the electronics device within this margin of confidence.

## 8 Analysis of the power factor variations in the evaluation of the energy

The power factor (PF) can be an important issue when calculating the energy through the measured values of current. Thus, part of this study was dedicated to realize an statistical analysis of the residential and small commercial customers in the AES Eletropaulo area, in order to obtain a statistical distribution of the power factor. This study, obtained with a data base of 4193 customers, indicates that when the high power resistive loads (represented by the electrical shower, which represents 38.8% of the energy bill in an average typical house [17] are not taken into account, the average power factor of these customers home appliances is PF = 0.76, with a variation of ± 9% within 2 σ.

The smallest load among all available electrical showers in the Brazilian market has a power of 4.4 kW, and this results in a current of at least 22 A (when installed in a bi-phase connection), the developed meter detects when currents higher than 15 A are turned on (so it can also detect other high resistive loads like clothing driers) and integrates this current in a separate register.

Thus, when the pre-inspection is finished, it is possible to obtain separately the Ah values of the low-current appliances (which have an average power factor of 0.76) from the high resistive loads (electrical shower and other appliances that drain more than 15 A), minimizing the error in the calculated energy due to the power factor.

# 9 Data Retrieving and Analysis

It is expected that, when in full operation, the pre-inspection activities will require hundreds or even thousands of metering devices will have its data retrieved every day in the AES offices for analysis.

Thus, to minimize the reading errors and speed up the data reading process, each measuring device received a radio circuit that communicates with a USB computer wireless device that, when in the presence of a measuring device, automatically download all the measured data and writes a file that is ready to be checked by the fraud detection software.

During this wireless data retrieving, the value of the battery voltage is also read and checked, so that any device which is reaching the end of its battery's life can be replaced.

# 10 Experimental Results

To evaluate the new proposed inspection routine for the detection of energy theft, the new strategy of performing a pre-inspection analysis was tested in the field. The tests started with selected customers who confirmedly were not tampering with the meter. The tests were realized in houses with substantial difference in the electricity bill, with different habits and economic situation, from small houses shared by graduated students to very large houses in large areas which have with tennis courts, swimming pools, etc.

One of the parameters which require further study to establish a valid routine is the sampling period. For the utility company, a very short period of sampling (for example, three days) would lead to a high productivity and allow for a large number of pre-inspections for a given number of devices per inspection team.

However, a short period of measurement can mask the energy theft depending on the customer's habits. For example, if the three days period include the week-end, if all the individuals that live in the house are away during the week-end, it is likely that even if this house has a by-pass in the electric shower it would not be identified as being irregular.

Thus, during the first tests the electronic device was left in the customer's installation for at least one week. The tests were repeated in many households (shown as Test 1 to Test 4) to check for the consistency of the results. The results measured in these first field tests are presented in Table 2.

Table 2: Deviation of the calculated energy

| | Percentage difference observed in energy | | | |
|---|---|---|---|---|
| House | Test 1 | Test 2 | Test 3 | Test 4 |
| 1 | 10.90 | 10.83 | 6.98 | 8.65 |
| 2 | -3.92 | -3.67 | -2.49 | -2.92 |
| 3 | 4.10 | 3.87 | - | - |
| 4 | -5.54 | - | - | - |

House 1 is a house shared by several working girls who spent the whole day out of home, with the following appliances: three refrigerators, five electric showers, all lighting provided by cheap, low-quality compact fluorescent lamps (with a very low power factor PF=0.6), five ceiling fans, seven notebooks, one washing machine and one CRT TV set. House 2 is a simple house, shared by graduate students that spent most of their time at the University, with only basic home appliances: a refrigerator, two electric showers, incandescent bulb lighting, a washing machine, a small CRT TV set and three notebooks. House 3 is also simple house, with a profile similar to House 2. House 4 is very large house, fully equipped with a large number of sophisticated home appliances, a lighted tennis court, and a swimming pool.

As it can be noticed, the results measured in all tests fell within the expected values (less than 15% of difference from the utility meter) indicating that the customers are not tampering with the meter and there would be no need to perform a physical inspection (as it was already known).

House 2, 3 and 4 presented results which were very close to the value read in the regular energy meter of the utility company. In House 1 the result was also correct, and the observed difference in energy consumption between measured values of the energy meter and calculated using the Ah reading of the electronics device was because of the low power factor of the appliances of this house, showing the importance of including the errors due to power factor, voltage fluctuation and current clamp errors to avoid generating false inspections.

All AES Eletropaulo inspection teams are now being trained and the new routine of pre-inspection is already being executed in small scale. It is expected that, after many months of practical application, the threshold value used today to define if a physical inspection is needed or not (currently set at 15%) can be optimized based on the field results.

Since the number of physical inspections will be dramatically reduced by the pre-inspection activity, it is possible in that, in the future, a much lower threshold value (for instance, 10%) could be used to select customers' installations which deserve to be physically inspected. This would increase the number of false results (unnecessary inspections), but the system would be able to find customers who are stealing a low percentage of their energy bill (at 10% level), still keeping a good cost/benefit ratio for the inspection activity.

## 11 Conclusions

A novel methodology and measuring circuits necessary to implement a field pre-inspection phase in the procedure of finding theft of electrical energy is presented. The new technique measures and calculates the true RMS time integral of the current in the phases of the customer wires installation.

Using the available data of the typical values of the voltage, the consumed energy is calculated and compared to the energy registered in the customer's standard meter. Laboratory tests showed that the developed measuring device presents a very small error (less than $\pm$ 1.25% in worst case).

The maximum observed variation in the voltage of the lines were $\pm$ 3.6%. Statistic studies of the power factor in the region of AES Eletropaulo indicates that, when the high resistive loads are not taken into account, the average values for the power factor is 0.76, with a margin of error of $\pm$ 9%.

These errors can be cumulative (all go in the same direction), resulting in an uncertainty of $\pm$ 13.85%, so it is expected that all tampering actions that present energy theft of more than 15% shall be indubitably detected during this pre-inspection phase, improving dramatically the efficiency of the inspection teams.

The meter was completely characterized and tested in selected customers, presenting excellent results. Exhaustive field tests are currently being conducted, and the results from some preliminary tests realized in controlled customers indicate that the introduction of the proposed pre-inspection routine will increase substantially the cost/benefit ration of the inspection activity.

It is expected that AES Eletropaulo shall be able to achieve an effective reduction in the cost of the energy theft detection process and at the same time an increase the amount of revenue recovered.

Genuine customers shall benefit from this optimization of the inspection routine because it can lead to reduction in tariffs and improvement of the quality of the service offered by the utility company.

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