

Analysis of Power Quality Problems in Low-Voltage Circuits

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Abstract – This paper presents the analysis and the diagnosis of two cases with power quality problems in AES SUL’s commercial / residential customers, fed through low-voltage net. After a lot of monitoring of the customers’ feeding voltage, performed using specific equipment and a detailed and careful investigation, it was determined that the causes of the disturbances derived from the customers’ systems themselves. Then, the main steps used in the in the analysis and the results of the measurements that led to the identification of the problems are described.

Index Terms — Monitoring, Disturbances, Diagnosis, Power Quality.

I. INTRODUCTION

A NUMBER of problems in the power quality affects significantly the operation of sensitive equipment of the most varied types of consumers. They, in turn, claim that the Utility is responsible for the source of the problems that can be caused. Cases with large consumers are studied and widely disclosed in the technical literature and, in general, they involve both consumers and the power utilities, aiming to reach the solution of the problems and a better relation between the utility and consumers, provoking a big involvement between the parties. Since these kinds of customers are relatively reduced in terms of number, based on the total number of customers of the power distribution utilities, it is easier for the utility to serve them, although many of them have a complex solution. In order to determine the causes of power quality problems, specific equipment is used as a key tool, since it helps, in a decisive manner, in the required investigations to be performed [5]. Some of this equipment can even provide information about the most probable direction of the origin of the disturbances [3]. Other factors are also important in identifying the origins and causes, like the accurate survey of information on the

disturbances, besides the identification of similar cases available in the technical literature, upon starting the analysis of possible problems in the supplied voltage quality [1]. These experiences acquired during the monitoring of related problems help a lot find the solution for new cases, enabling a shorter time in the analysis and solution of the disturbances [2]. The meters are very expensive, deeply affecting the utilities’ operating expenses (they are usually contracted services), mainly if one takes into account the quantity of low-voltage customers, typically residential, commercial and small-sized industrial consumers. Also, the costs of the utility’s skilled professionals or even outside consultants involved in the surveys, analyses and solutions of the problems should be stressed. Additionally, more and more often, there is some equipment in the internal facilities of these kinds of consumers that can jeopardize the quality of the electric power supplied by the distributing utility.

II. DESCRIPTION OF THE PROBLEMS

The procedures necessary for the diagnosis, recommendations and alternatives aiming at the solution of problems reported by AES Sul’s consumers are performed according to the company’s power quality program.

This paper describes two cases involving low-voltage circuit consumers that had been constantly complaining about problems existing in the feeding voltage supplied by the utility. The company, in turn, has initially checked several times the technical conditions of the circuits, through traditionally used surveys, such as state of the secondary network conductor, extensions for customers supply, firmness of the secondary network poles, grounding existing in the distribution network, voltage drops on steady state, etc. After all inspections carried out, no problem of any kind whatsoever was found. Due to the continued complaints, AES Sul pursued to investigate the compliance level of the voltage wave shapes.

The first case reported is related to interferences in a given consumer’s recording system, due to the loss of quality of the reproduction because of considerably intense noises. Accordingly, a survey of the nearby consumers was carried out and, initially, no evidence concerning the probable cause of the interferences was found. In the second case, the circuit was presenting constant short variations in the voltage, which were demanding too much from the voltage stabilizers used to feed the consumer’s computers. They could be visually noticed through the fluorescent lamps existing in the facility, with the presence of constant voltage flickers. In both cases,

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measurements were performed to check the characteristics of the variations and point out their probable origin.

III. ANALYSIS OF THE DISTURBANCES

Initially, the voltage behavior was recorded so that the characteristics of the wave shapes during the disturbances could be evaluated. Next, an investigation process to determine the probable causes of the problems was performed. The monitoring procedures carried out helped achieve the final objective, solving the cases after the definition that the problems were related to the load operation. The analyses referring to the power quality problems, which after the final diagnosis indicated an internal-type origin, that is, present in the consumer's facilities, are described below. The results obtained during the monitoring are presented and illustrate the steps adopted during the investigations.

A. Case I – Notching

After a number of complaints from a given low-voltage system consumer, located in the city of São Sebastião do Caí, in the state of Rio Grande do Sul, Brazil, the process of investigation and diagnosis of this case was started, with the survey of the characteristics of the problems mentioned. The interferences occurring in the consumer's system did not show regular intervals, however, they were more frequent and noisier late in the afternoons.

In this case, the consumer works with audio reproductions used in advertisements through a recording system of its own, which were affected by high intensity noises that damaged the product's final quality.

1) Measurement Results

To evaluate the characteristics of the disturbances, the meter was connected to the point of common coupling of the consumer's low-voltage system, in compliance with the voltage wave shapes. Since the problems would occur rather frequently, the events related to the noises that damaged the consumer's recording system were registered already in the first measurements. Therefore, the data obtained during the monitoring with the Dranetz/BMI power platform PP 4300 is presented. By analyzing the results, one concludes that the notching-type events were probably responsible for the disturbances. Fig. 1 shows the voltages in a given moment when the problems occurred, as described by the consumer. One notes that only phase B was affected significantly, with typical characteristics of thyristors switching, deteriorating the voltage wave shape in each semi-cycle. After about 18 minutes, the consumer indicated the presence of the noises in his system again, but, at this moment, the disturbances in the wave shape occurred in phase A, as shown in Fig. 2. Thus, it was noted that the notching was related to the operation of non-linear single-phase loads connected to at least two phases of the three-phase system.

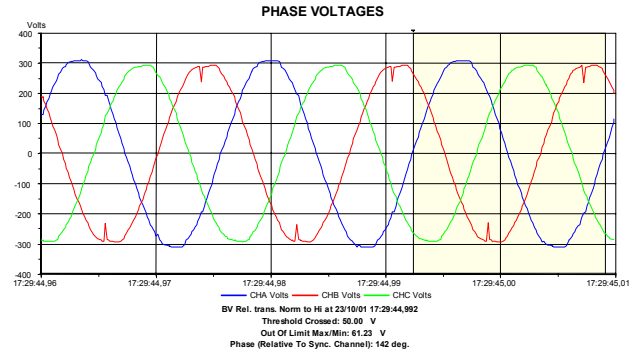


Fig. 1 Disturbances in phase B

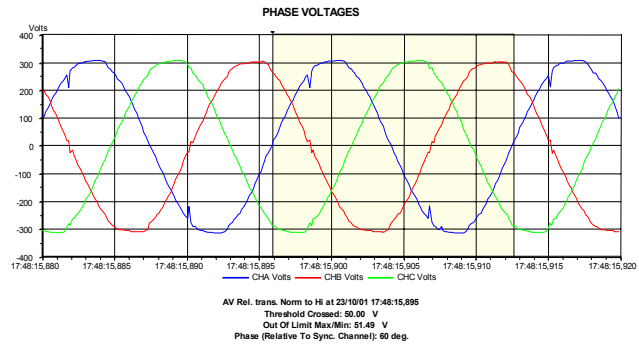


Fig. 2 Disturbances in phase A

Fig. 3 shows the harmonic of phase A related to the cycle illustrated in Fig. 2. The prevalent harmonic refers to 3rd order (zero sequence), but there is the contribution of harmonic components in the whole spectrum, with low total harmonic distortion (THD) of 3.2%.

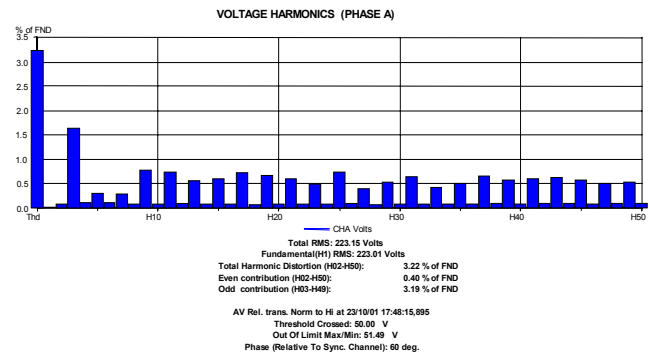


Fig. 3 Harmonic spectrum of phase A during the occurrence of the problems. Theoretically, the disturbances tend to be the more intense closer to the origin the monitoring is performed. Based on the first disturbances, a simultaneous measurement was carried out in the terminals of the transformer supplying the customer, and the results were compared. Figures 4 and 5, respectively, show the voltages in the transformer and in the consumer's during the interference problems. It is possible to note that the disturbances are more severe at the point of the complaining consumer than at the point of installation of the transformer. This fact helps to the extent that the probable disturbances were related to some load of the low-voltage network, characterizing as a case of origin internal to the consumer's facilities. The non-correspondence between the phases derives from the difference of sequences during the connection to the meter at the points of analysis.

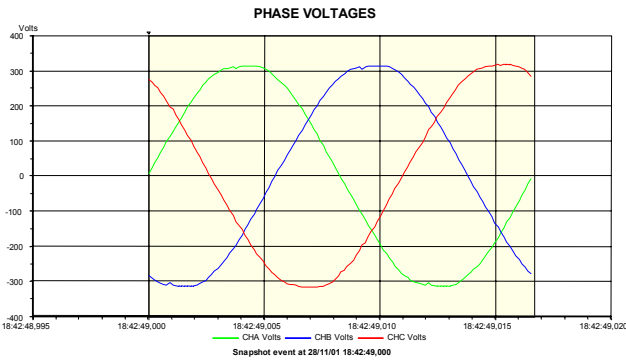


Fig. 4 Transformer Voltage

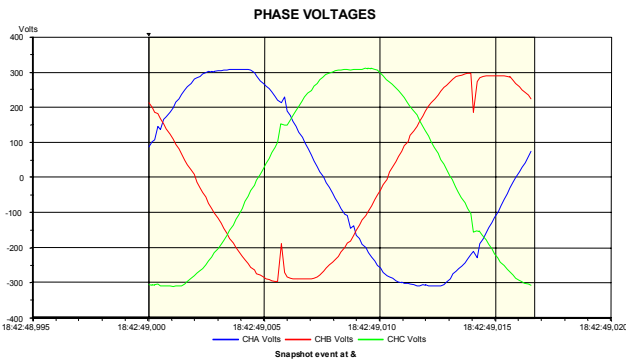


Fig. 5 Load voltage

In a detailed survey of the main loads of the system, it was noted that there were electric showers with electronic temperature setting, that is, controlled by thyristors, in the complaining consumer's facilities, as well as in another consumer fed by the same low-voltage circuit and located electrically near the former. In this case, it was concluded that the operation of these loads, which usually present a rated power of 6 kW, was affecting the voltage wave and were directly related to the reported problems. Consequently, the consumer's shower feeding circuit current was monitored, and it was concluded that the currents of this load were significantly affecting the voltage wave, producing the noises in the consumer's system, which technically made the recording and reproduction of the final product impossible. Fig. 6 shows the record of the voltages and currents responsible for the disturbances (opposed polarities), thus resulting in the saturation of the current transformer of the metering instrument during the operation of the non-linear load of the complaining consumer himself, generating the noises in his audio system.

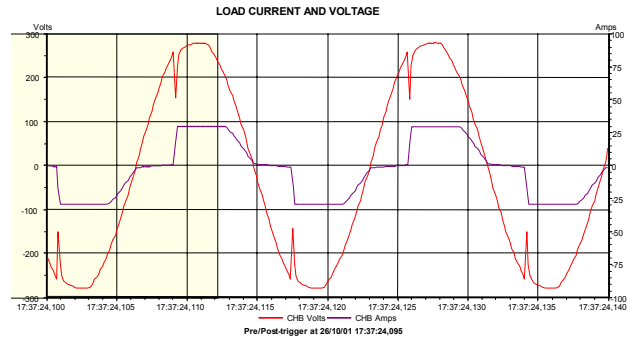


Fig. 6 Load current and voltage during disturbances

2) Simulation Results

To evaluate the effect of the thyristor switching in such low-voltage system, the supplying electric system seen from the medium-voltage bus of the substation was modeled in the electromagnetic transients program Microtran, as showed in Figure 7, below. The controlled shower was represented by anti-parallel thyristors, operating with a fire angle of 60°. In Figure 8, one can note the voltage resulting from the non-linear load connection near the complaining consumer's facilities. The simulation results were very similar to those obtained during some measurements. Therefore, this new type of load, besides the specific problem generated, considerably affects the network voltages, which causes some concern due to its proliferation in the Brazilian market, making the attainment of the power quality and compliance of the voltage wave difficult.

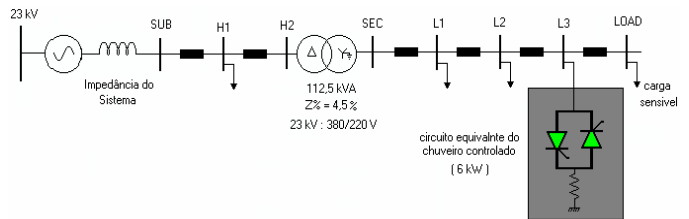


Fig.7 System's one-line diagram

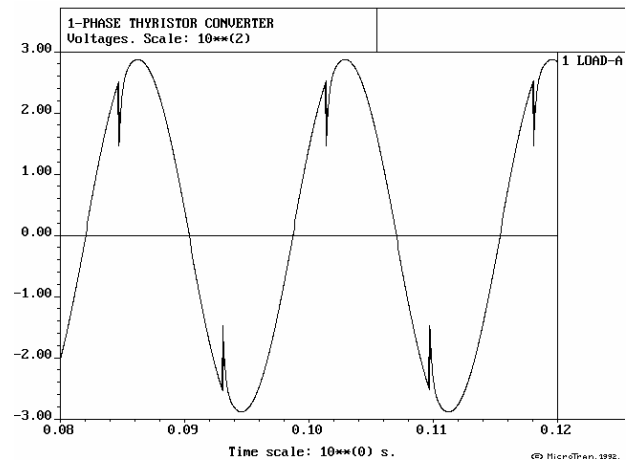


Fig. 8 Load voltage simulation

3) Mitigation Alternatives

For tests of mitigation of the interference problems caused by the noises, the utility has purchased an isolation transformer with electrostatic shielding, which would feed the

notching-sensitive recording system. The results were not satisfactory and the noises continued disturbing the consumer. In this case, as an alternative, the use of an Uninterruptible Power Supply system or power conditioners to feed the consumer’s sensitive load [6] was recommended. The principle of functioning and equivalent power induces to a deterioration of the voltage wave, due to the operation of these loads. Concerning that, manufacturers are being contacted for clarifications as to other similar cases since, despite the improvement in terms of the electric shower operation (comfort and rationalization), it can cause severe problems and considerably damage the wave shapes of the voltages of the low-voltage systems.

B. Case 2 – Flicker

The results of the monitoring and analysis of the second case are presented below, where the disturbances resulted in voltage oscillations typical of the flicker phenomenon, causing some visual discomfort to the main consumer of the circuit.

1) Measurement 1 (single-phase voltage)

Since the problems were constant and almost permanent, the first measurement already indicated the variations disturbing the consumer’s operation. Fig. 9 shows phase-to-ground voltage measured at a point of the facility, used to supply power to computers. One notes the repeated variations in the wave shapes, significantly affecting the operation of the sensitive equipment available in the internal facilities.

During such period, there was an instant voltage sag of 15.75% below the rated value. Therefore, the disturbances are characterized as relatively intense events, besides having a very high frequency of occurrence. During some periods, the voltage variations would decrease, as reported by the consumer.

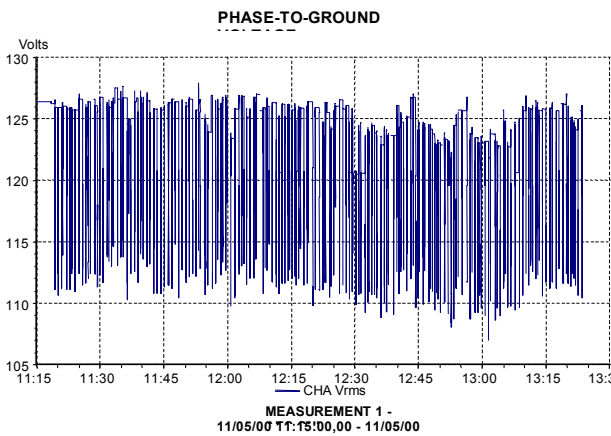


Fig. 9 Phase-to-ground voltage behavior

Fig. 10 shows a detail of the RMS variations, where one can note the characteristics and typical intervals between the disturbances. While Fig. 11 shows the voltage wave shape during one of the voltage sags occurred.

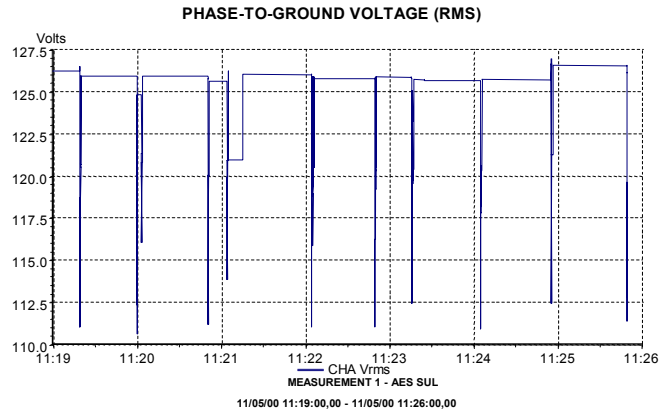


Fig. 10 Detail of voltage variations

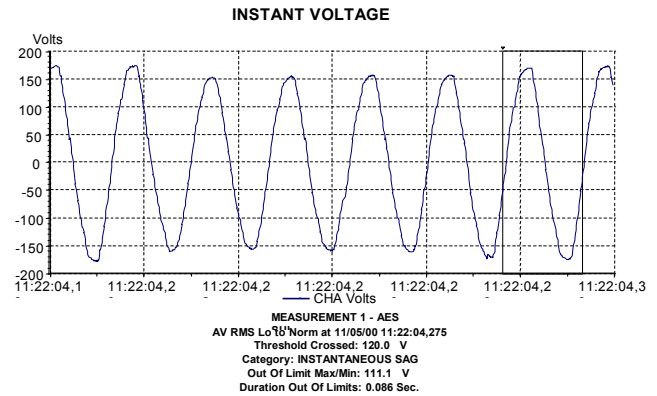


Fig. 11 Voltage sag

2) Measurement 2 (three-phase voltages)

Fig. 12 shows the results of the measurement carried out at the consumer’s inlet during its normal operation, by obtaining the three-phase voltages. According to the previous results, phase A is the one presenting the most significant variations.

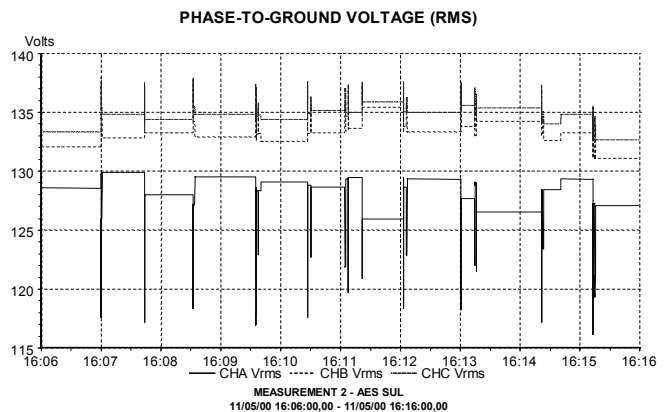


Fig. 12 Phase voltage behavior at the consumer’s inlet

The maneuver and change of the voltage circuit and respective supply transformer of the consumer were performed. In this case, one can assess the conditions or correlation between the low-voltage circuit and the reported problems. The results showed that the variations remained basically with the same behavior.

3) Measurement 3 (side of low voltage of the transformer)

This measurement lasted approximately one hour and refers to a supply point existing right at the outlet of the transformer supplying the consumer. It must be stressed that the intensity and propagation of the disturbances depend on their location and on the monitoring point [2]. Figure 13 shows the RMS voltages in the terminals of the transformer of the distribution network, which presents a normal and basically balanced behavior. Therefore, an additional important indication that confirms the suspicion that the origin of this problem is also internal to the consumer.

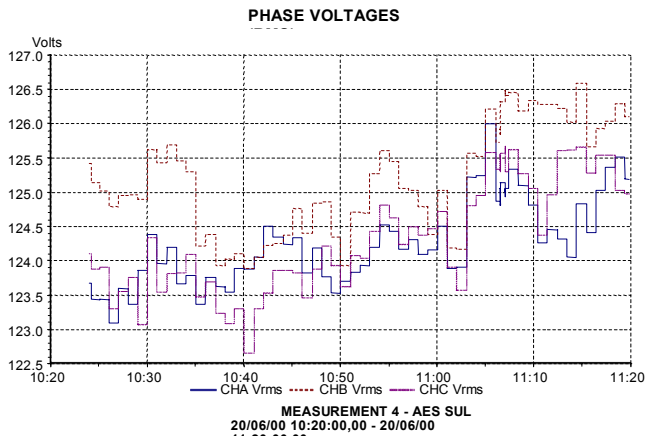


Fig. 13 Transformer terminal voltages

4) Measurement 4 (internal circuit)

This measurement was performed at the inlet of the protection circuit breaker of the consumer and clearly shows that the disturbances occur only during the customer's regular working hours, indicating the consumer's operation under load as the cause. Fig. 14 illustrates the behavior of the voltages, which suffer the variations only during the business hours.

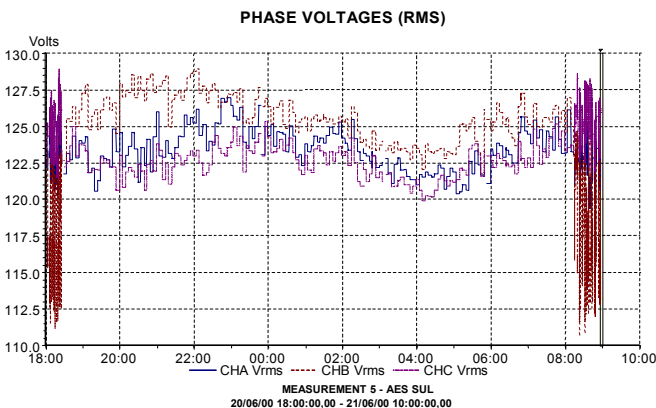


Fig. 14 Voltage behavior in consumer internal circuit

5) Measurement 5 (final diagnosis)

In order to find the actual location of the disturbances, measurements were also performed to observe the behavior of the current feeding the circuit under analysis. After limiting the analysis to the phase presenting the most severe variations, tests were done in the respective circuits, when it was noted that a given sector and piece of equipment (copier), demanded

excessive currents exactly during the voltage sags.

Figure 15 shows the RMS voltages obtained during this monitoring. As from 5.00 p.m., when several disturbances would occur, tests were done for a final check of the disturbing equipment. At 5.06 p.m., the breaker supplying power to the copier's circuit was opened, and the voltages returned to the normal condition. After approximately 10 minutes, the copier was connected again and the voltages presented significant variations once more. At this moment, it was defined that the cause of the disturbances was the bad functioning of the copier. So, at about 5.49 p.m., it was deenergized and the sequence of the voltage sags in one of the phases was interrupted again.

It must be stressed that current rises in the same phase during almost the whole period of this measurement were monitored, coinciding with the disturbance moments, as showed in Figure 16. Such copier, operating in the standby mode, requested around 0.5 [A], and suddenly drained an excessive current during some cycles, causing the short undervoltages. We highlight that the maximum values of the currents were not recorded by the measurement equipment due to the saturation of the current transformer. In this case, it is estimated that the peak values of the currents during the disturbances were higher than 50 [A].

Due to the correct determination of the equipment responsible for the disturbances, it was proven that the cause of the voltage sags that generated the flicker phenomenon derived from the high currents requested during its inadequate operation, being characterized as a case of internal origin as well.

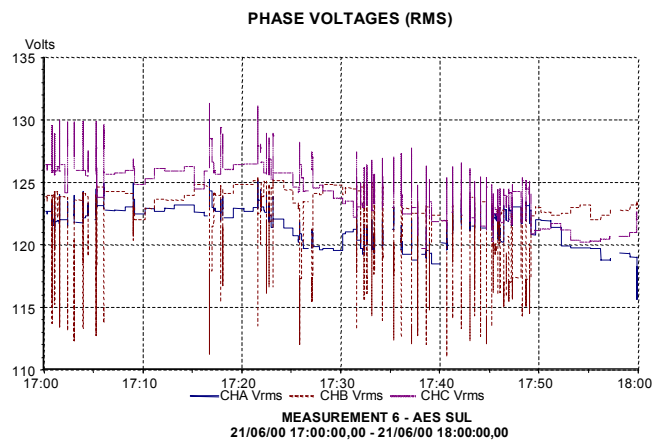


Fig. 15 Voltage behavior in the switchboard

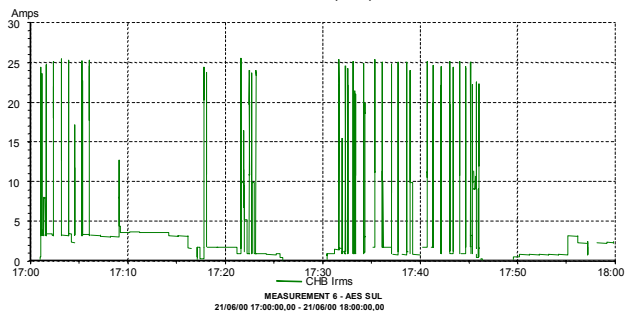


Fig. 16 Phase current in the copier's supply circuit

Fig. 17 shows, simultaneously, the voltages and currents during one of the events related to the flicker problems; therefore, as a result of the respective current rises.

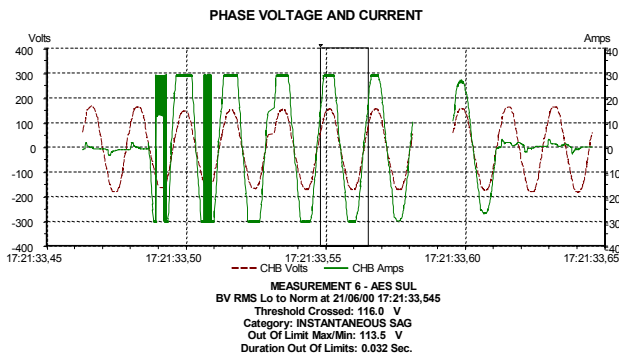


Fig. 17 Phase voltage and current with disturbances

IV. CONCLUSIONS

This paper reported the results obtained during the monitoring and investigation of power quality problems in two consumers served by AES Sul's low-voltage system. During the analyses, the disturbances were registered with specific power quality analyzers, whose results indicated the loads operation itself as the cause of the problems; therefore, the origin of the reported problems was internal. The first case analyzed referred to interferences in the consumer's audio system deriving from thyristor overlaps during the operation of non-linear loads. In this case, after the investigations, it was concluded that the noises disturbing the consumer's recording system derived from the operation of thyristor-controlled showers, a typically non-linear load and with a considerable power for low-tension networks. After careful analyses, it was possible to define that the loads of this type connected to the consumer himself and to another one nearby were responsible for the disturbances, affecting mainly two phases of the system. Of course that the noises were more intense during the operation of the shower the complaints stemmed from. However, the operation of this kind of load at a point near the consumer's facility also made the reproduction and execution of the final product impossible.

The simulation results were similar to those obtained during the monitoring and show the impact of the operation of this load, significantly affecting the system's voltage.

This fact generates some concern regarding possible violations due to these new settable thyristor-controlled showers. Similar cases in other systems and alternatives are being studied with manufacturers. In order to mitigate the problems reported in this case, it was recommended to install UPS or power conditioners in the supply of the sensitive load, or even to abandon the use of such loads.

In the second case, by using the same analysis procedures and methodologies, the diagnosis of another low-voltage consumer with power quality problems was performed. This consumer's main complaint was the constant visual inconvenience due to the flicker effect. By registering the wave shapes, it was noted that the disturbances occurred due

to voltage sags. The monitoring indicated that even after the change of the low-voltage network and transformer, the repeated variations would continue. The results pointed that the short variations did not occur in the transformer terminals and that the disturbances would only occur during the regular working hours of the consumer himself. Therefore, the load had a direct influence in the registered disturbances. After a number of measurements, it was proven that the inadequate operation of a regular copier was causing the disturbances. Therefore, it was recommended to check the occasional defects of this equipment with its respective manufacturer. Accordingly, the measurements performed during the monitoring of both cases were key to diagnose the problems, indicating that the origin was internal. An important aspect to be highlighted has to do with the involvement between the utility and the consumer with power quality problems, for, based on the origin and cause of the disturbances, criteria and resolutions should be established, considering or making each one of the parties responsible as far as the efforts, measures and recommendations to eliminate power quality problems are concerned.

Thus, the quality of the power supplied depends both on the power utilities and on their consumers, but also, in some cases, mainly on the equipment manufacturers.

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