VERY LOW COST DEVICE FOR POWER QUALITY AND RELIABILITY MEASURING AND RECORDING

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Abstract

Power Quality (PQ) related issues are of great concern nowadays. In order to improve the quality of service supplied to the customer, organizations involved in the electrical sector have been adopting strategies and producing regulations. The main reason for these initiatives is to mitigate the impact of the electrical power disturbances over the customers' processes. However, this new context requires a new category of measuring equipment that supports monitoring and recording relevant parameters relating to electrical power received from the utility so as to supervise and control compliance with existing regulations. The device with these capabilities is the Power Quality and Reliability Meter and Recorder (PQMeter).

In this paper a brief description of some PQ issues is presented. We also describe the implementation of a PQMeter characterized by its simplicity. This will constitute a low-cost solution (negligible when compared with alternatives) with wide application. We will also present the performance of our solution applied to a case study where the electrical power supplied from the utility to a facility was monitored for a period of eleven months**.**

Keywords

Power quality, power reliability, transient and steady state disturbances meter, power quality costs, liberalisation of the electrical sector, energy auditing, increasing industrial productivity, Quality of Service on Power Delivery (RQS) in Portugal.

1. Introduction

Over the last two decades the electrical sector has undergone profound changes resulting firstly from attempts to respond to the rapid developments that have taken place in all of its domains. The main factors responsible for these transformations are: i) great technological advances and modifications of loads to which electricity flows; ii) globalization that currently forces many companies to compete globally without similar requirements on social and environmental responsibilities; iii) the operation of many processes with marginal levels of profitability, leading to a situation where the availability of electrical power with quality constitutes a *crucial factor* for competitiveness and survival; and iv) the emergence of more demanding customers for all types of products and services.

In their search for solutions, organisations involved in the electrical sector have sought to provide an increasingly higher level of quality, better suited to the new demands. The ways followed to achieve these objectives are: *1.* The adoption of liberalisation of the electrical sector around the world as an attempt to introduce market working rules, competitiveness, better management practices and better adapted electrical power to the new needs of the customers; *2.* Introduction of new technologies and equipment (mainly in the transport and distribution domains) that make it possible to achieve higher quality and reliability levels; *3.* Adoption of new policies in the supplier/customer relationship, translated into Directives for the Quality of Service on Power Delivery (RQS), which specifies – without ambiguities – the obligations for both sides, what is expected to be supplied by the utility (the minimum quality of service) and what are the customer's duties and responsibilities in the use of the energy received; and *4.* Adoption of directives that specify the minimum immunity level of the loads to support their functionality properly with the achievable and available quality, defined in the policies mentioned in the previous point 3.. In accordance with the current rules and directives the consequences in the customers activities attributed to the disturbances in the electrical power received – that do not match the rules – are the responsibility of the supplier [1].

As a consequence of the implementation of these policies over the last two decades, the sector has observed advances in the power quality and reliability levels widely available today. Nevertheless, that increase in the quality does not adequately match the growing demand of the loads which support the digital economy nowadays. Due to this fact we can say that the electrical power quality available today is inadequate for the demands of the customers' processes. The economic impacts resulting from this mismatch are widely known as *Power Quality Costs* and constitute an increasing preoccupation in all developed countries.

Due to these scenarios the existence of a new category of measuring equipment that continuously supports the monitoring and recording of relevant parameters regarding electrical power received is fundamental today. The device with these capabilities is the Power Quality and Reliability Meter and Recorder (PQMeters) and its usefulness can be, quite simply, grouped into following domains:

- The customer can know, in real-time, what kind of disturbances are received at their facilities, and use that information to claim his rightful demands from the supplier (if the disturbances do not respect the Quality of Service accorded in the RQS);
- Those responsible for the facility can use the information recorded to correlate registered disturbances with the perceived impacts (technical and economic) on their activity, and to identify where the weakest equipment in their processes is located. Based on this helpful information managers can quantify the disturbances in terms of monetary costs – the only language that the managers understand – and schedule well-supported decisions to mitigate power quality problems with the introduction of *Ride Through Capability Technologies* to increase the immunity of the weak components identified at the facility.

Among the available options to install PQMeters, the alternatives are: *1.* Traditional PQMeters, *2.* Solutions based in remote monitoring using telecommunication networks or the Internet; and *3.* The solution proposed in this paper. Options 1. and 2. are both expensive. In the third category we present an original solution called Power Quality Monitoring System (PQMon). It is characterized by its great simplicity, wide range of application and very low cost (negligible when compared with alternative solutions). The PQMon can be used to supervise and record the fulfilment of the power quality directives for monophasic systems and to account the Time of Accumulated Power Supply Interruptions (TIA) for any period. We will describe its philosophy of work and will present the results of its application in a case study where the electrical power supplied to an educational institution was monitored and recorded for a period of eleven months.

2. Power Quality supplied from the traditional systems

The traditional delivery system still predominant is not able to provide (in an economically viable way) electrical power with the desired level of quality and reliability for the proper functioning of the loads in the current digital economy. Modern transmission and distribution systems are limited from 99,9% to 99,99% availability. This value is highly dependant on the redundancy level of the network, which is different according to geographical location and voltage level. The typical demand processes in the modern digital economy need electrical power with at least 99.99999% availability (6-nines reliability) to function properly.

Between 1993 and 1999 the Electrical Power Research Institute (EPRI) carried out a study in the USA to examine the average duration of disturbances in order to characterize the PQ on Low Voltage distribution networks. This study concluded that 92% of disturbances in PQ were voltage sags with amplitude drops of up to 50% and duration below 2 seconds [2].

The situation in some European countries is very similar to that of the USA. Figure 1 shows the characterization of PQ in an industrial area of the Center of Portugal by monitoring of the supply (at 60 kV) in the period from February 1999 to January 2000 [3].

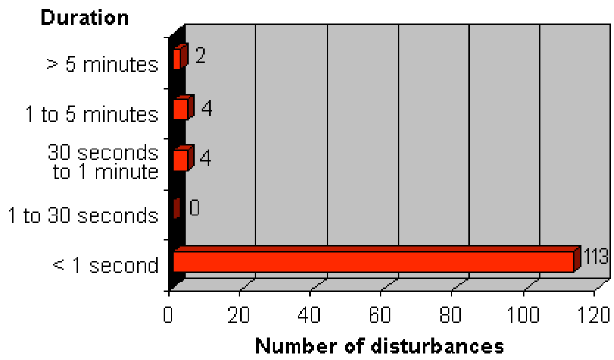

Fig. 1 – Characterization of the observed disturbances in an industrial facility in Portugal.

3. Power Quality Costs

The consequences of PQ disturbances are known as *Power Quality Costs* and these are highly dependant on several factors, mainly the business sector. Other factors, such as the sensitivity of the equipment used in the facilities and market conditions, also influence the dimension of PQ problems.

➢ Power Quality Costs Evaluation

The costs related to a PQ disturbance can be divided into • direct costs, • indirect costs and • non-material inconvenience.

• Direct costs can be directly attributable to the disturbance. These costs include damage to equipment, loss of production, loss of raw material, salary costs during non-productive periods and restart costs.

• *Indirect costs* are very hard to determine. Due to some disturbances and non-productive periods, a company may not be able to meet its deadlines for some deliveries, lose future orders and damage its image on the market. Investments to prevent PQ problems may be considered an indirect cost.

• *Non-material inconvenience*, some inconveniences due to power disturbances cannot be expressed in monetary terms, such as not being able to listen to the radio or watch TV. The only way to account for these inconveniences is to establish an amount of money that the consumer is willing to pay in order to avoid this inconvenience [4], [5], [6].

➢ Estimates on Power Quality Costs

Several studies have been carried out to evaluate the costs of PQ problems for consumers. The assessment of an accurate value is nearly impossible; so all these studies are based on estimates. The conclusions of some of these studies are: • *Business Week (1991)* points to PQ costs estimated at 26,000 million USD per year in the United States; • *EPRI (1994)* pointed to 400,000 million USD per year for PQ costs in the United States; • *US Department of Energy (1995)* pointed to PQ costs estimated at 150,000 million USD per year in the United States; • *E Source (2001)* a study comprising continuous process industries, financial services and food processing in the United States, estimated the average annual costs of PQ problems from 60,000 to 80,000 USD per installation; • *PQ costs in EU (2001)*, a study of the overall PQ costs in industry and commerce, in the European Union, are estimated at 10,000 million EUR per year [7].

The estimates differ greatly, but all point to a common factor: **PQ costs are extremely high**.

4. Different alternatives of PQMeters

As we have mentioned in the introduction, there area several types of PQMeters available today. These are:

➢ *Traditional PQMeters* **-** this type of PQMeters usually supports high capacity sampling, processing of information in real time, storage and display. The usual information monitored is: instant voltage levels, sags, overvoltages, dips, very short interruptions, long interruptions, voltage harmonic distortion, current harmonic distortion, voltage unbalance, energy consumed and, in more sophisticated situations, they can generate alarms and produce automatic reports concerning the situation.

➢ *PQMeters through telecommunication systems or the Internet* **-** this type of PQMeters integrates almost the same characteristics as the traditional ones, but they have transducers and sampling capacity to capture electrical parameters in the field and the processing, storage and displaying capacity in a centralized place. Their big advantages in comparison to traditional PQMeters are the use of powerful hardware and software that runs in traditional PCs to handle the information gathered from the field. The data can be remotely gathered and the information produced can be accessed, or automatically sent to any device connected via Web or any other interconnection system. The most common alternatives today use IP addresses, traditional modems via the telecommunications network or via wireless GSM network widely spread nowadays. This technology is cheaper than the traditional one to support similar capabilities.

➢ *Use of the monitoring capabilities supported by the modern Smart Uninterruptible Power Supply (UPS)* **–** the modern Smart UPS systems, in addition to their main function which is to assure continuous power supply to critical loads, incorporate extra hardware and firmware to support the monitoring of a large set of parameters related to the electricity received from the grid. When any disturbance occurs at the input of the Smart UPS its monitoring system produces a message (normally one ASCII line code) with the relevant data about that event (see Figure 3). It is this capability that we use to implement our PQMeter.

Therefore, the only hardware that we need to implement our PQMeter is a Smart UPS that is widely used today and a PC that is shared with normal tasks. As a result the cost of the system is very small (negligible when compared with alternative solutions) and the recording, processing and presentation capabilities are the same as those supported by PCs.

5. Implementation of the PQMeter

The designation attributed to the PQMeter presented in this paper is Power Quality Monitoring System (PQMon). Its philosophy consists basically in the use of sampling capabilities supported by a Smart UPS from APC (model SU700XL), the standard monitoring software provided with the UPS (PowerChute Plus 5.0 for Windows) and a software application, which we developed and runs on a PC to process the data gathered. The Figure 2 shows the layout of the system.

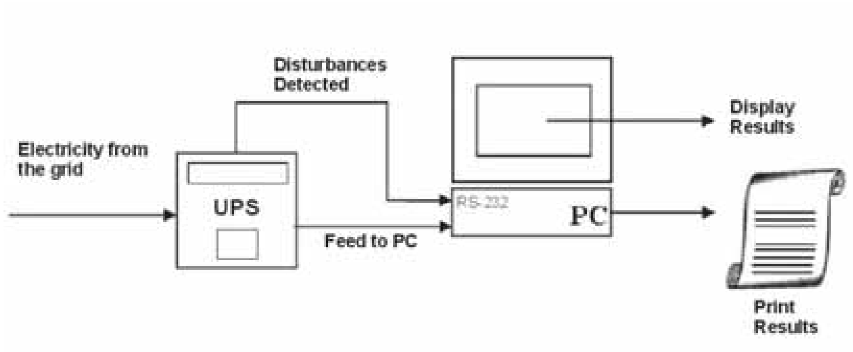

Fig. 2 – Layout of the Power Quality Monitoring System.

The format of the information generated by the Smart UPS for each event detected, labelled in Figure 2 as **"Disturbances Detected"** and sent via RS-232 to the serial port of the PC, is specified in Figure 3.

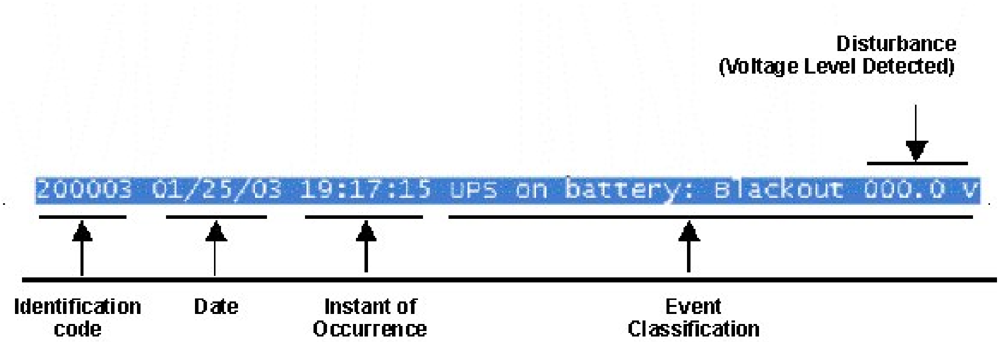

Fig. 3 – Format of the message generated by the UPS for each disturbance detected.

Table I presents a sample of the data received from the PC (one line register for each occurrence). Some of the registers correspond to real disturbances detected that are relevant to the function of PQ Metering (the underlined ones) and others correspond to the operation status of the Smart UPS and do not have relevant data for our application. Thus, the first step carried out by the software application is to filter the information so as to retain only the relevant data.

Table I – Sample of the data gathered by the PC.

Id. Code	Date	Time	Event Classification (Disturbance detected)
100403	01/06/03	21:16:10	Self-test at UPS passed
200005	01/12/03	07:12:53	UPS on battery: Small momentary spike 237.9 V
100300	01/12/03	07:12:53	Normal power restored: UPS on line
200004	01/12/03	09:59:10	UPS on battery: Small momentary sag 215.8 V
100300	01/12/03	09:59:10	Normal power restored: UPS on line
100200	01/13/03	10:24:18	Communication established
200006	01/14/03	09:00:44	UPS on battery: Deep momentary sag 224.9 V
100300	01/14/03	09:00:44	Normal power restored: UPS on line
100000	01/14/03	17:31:13	*** PowerChute PLUS Version 5.0 Started ***
100200	01/14/03	17:31:23	Communication established
200003	01/25/03	19:17:15	UPS on battery: Blackout 000.0 V
100300	01/25/03	19:17:17	Normal power restored: UPS on line
200002	12/01/03	09:55:35	UPS on battery: Brownout 193.7 V
...			

Using the data shown in Table I as a source, our application supports the following functionalities to generate detailed information related to the level of Power Quality and Power Reliability at the point of measurement:

1. Presentation of disturbances over the CBEMA/ITIC Curve;
2. Presentation of disturbances in chronological order of occurrence;
3. Statistical distribution of disturbances by types;
4. Presentation of disturbances by duration;
5. Separation of disturbances by classification and ordered chronologically;
6. Accounting of TIA.

6. Performance of the PQMon (case study application)

In order to evaluate the performance of the PQMon we have applied our solution to process a file with all the information gathered from January 6, 2003 to December 1, 2003.

The designations used to classify the information processed are carried out in accordance with the specifications of the NP EN 50160 directive. The practical results are displayed and commented bellow.

Option 1: Presentation of disturbances over the CBEMA/ITIC Curve.

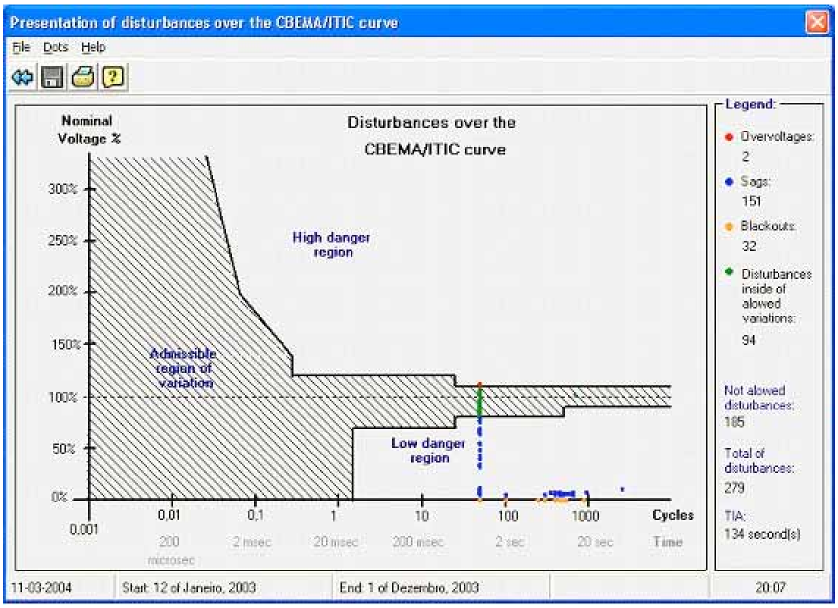

Fig. 4 – Disturbances over the CBEMA/ITIC Curve.

Comments: In this option we can observe that during the period of study, 279 disturbances were detected by the PQMon, with 94 in the admissible region of variation (±10% of nominal tension, small sags and small overvoltages) and 185 outside the admissible variation region. In this group, 2 are overvoltages, 151 are sags and 32 are blackouts. We can also see that, at the measuring point, the TIA during the period was 134 seconds.

Option 2: Presentation of disturbances in chronological order of occurrence.

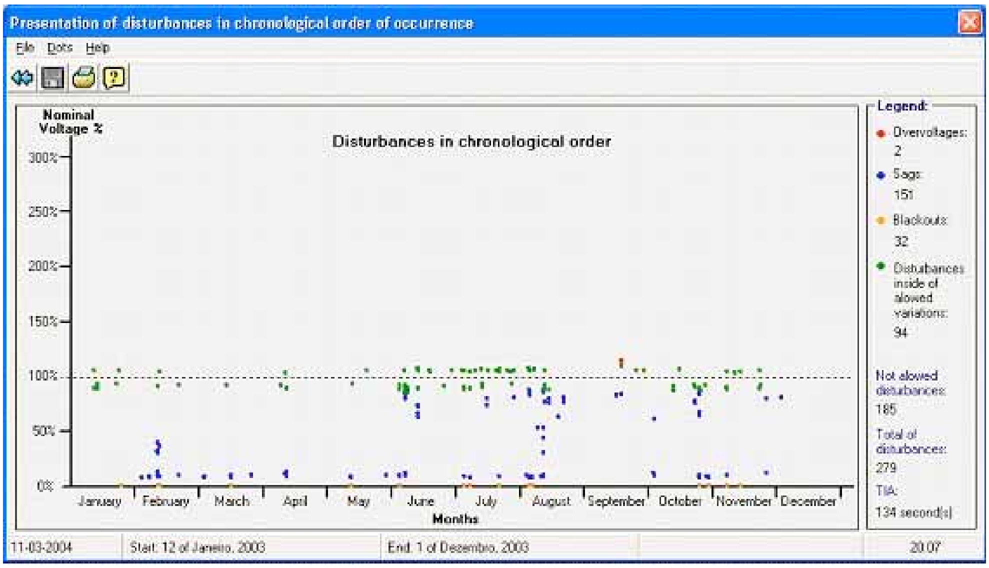

Fig. 5 – Disturbances in chronological order of occurrence.

Comments: In this option we can observe the severity of the disturbances detected and their chronological evolution. We can identify a high incidence of disturbances in the months of June, July and August. This fact was provoked by the wave of forest fires that affected Portugal in 2003 and the exposure of the High Voltage transmission lines that pass through the forests.

Option 3: Statistical distributions of disturbances by types.

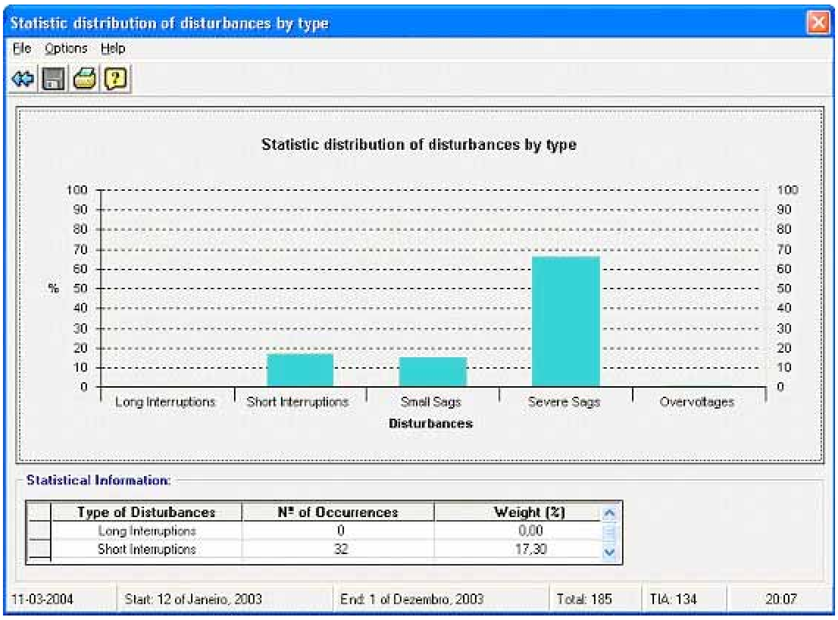

Fig. 6 – Distribution of disturbances by types.

Comments: In this option we can observe the separation of all the disturbances by types. In accordance with the NP EN 50160 norm there is no register of long interruptions, short interruptions present 17,3% of the disturbances, the small sags, about 15% and the severe sags over 67% of the disturbances.

Option 4: Presentation of disturbances by duration.

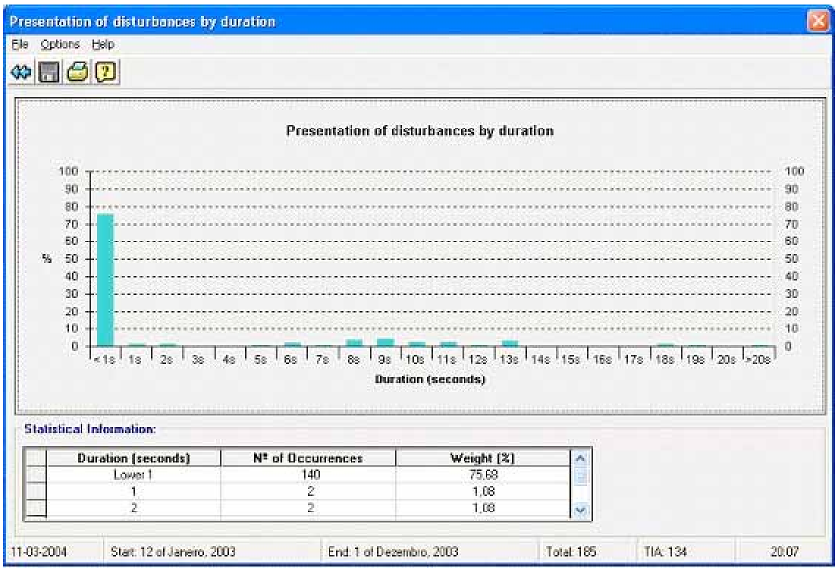

Fig. 6 – Disturbances by duration.

Comments: In this option we can observe a histogram with the distribution of disturbances by duration. It is evident that the predominance (75,68%) of disturbances are under one second. This information in accordance with all the studies conducted all over the world [2] due to the operation of automatic reclosers largely used today, with a typical actuating delay of 400 ms in Portugal.

Option 5: Separation of disturbances by classification and ordered chronological.

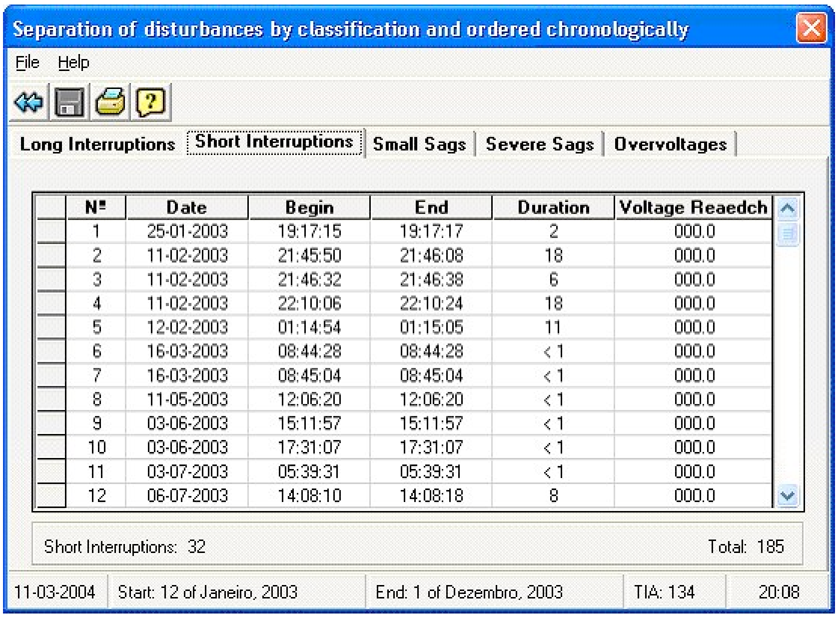

Fig. 7– Evolution of all the types of disturbances in time.

Comments: In this option we can visualize and print detailed reports of all the monitored and recorded disturbances. That includes type, instant of occurrence, duration and value. The available sub-options are: 1. long interruptions (or long blackouts), 2. short interruptions (or short blackouts), 3. small sags, 4. severe sags and 5. overvoltages.

7. Conclusions

With the practical results reached we can conclude that our solution is good enough to supervise and record the relevant information about the performance of the electrical power supply system (at the measuring point). It is obvious that the capability and performance of the traditional PQMeters is superior, but for many situations the type of information produced with the PQMon is sufficient and very useful; and the investment involved is insignificant.

The biggest limitation of the PQMon is the restricted sampling capability of the hardware from the Smart UPS monitoring system. In order to supervise compliance with the NP EN 50160 norm and the Portuguese RQS by the supplier (within the relevant parameters of the monophasic systems) it is more then sufficient.

The PQMon constitutes, then, a powerful tool characterized by its low cost and great usefulness in these domains.

If you want to have a cheap Power Quality and Reliability Recorder, please contact us, the software is available.

8. References and Bibliography

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