Measure-Based Method for Detection of Special Events in Power Distribution

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***Abstract*— Most quality regulations distinguish between different types of interruptions or events. The ones that affect to a lot of customers or last a long time period, what we call here special events, can be caused either by the so-called *force majeure* causes or by a lack of investment in order to avoid outages with a very low probability of occurrence. In this paper, a measure-based method is proposed in order to accurately define special events, in a clear, transparent and non-discriminatory way. It is a flexible method which can be adapted to various regulations and circumstances of different systems. The case of study contains all the interruptions data of a real distribution company with over 2,100,000 customers, during 4 years.**

***Index Terms*— Power distribution reliability, power quality, performance-based ratemaking, statistics, major events.**

I. Introduction

THE regulation of the supply activity has been affected by the changes of electricity markets. The activity is a natural monopoly, but its regulation and remuneration scheme have changed in several countries. The methods commonly applied in the regulation of supply try to stimulate efficiency and encourage cost reductions. In order to achieve this target, the income of the companies is indexed somehow to their efficiency. These remuneration schemes are called Performance Based Ratemaking (PBR) schemes [1]-[3].

The traditional regulation of supply used lax rules in order to ensure the reliability of supply, and usually they worked. Additionally, the demand of reliability and its control was not as strong as nowadays. The cost reduction encouraged by PBR schemes can lead to a degradation of the system's reliability, in a time when the demand of a good reliability level is raising rapidly in supply systems. Consequently, it is necessary to implement an explicit power quality regulation. Several countries have imposed a power quality regulation, establishing minimum quality levels or more sophisticated schemes [1]. Power quality regulations often deal with usual interruptions, which last a reasonable time period and affect to a limited number of customers.

Besides usual interruptions, there are some events in the power supply system that can be defined as special events. They affect to a very large number of customers or last a long time period. Special events have strong social, economical and even politic consequences. Its related costs are much larger than the ones caused by normal interruptions.

Special events may have two causes: extreme conditions that are beyond the design limits of the system, or lack of investment in order to avoid big, low-probability faults. Many quality regulations deal with the former kind of special events, usually called *Force Majeure*. Usually, the specific regulation of events that fall under the denomination of *Force Majeure* tries to protect distribution companies, excluding the special events from the calculation of reliability indexes and avoiding that the companies pay for the *Force Majeure* interruptions that have taken place. However, there's not a specific regulation for special events that are caused by a lack of inversion. Those events should be taken into account by regulators, in order to impose deterrent penalizations when they take place.

This paper proposes a method in order to characterize special events, both the ones which can lay under the denomination of *Force Majeure* and the ones which are caused by a lack of inversion. A simple, clear and non-discriminatory regulation framework is proposed. For this purpose, real interruptions data of a distribution company are used, taking into account the interruptions suffered by over 2,100,000 customers along a 4-year period. This work is intended to complete the previous paper [4], including a revision of the state of the art and a deeper look at the data.

This paper is organized as follows. Section II is devoted to existing power quality regulations, and the state of the art concerning special events. In Section III, real interruption data from a distribution company are statistically analyzed, in order to develop an adequate method to characterize special events. Section IV proposes a regulatory scheme that characterizes special events in order to establish deterrent penalizations for this kind of events.

II. Continuity Of Supply And Special Events Regulation.

One essential aspect of power quality regulation is the continuity of supply, also called reliability [2], [5]. Usually, the continuity of supply refers to interruptions that last more than 3 minutes, therefore excluding interruptions that can be eliminated through automatic mechanisms.

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PBR regulatory schemes often regulate the continuity of supply on an incentive-based system. In most of the countries that have implemented this regulation, the measured quality levels are compared with reference or limit levels. The quality levels are measured through global or individual quality indexes depending on the country, and depending on how sophisticated the regulation is. Anyway, if the measured quality levels are worse than the reference or limit levels, companies may be penalized.

The amount of penalizations is determined according to the non-supplied energy cost, or to the cost of each interruption. Different kinds of customers have different costs of non-supplied energy, thus they suffer different costs due to interruptions. For instance, a five-minute long interruption has not the same consequences for a domestic customer as for an industrial customer. The first one will not suffer strong economical consequences, whereas the second one can lose a lot of money because of the same interruption.

The control of power quality using global or individual indexes tries to lead the utility performance to an optimal point. It tries to send an adequate economic signal to distribution companies, so they invest in order to improve quality towards an optimal level [5]. At this optimal level, an equilibrium between quality investment and penalizations is achieved.

If the regulation described above is well designed, it can work properly with usual interruptions. The economic signal that companies perceive using this scheme is adapted to repetitive events, which have a relatively high probability of occurrence. These events cause relatively low costs to users.

When an interruption lasts for a long period of time, or when many customers are affected, its consequences are largely different. The power quality regulation scheme mentioned above does not work properly. This kind of interruptions can be called special events. Special events have strong economical, social and even political consequences. The costs caused by these events are much higher than the proportional costs caused by usual events. That's a reason because special events shall be considered distinctly than common events in the power quality regulation. Additionally, they shall be excluded in the calculation of global indexes that are to be used in order to evaluate system's quality under normal conditions [6].

Special events can have two main causes:

- Extreme natural conditions that force the system to work in a way that it is not designed for. For example, ice storms, earthquakes and hurricanes. Many times this kind of events are classified under the denomination of Force Majeure or Major Events. IEEE Trial Use Guide P1366 [7] defines a major event as a *"catastrophic event which exceeds reasonable design or operational limits of the electric power system and during which at least 10% of the customers within an operating area experience a sustained interruption during a 24 hour period"*. Most studies about special events are focused on this kind of catastrophic events, and the concept of Force Majeure [8]-[10]. References [8]-[11] try to improve the definition of P1366, as it's not completely clear and non-discriminatory.
- Lack of investment that should be made to avoid low-probability but critical events, or the absence of an adequate crisis management. In this case, serious outages can be suffered by customers, and they can't be justified by Force Majeure reasons. An example of this kind of events is the fire of a HV/MV substation. Distribution companies shall perceive then an adequate economic signal (deterrent penalizations) in order to avoid this kind of special events. Therefore, they will invest money to prevent these events despite of their low probability.

In order to appropriately handle the regulation of special events, they have to be characterized in a proper way. The events that can lay under the denomination of *Force Majeure* should be treated in a different way than special events that are caused by a lack of investment, which should be strongly penalized.

A possible scheme that could be considered in order to avoid special events is a deterministic criteria based scheme. These kinds of criteria are usually applied to events that have their origin in the transmission network, which cause also important outages. For instance, N-1 and N-2 criteria are commonly used for the design of transmission networks. The authors think that those methods should not be applied to distribution networks, due to several reasons. Firstly, the complexity and extension of distribution networks, even concerning at high-voltage levels, makes it very difficult to apply deterministic criteria. Secondly, the regulation framework should let the distribution company invest and plan the network expansion as freely as possible. Besides, the method to avoid special events should also be as coherent as possible with the general regulation framework.

In this paper, real interruptions data from a distribution company are analyzed in order to develop a method to appropriately characterize special events. This method is clear, non-discriminatory and easy to apply. Besides, it is simple enough to be understood even at not expert level. It tries to be as coherent as possible with general power quality regulation schemes. This paper also proposes a suitable regulatory scheme in order to estimate the appropriate deterrent penalizations to be applied when an special event is caused by lack of investment. These penalizations should send an adequate economic signal to avoid that kind of special events.

The data analyzed in this paper belong to a distribution company which supplies energy to more than 2,100,000 customers, in a mostly urban market. They include a very important interruption that took place on 1999. More than 150,000 customers were affected, and some of them suffered the interruption for more than 10 days, due to a combination of under-investment, inadequate crisis management and bad luck. The interruption had strong social, economical and political consequences.

In the case studied, the regulator dealt with special events through ex-post measures. He applied a high penalization to the company. The amount of the penalization was determined using an estimation of the economic consequences of the interruption that had taken place. The total amount of the penalization was nearly equal to the net profit of the utility during that year. As the measure was taken ex-post, the utility refused paying the fine, as it was not part of the regulation. The case took long time to get to a solution in the court.

III. Real interruptions analysis.

The results presented in this paper were obtained from real interruption belonging to a distribution company. It is a company that supplies energy to more than 2,100,000 customers, in a mostly urban environment.

The data are taken from a four-year control period. During this period, all the individual interruptions suffered by customers were registered. The interruptions with a high-voltage, medium-voltage and low-voltage origin were included. However, only the interruptions with high-voltage and medium-voltage origin were studied for this paper, due to two reasons. Firstly, a high percentage of interruptions suffered by customers (80%) have a medium or high voltage origin. Secondly, the interruptions that have a low-voltage origin usually affect to a low number of customers. Consequently, they cannot be included among special events, unless they last for long periods of time. Anyway, the method used for the registration of low-voltage origin interruptions is via warnings, so it is less accurate than the registration of medium and high-voltage origin interruptions. Consequently, low-voltage events are not considered from now on.

More than 31,000 interruptions were registered during the four-year control period. Each interruption has a set of associated repositions, so that the total number of repositions is about 42,500.

From the total amount of repositions registered, about 41,000 (95%) belong to medium-voltage origin interruptions. The number of repositions that belong to high-voltage origin interruptions is about 1,500 (5%). However, the number of customers affected by high-voltage interruptions is usually much higher, whereas medium-voltage interruptions are usually longer.

Most studies about special events focus on daily measures of quality indexes, like SAIDI or SAIFI. Thus, they try to obtain the days of the year that can be classified as major event days. In [8], daily SAIDI indexes are assumed to have a log-normal distribution, and major event days are classified taking into account some properties of this probability distribution (beta method). In [9], daily SAIDI and SAIFI are used jointly to obtain major event days, using their ratio (CAIDI index) to make a bound for major event days. That days are to be excluded for quality control, thus obtaining a system which is clearer than the definition of [7]. In [9], it is also proved that daily SAIDI index can’t be assumed to be log-normally distributed.

In this paper, advantage is taken of the large amount of information that is available. Thus, single events are used, instead of average measures like SAIDI an SAIFI.

There are two essential measures that are useful for the objectives of this paper. The first one is the duration of each event that has taken place. The second one is the number of customers affected by each event.

In order to properly analyze data and to obtain results, it is necessary to accurately define what is considered an event. For each interruption, there is a set of associated repositions. In each one of the repositions, the power supply is recovered for a set of customers. The service is reposed little by little, until there are no interrupted customers.

In this study, each reposition is associated to an event. The duration of the event is the time lasting between the moment on which the interruption took place and the moment of the reposition.

It is also important to define how the number of affected customers is obtained. It is considered that, for each event, the affected customers are all the customers affected by the interruption that are still without power supply. In other words, the customers affected are the customers who are reposed at that moment plus the ones who are reposed later and have been affected by the same interruption.

The definition of the number of customers affected by events and their duration is illustrated with the following example. An interruption with three associated repositions is considered. The table I indicates the total number of customers affected, and the customers reposed in each reposition. The time lasted between the beginning of the interruption and each of the repositions is also specified.

TABLE I
EXAMPLE OF EVENTS DEFINITION

Reposition	Customers	Time (minutes)
1	327	27
2	521	67
3	211	142
Total	**1059**	**142**

The interruption presented in this example would have three related events. Firstly, the interruption affects to 1059 customers. 27 minutes after the interruption, 327 customers recover their power supply. Thus, the first event has a duration of 27 minutes, and customers affected are the total number of customers affected by the interruption, i.e., 1059 customers. 67 minutes after the interruption, there is another reposition, related to the second event. The number of customers considered for this event is the total number of customers that still without power supply since the first event, i.e., 1059-327=732 customers. This second event lasts 67 minutes. Finally, 142 minutes after the interruption, the power supply is recovered for all customers. Thus, the third and last event has a duration of 142 minutes, and customers affected are the ones that do not have their power supply recovered until this moment, i.e., 211 customers.

This definition of events is appropriate to characterize the special events and to statistically study them. However, it is necessary to take into account that some clients are computed more than one time for each interruption. Thus, the 732 customers that are computed on the second event related to the example are also computed on the first event. This fact must be considered when determining the penalizations which are going to be imposed to the company. Otherwise, customers affected by a special event could be computed more than one time.

Once events have been properly defined, they can be statistically studied. By this way, special events can be identified. Table II includes a summary of the basic statistical data of duration and number of customers affected by studied events.

The histograms obtained for duration and customers affected are represented in figures 1 and 2, respectively.

TABLE II
BASIC STATISTICAL DATA

	Mean	95% percentile
Customers affected.	1,980	6,486
Duration (hours)	3	8.18

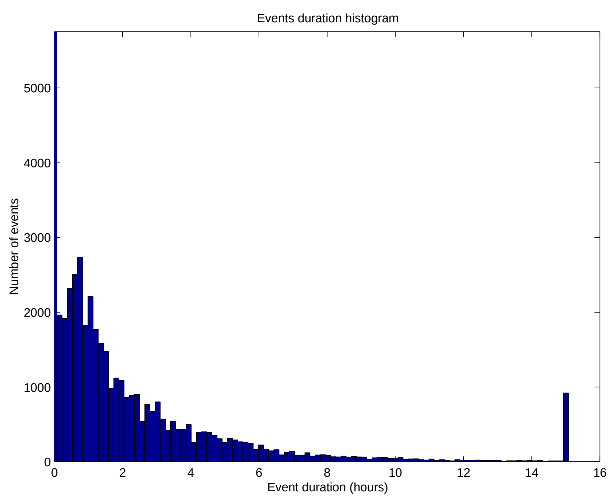

Fig. 1. Event duration histogram.

Figure 1 represents the histogram of the duration of events. The bar placed at the right side represents the accumulated number of events that last more than 15 hours. It can be observed that most events (96.53%) do not last more than 10 hours.

Figure 2 represents the histogram of the amount of customers affected by events. Most events do not affect to more than 5000 customers. The bar placed at the right side represents the accumulated number of events that affect to more than 10,000 customers. The events that affect to more than 10,000 clients are 2.07% of studied events.

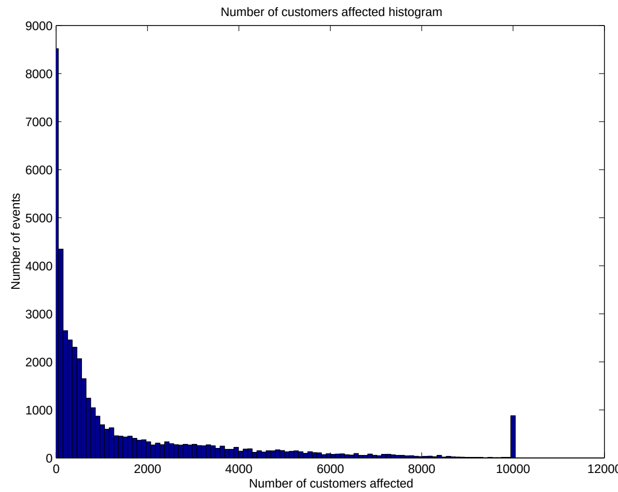

Fig 2. Affected customers histogram.

The set of data of duration of events and number of customer affected can be tested in order to check if it can be assumed that they have a log-normal distribution function. The Kolmogorov-Smirnov test was applied to both sets of measures. The result of this test was that the hypothesis can be rejected for both sets, with significance level of 0.05. As it can be seen on the histograms, the weight of the first column (this is, the left tail of the distribution) is too high to assume a log-normal distribution.

The most appropriate graphic representation of events is a representation on a duration-number of customers plane. This is, the x-axis represents events duration and the y-axis represents the number of customers affected. Each event is represented by a point. This kind of representation allows to clearly evaluate the magnitude of an event, using its most important characteristics (number of customers and duration) to locate them in the plane. Thus, it is easy to identify special events, which last a lot of time, affect to a very large number of customers, or both. Special events are the ones that fall far from axis.

The representation of real events on the time-number of customers plane is represented on figure 3. It can be observed that most events fall very near to the lower-left corner. The total number of points is about 42,500. Many of the events that fall far from lower-left corner can be considered special events. As it can be seen in figure 3, special events represent a very little part of the events that can happen in the company network. This kind of events has a very low probability of occurrence. This fact causes that the distribution companies may not take into account the risk of these events when planning their network investment, specially in the new regulatory frameworks (PBR) where cost restrictions are imperative.

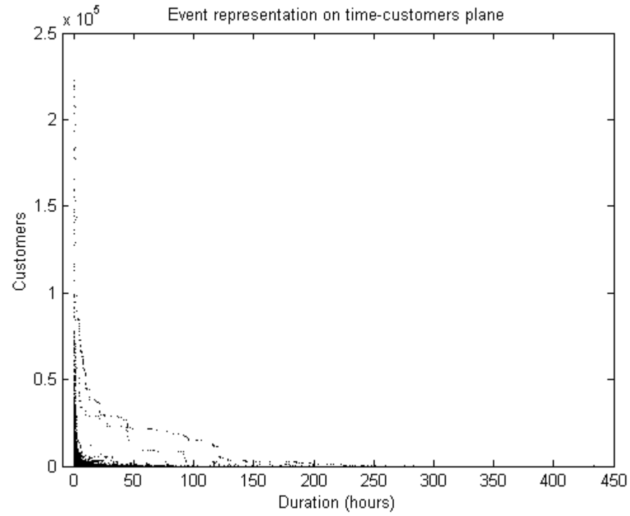

Fig 3. Event representation.

Many of the events which fall far from the lower-left corner correspond to the long interruption mentioned above, which took place on 1999. The events related to that interruption are represented on figure 5 as crosses, while the other events are represented as points. It can be observed that very few events are far away from the lower-left corner besides the ones related with the long interruption.

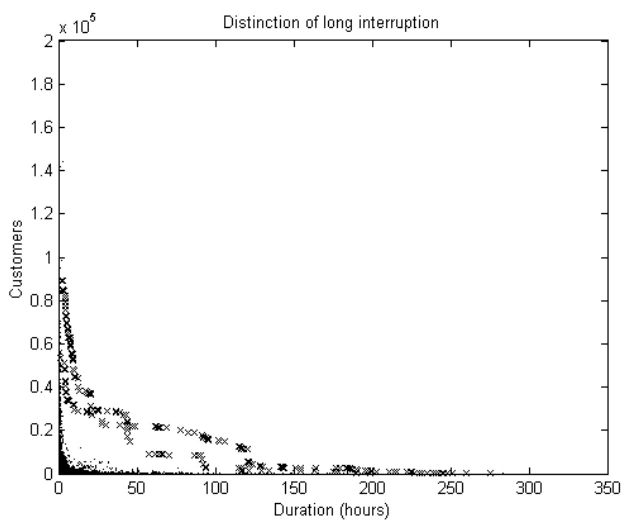

Fig. 5. Contrast of events related to long interruption and the others.

There are also very few events which last a short time but affect to a very large number of customers, and fall near the upper-left corner of the representation in the duration-number of customers plane. That events usually are interruptions which have a high-voltage origin.

Figure 4 represents events on the duration-customers plane, but making distinction between high-voltage events and medium-voltage events. High-voltage events are represented as crosses, and medium-voltage events are represented as circles. In this case, it can be observed that most high-voltage events affect to a high number of customers. If events related to the long interruption are not taken into account, it can be said that usually medium-voltage events affect to less customers but last more time than high-voltage events.

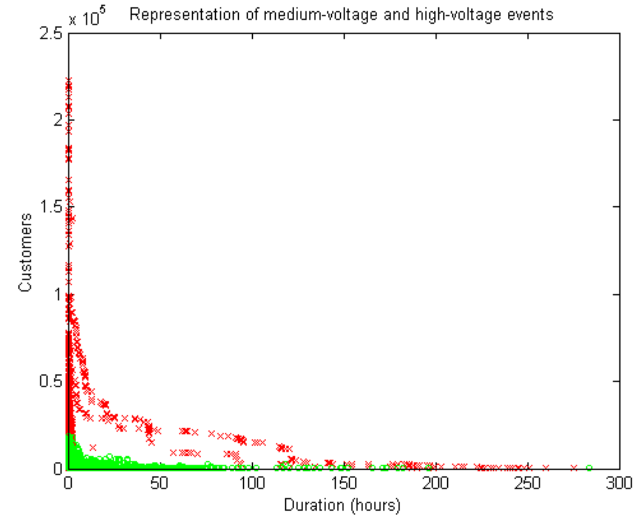

Fig. 4. Medium voltage and high-voltage events.

IV. Special events characterisation.

Once the events have been statistically analyzed, special events shall be accurately defined. The objective is to establish a clear, simple and non-discriminatory method to classify special events. Then, deterrent penalizations should be applied to events which don't fall under the denomination of *Force Majeure*. One of the targets of this method is to enclose events which have its origin on the high-voltage network. By this way, an adequate economic signal can be sent to companies in order to avoid these harmful events.

An event can be considered special because of an excessive duration, an excessive number of customers affected or a combination of both factors.

The most suitable method in order to define special events is to create a bound on the time-customers plane. Non-special events shall be contained inside this bound. The special events shall fall out of bounds.

In order to give shape to the bound, three possibilities were considered:

- Exponential curve.
- Asymptotic curve.
- Linear bound.

The possible bounds shall verify the following condition: Most of the events related to the long interruption of February 1999 should fall out of bounds.

Besides, two limits were imposed for events:

- Events which last more than 96 hours should be always considered special.
- Events which affect to more than 100,000 customers should also be considered special, independently of their duration.

These two limits were imposed taking into account the statistics of analyzed events. They could be changed in order to adjust them to any kind of supplied markets.

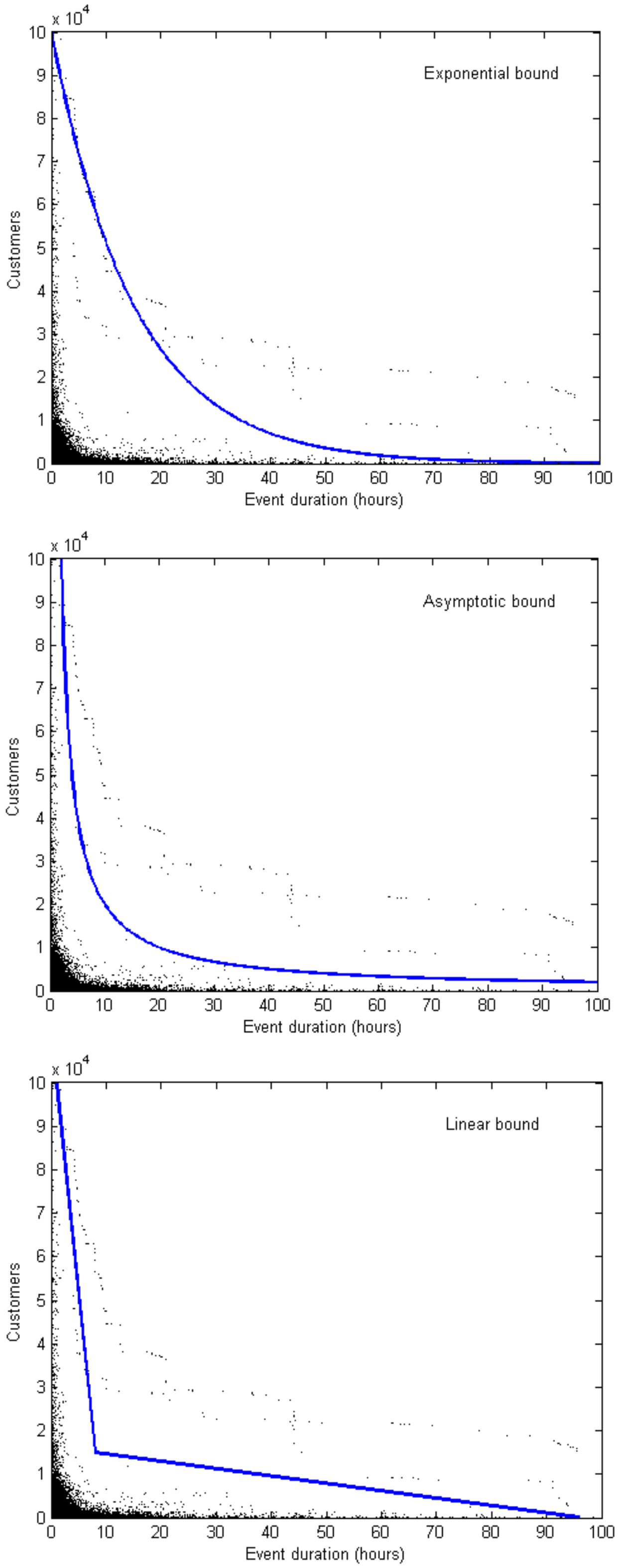

Fig. 6. Possible bounds.

The three possibilities that were considered are represented on figure 6, together with events. Exponential curve does not seem the best shape for the bound. It does not fit well with event data, and includes a lot of special events inside bounds. A lot of events related to the long interruption of February 1999 are inside bounds if exponential shape is used.

The asymptotic curve is the bound which has a clearest physical meaning, because its shape corresponds to the formula:

$$N \times T = k \quad (1)$$

where N is the number of customers affected by events, and T is the duration. k is a constant value that could be considered as an approximation to non-supplied energy. Thus, the bound would be proportional to a limit value of ENS for any event occurred.

Finally, linear bound was selected, due to a powerful reason. Although asymptotic curve fits well to special events and has a clear theoretical meaning, linear bound is much more simple and flexible, and can be easily defined by three points, reaching the same result with a simpler and more flexible definition.

The three points, together with the conditions mentioned above, define the bound accurately. It is set up by two lines. If necessary, the three points can be changed depending on the country or the supplied market and its characteristics.

The bound that best fits the event data used is represented on figure 7. The three points that define the bound are the following:

- The first point represents 100,000 customers and 1 hour duration. It is considered that any event that affects to more than 100,000 customers shall be classified as special.
- The second point is placed at 8 hours and 15,000 customers. Is the point in which both lines cross.
- The third point is placed at 96 hours and 100 customers. Any event which lasts more than 96 hours (4 days) is classified as a special event.

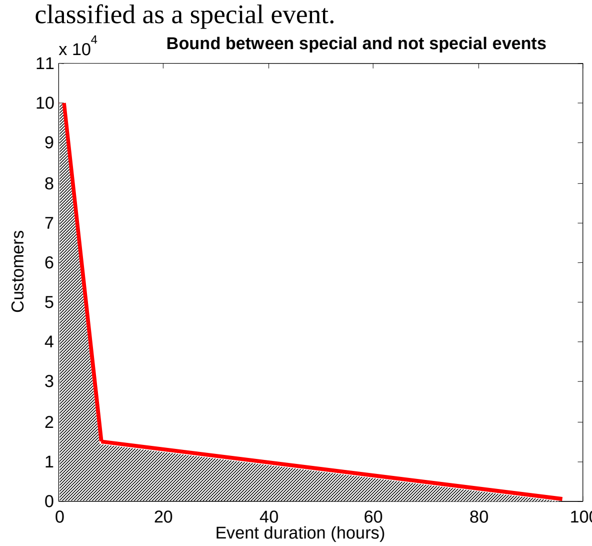

Fig. 7. Linear bound for special events.

All events studied are represented on figure 8, together with the defined bound. The events related to the February 1999 interruption are marked with crosses.

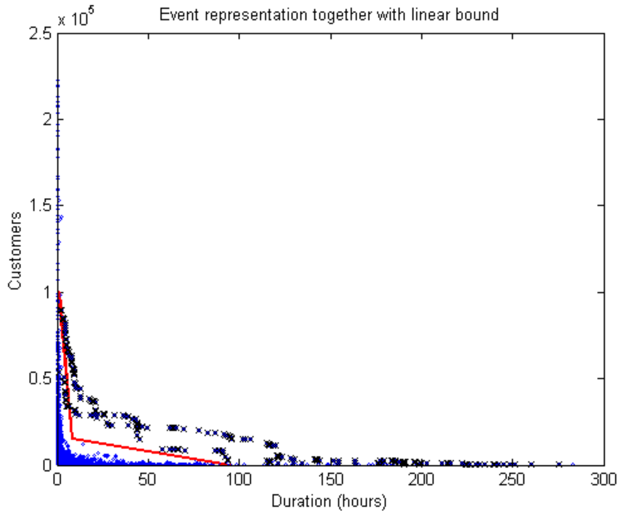

Fig. 8. All-event representation together with linear bounds.

It can be observed that almost all events related to that interruption fall out of bounds. Even though there are some of the events which are not related to that interruption fall out of bounds, but they are very few and usually correspond to high-voltage interruptions which affect to a large number of customers during a short period of time. The authors think that it is correct to classify them as special events too.

Once the bound is defined, event data can be statistically analyzed and classified. The results of the events classification are summarized on table III. Besides of the complete set of events, three sets were separately classified. Firstly, interruptions with a HV origin, which present a considerable percentage of out-of-bounds events. Secondly, MV interruptions are classified. Very few of them can be considered as special events. At last, events related to the long interruption of February 1999 are classified. Most of them fall out of bounds.

TABLE III
SUMMARY OF EVENTS OUT OF BOUNDS AND INSIDE BOUNDS

	Absolute		Events out of bounds (%)
	Events	Out of bounds	
HV	1,363	258	18.93
MV	40,908	27	0.07
Long interruption February 1999	234	218	93.16
Total	42,428	285	0.67

Once special events are defined, adequate deterrent penalizations shall be established. The adequate penalizations depend on the country and the characteristics of its regulation.

The most suitable method for determining penalizations on a power quality regulation framework is to evaluate the cost of interruptions or energy non-supplied. The fines imposed to distribution companies are calculated depending on this value and the number and duration of interruptions.

If an special event takes place, affected customers should receive direct compensations. Each user should be computed only once for each interruption related to special events. As it was mentioned above, if the set of events related to an interruption are considered separately, customers could receive double compensations.

The value of energy non-supplied in order to determine the compensations related to an special event should be about twice or three times as much the normal value of non-supplied energy. This value may send correct economic signals to distribution companies, to invest in order to avoid special events that cannot be considered as *Force Majeure*.

V. CONCLUSIONS.

Many energy supply regulations deal with interruptions which affect to a lot of customers or last for a long time period. Usually, the regulation concerning this kind of interruptions uses the concept of *Force Majeure*, in order to treat in a different way the interruptions which are caused by abnormal working conditions. However, it's not considering the fact that special events can be produced due to a lack of investment. The very-low probability of occurrence of these events provokes that utilities don't perceive an adequate economic signal that forces investment in order to avoid them, specially in new power regulations (PBR) where cost reduction is imperative.

A measure-based method to characterize special events has been proposed in this paper. Using the proposed method, an event can be easily classified as special. A deterrent penalization should be associated to special events in order to avoid them and to send a correct economic signal to distribution companies.

The proposed method is applicable on a PBR framework of power quality regulation. Consequently, special events with harmful consequences can be avoided without applying deterministic criteria. The proposed characterization is consistent with usual power quality regulations, and it allows distribution companies to plan their investment and management in a liberalized frame. It takes advantage on the increasing computational ability to register and analyze events related to distribution activity.

Using the method proposed, ex-post measures can be avoided when an special event takes place. As deterrent penalizations are previously defined, the problems associated to ex-post measures are prevented.

REFERENCES

[1] R. Baldwin and M. Cave, *Understanding regulation. Theory, strategy and practice*: Oxford University Press, 1999.

[2] T. Gómez San Román and J. Rivier Abbad, "Distribution and power quality regulation under electricity competition. A comparative study," presented at International Conference on Harmonics and Quality of Power, Orlando, Florida, 2000.

[3] J. Román Úbeda, T. Gómez San Román, A. Muñoz, and J. Peco, "Regulation of distribution network business," *IEEE transactions on power delivery*, vol. 14, pp. 662-669, 1999.

[4] J. Cimadevila and J. Rivier, "Characterisation of special events in new power quality regulation frameworks," presented at Med Power, Athens, Greece, 2002.

[5] J. Rivier Abbad, I. De la Fuente, T. Gómez San Román, and J. Román Úbeda, "Power quality regulation under the new regulatory framework of distribution systems," presented at 13th PSCC, Trodheim, Norway, 1999.

[6] J. D. Bouford, "The need to segment abnormal events from the calculation of reliability indices," presented at Summer Power Meeting 2002, Chicago, Illinois, USA, 2002.
[7] IEEE, *IEEE P1366 Trial Use Guide for Electric Power Distribution Reliability Indexes*. Piscataway, NJ: IEEE Press, 2000.
[8] R. D. Christie, "Statistical classification of major event days in distribution system reliability," *IEEE transactions on power delivery*, vol. 18, pp. 1336-1341, 2003.
[9] E. Fumagalli, L. Lo Schiavo, S. Salvati, and P. Secchi, "Statistical identification of major event days: An application to continuity of supply regulation in italy," Dipartimento di Matematica, Politecnico di Milano MOX Report No. 38, April 2004.
[10] C. A. Warren, J. D. Bouford, R. D. Christie, D. Kowalewski, J. McDaniel, R. Robinson, D. J. Schepers, J. Viglietta, and C. Williams, "Classification of major event days," presented at PES General Meeting, 2003.
[11] C. W. J. Williams, "Major Reliability Events - Self-Defining?," presented at Power Engineering Society Summer Meeting 2002, Chicago, Illinois, USA, 2003.

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