Statistical Identification Of Major Event Days: An Application To Continuity Of Supply Regulation In Italy

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***Abstract*—The Italian regulatory mechanism for quality of service in electricity distribution links the tariff to the SAIDI indicator of average duration of interruptions per consumer. In order to separate major interruption events data from normal operation data the regulator introduced, in the year 2000, a criterion based on a given definition of *Force Majeure*. For the new regulatory period, beginning in 2004, the authors studied the possibility of substituting this criterion with one based on a statistical definition of *major event days*. The statistical two step methodology proposed here was tested using real data, compared with other statistical criteria found in the literature, and proposed to interested parties in the consultation process; it was found to be at the same time equitable, unambiguous and simple to implement. This criterion was thus adopted in the new regulatory framework.**

***Index Terms*--Continuity of service, electricity distribution, major event days, performance-based regulation, statistical methodology.**

I. Introduction

QUALITY regulation in electricity distribution has received significant attention in recent years, following a widespread adoption of performance-based regulation in the form of a price cap. It is known that price cap regulation, while providing strong incentives to reduce costs, always results in quality levels that are sub optimal [1]. Regulators, thus, usually design incentive mechanisms specifically targeted at quality of supply, assuming the form of financial penalties and rewards for the distribution company. A common problem encountered in implementing these incentive mechanisms is the treatment of major events. These are events that affect a very large number of consumers and/or that last for long periods of time. They present a low frequency of occurrence but also potentially high social and economical consequences, as well as a significant impact on the amount of penalties paid by the distribution utility.

Most regulatory authorities have established guidelines for identifying major events and treat them separately from the set of normal operation data. The identifying principle usually refers to a given definition of what is a *major event.* For instance, the Trial Use Guide P1366 [2] 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*. Identification of major events based on definitions of this type has been questioned in the literature for being not sufficiently equitable or unambiguous [3]. New definitions have been proposed, mainly based on frequency of occurrence criteria for classifying operating days into normal days and major event days (MEDs), i.e. days when reliability of the distribution system is significantly worse than normal. These methods use historical data from previous years to calculate a threshold for daily System Average Interruption Duration Index (SAIDI). When the SAIDI of a day in the current year exceeds the threshold, that day is classified as MED. These approaches are based on the observation that MEDs are large, rare events that are found on the right tail of the distribution of daily SAIDI; hence the threshold is set using the mean and standard deviation of the distribution [3], [4].

Other definitions are more focused on the idea of *Force Majeure.* In this case, an event is considered due to *Force Majeure* when it is outside of the range of normal situations or contingencies for which the utility can reasonably or economically design its facilities to operate without interruptions to service.

The Italian regulator adopted this latter approach in 2000 [5]; however, its application, during the regulatory period 2000-2003, resulted in some practical cases quite troublesome. The experience suggested trying to simplify the procedure, identifying an “exceptional event” on the basis of the nature of the interruption it caused, compared to the characteristics of the interruptions caused by “normal events”.

The approach proposed here is similar in concept to the statistical identification of MEDs presented in [3] and [4]; it is based, however, on a model-free statistical methodology, that first identifies a subset of days with large daily average interruption duration (CAIDI = SAIDI/SAIFI), and then uses

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the SAIDI distribution of these particular days to fix the threshold for MEDs.

This paper is organized as follows: Section II briefly introduces the Italian regulation of continuity of supply and describes the difficulties encountered with the previous identification criterion; Section III describes the search for an efficient statistical methodology; Section IV gives a formal description of the proposed methodology and presents some numerical results; Section V describes the regulatory framework, and Section VI concludes.

II. Regulation Of Continuity Of Supply In Italy

The Italian Regulatory Authority introduced, in the year 2000[1], a quality targeted incentive mechanism linking the electricity distribution tariff to a unique indicator of quality of supply: the cumulative duration of long, unplanned interruptions, expressed in minutes per consumer per year (SAIDI). This indicator, together with SAIFI, is measured separately in more than 300 territorial districts, homogeneous in population density, and covering the entire national territory. This enables the regulator to account for exogenous (mainly geographical and technical) factors that influence company performances. At the beginning of the regulatory period the regulator fixes, for each territorial district, yearly improvement targets in SAIDI, differentiated according to population density and initial level of continuity. The baseline, or, yearly-required improvement per district, is designed so that higher improvements are required in districts having an initial quality level that is worse. Quality-related company performances are measured annually, as the difference (positive or negative) between the baseline and a two-year moving average of the measured SAIDI per each territorial district (ΔSAIDI). Financial incentives are calculated on an annual basis, as a function of a monetary incentive (or penalty) rate, the energy delivered in a given district at MV and LV customers, and the ΔSAIDI

The distribution tariff, p_t, in the year t varies according to a modified price cap formula, of the type:

$$p_t = p_{t-1}(1 + RPI - X + Q) \qquad (1)$$

where RPI is the retail price index, X is the efficiency gain fixed by the regulator for the four year tariff period, and Q is a quality parameter. Yearly values of the parameter Q are calculated, *ex post*, on the basis of company performances and relative financial incentives [5], [6].

At the end of the period 2000-2003, it was clear that this regulatory mechanism had been quite successful in reaching the objectives that were set at the beginning: average duration and number of interruptions had been significantly reduced, especially, in those regions were the initial situation was worse [7]. On the other hand, a few implementation aspects of the regulatory framework clearly required improvements: among them, a new methodology for identifying major interruption events was needed.

A. Implementation problems

One of the main questions that emerged in the period 2000-2003 was the correct attribution of responsibility of service interruption to the distribution utilities, in particular, in case of extreme weather conditions. Interruptions registered by the distribution companies are classified as i) due to *Force Majeure*, ii) due to external causes, iii) due to utility responsibility. *Force Majeure* includes public authority (police, firemen) interventions, exceptional natural events leading to either a natural calamity declaration or to climatic conditions beyond the technical design parameters of the grid, and strikes. External causes include third party responsibilities and interruptions originated on the transmission grid (or on other interconnected systems). The financial incentives scheme was applied only to long, unplanned interruptions net of the first two categories, given that the utility provided documentation proving the correct attribution of the event to one of the former two.

The documentation requirement, however, proved to be ambiguous at least in one case: the large snowstorm that hit the Northern Regions of Italy on December 13th, 2001. The interruption of service related to this event was particularly widespread: it affected up to 2 millions consumers and resulted in extremely long restoration times, as a thin ice film covered most of the roads in the affected area (*verglass*). Although public authorities did not declare the state of calamity and climatic conditions never went beyond the design and operational limits of the system, utilities claimed that the event was attributable to *Force Majeure*. An investigation on the case, opened by the Regulatory Authority, concluded that, even if a "drifting snow" phenomenon was actually an extremely rare climatic condition for the area, the occurrence of the interruptions was, within the existing regulation, not a case of *Force Majeure*. On the other hand, the investigation concluded also that the long time necessary for service restoration was indeed due to *Force Majeure*. In particular, daily SAIFI and daily CAIDI were used to separate that part of the SAIDI that was to be considered as attributable to *Force Majeure* from the part that was to be classified under the utility responsibility [8].

The December 13th, 2001 snowstorm showed the drawbacks of working with a documental approach. The *Force Majeure* criterion captures large as well as relatively small events, as long as it can be proved that the system design criteria are exceeded. Nevertheless, the criterion may fail to capture widespread, long interruptions when operational limits of the system are not reached. Furthermore, the implementation problems provided the insight for further considerations on the importance of the daily CAIDI indicator, as a signal of difficult operational conditions.

[1] Other European countries adopted similar incentive schemes only in subsequent years: Norway and Ireland in 2001, UK in 2002, and Hungary in 2003.

B. Objective of the new methodology

In searching for a new methodology for identifying major interruption events, a statistical approach seemed to offer significant advantages over the existing system. The objective was to design a scheme that did not require documentation by public authority (or weather centers), was based on sound theoretical background (for instance, statistical parameters), was equitable when applied to distribution utilities with different distribution territories (made use of the data history of the territory itself), was unambiguous in its implementation (and therefore readily acceptable by all parties), and was easy to understand even at non expert level (i.e. understandable also by consumer associations).

III. The Search For A Statistical Methodology

The idea of identifying MEDs by inspecting the distribution of daily indicators measuring interruptions had already been examined in the literature.

In [3] and [4] for instance, the authors concentrate on daily SAIDI and fit a log-normal statistical model to historical data. They conclude that the model is reasonable for practical purposes, even though there are no strong theoretical reasons for daily SAIDI to be log-normally distributed. MEDs are defined as days with SAIDI greater than a reliability threshold. Coherently with the log-normal model, this threshold R is determined as a function of the mean α and the standard deviation β of the natural logarithm of daily SAIDIs (Beta Method). For instance, by setting $R= \alpha + 2.5\beta$, an average of 2.3 MEDs per year is obtained.

We tested the former approach on Italian historical data, and found that it did not suit well the Italian regulator's objectives and was not totally convincing theoretically. Hence, we explored a different statistical approach to major event days identification, based on the analysis of the joint distribution of daily SAIFI and daily SAIDI (along the lines of [9]).

For comparison with the literature, it is important to point out that, in the Italian case, SAIDI and SAIFI are calculated on the basis of those unplanned interruptions declared by the distribution company as being "long, originated on the MV or LV grids excluding interruptions due to external causes". The Italian regulator classifies as "long" an interruption lasting more than three minutes [10].

Data sets available for statistical analysis are relative to the years 2001 and 2002. Both data sets consist of 278 populations of daily SAIFI and daily SAIDI relative to 278 territorial districts, which cover more than 90% of the national territory. Districts are classified in three classes, depending on their population density: high, medium, and low density. The SAIDI indicator is computed every year, separately for each territorial district. In line with this, the statistical analysis has been conducted separately for each district and on an annual basis.

A. Is the distribution of daily SAIDI log-normal?

The Beta Method approach to MEDs identification, being based on the log-normal model, is particularly appealing because it is easy to implement and to understand. Hence we tested it on the sample distributions of daily SAIDI. Fig. 1 illustrates a few summaries for these distributions relative to year 2002. For each district, only days with positive SAIDI have been considered; their number is represented by the broken line in the lower part of the picture. In the top part of the picture percentiles of the standardized sample distribution of the natural logarithms of daily SAIDI, appear for the 278 districts. For k in [0,1], the percentile p(k) of a sample distribution is a real number such that at least k*100% of the units in the sample are less than or equal to p(k) and at least (1-k)*100% of the units in the sample are greater than or equal to p(k) [11]. Pecentile p(0.5) is called the median. If the annual distribution of daily positive SAIDI for a district is log-normal, percentiles computed for the standardized sample distribution of the natural logarithms of daily positive SAIDI ought to be close to those of a standard normal. For a standard normal distribution:

p(0.00135) = -3, p(0.15865) = -1, p(0.5) = 0,
p(0.84135) = 1, and p(0.99865) = 3.

In ascending order, the same percentiles are represented by the broken lines in the top part of Fig. 1 when computed for the standardized sample distributions of the natural logarithms of daily positive SAIDI, for the 278 districts. Were the hypothesis of log-normality be true, we would expect these broken lines to be close to the horizontal lines at levels –3, -1, 0, 1, 3 respectively.

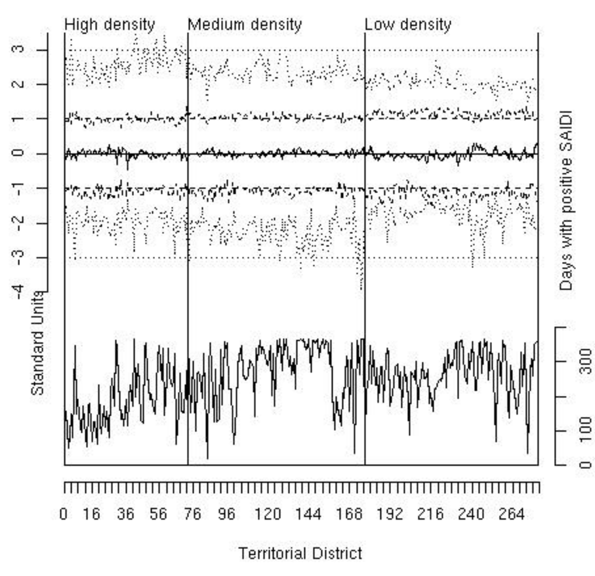

Fig. 1. Percentiles of standardized distributions of the logarithm of positive daily SAIDI for 278 Italian districts (year 2002).

At first glance the picture seems to confirm that adoption of a log-normal distribution for daily SAIDI is not unreasonable. However, on a closer inspection these distributions look fatter in the middle and thinner in the tails than a standard normal: this is especially true for districts with low density. We then proceeded to check normality for each of the 278 annual distributions of natural logarithms of daily SAIDI with a Shapiro-Wilks test [12]. The histogram of the 278 p-values thus obtained is shown in Fig. 2. When data are generated by a normal distribution, the p-value statistic defined by a Shapiro-Wilks test is uniformly distributed on [0, 1]. The histogram in Fig. 2 is markedly non-uniform: p-values are strongly concentrated on the [0, 0.05] interval, thus supporting the hypothesis that daily SAIDI are not log-normally distributed for most districts.

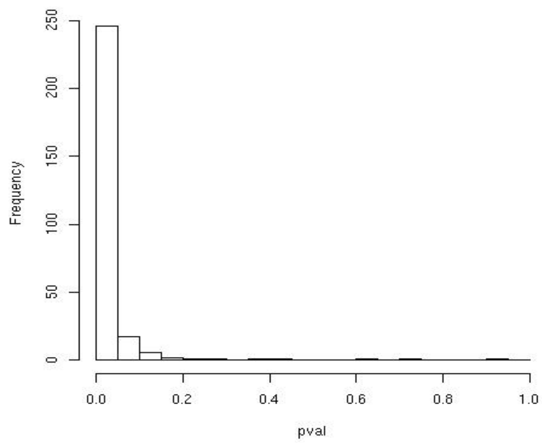

Fig. 2. Histogram of p-values generated by the Shapiro-Wilks test for normality applied to the distribution of the logarithm of positive daily SAIDI for 278 Italian districts (year 2002).

Of course, the result might depend on a poor fit of the log-normal distribution in the left tail or in the central part of the daily positive SAIDI distributions, while identification of MEDs is only concerned with their right tail. We believe that this shows the principal theoretical weakness of the Beta Method that, being based on a threshold generated by a parametric statistical model fitted to the entire distribution of daily SAIDI, is non robust to departures from it, even when this happens in regions of the distribution not directly connected with MEDs identification. With respect to this, we note that, contrary to what [3] and [4] suggest, we excluded from our data days with null SAIDI since, in most districts, there are many days a year without long interruptions (districts have a smaller geographical extension than an utility distribution territory).

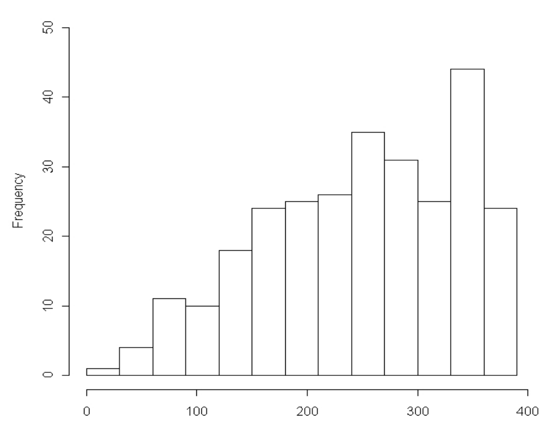

Fig. 3. Histogram of the number of days with positive SAIDI observed in year 2002 in 278 districts.

Fig. 3 shows an histogram of the number of days with positive SAIDI observed in the data set. Including days with null SAIDI in the analysis, maybe changing their values to the lowest SAIDI observed in their respective distribution as proposed in [4], would have generated a noticeable point mass, thus spoiling any procedure aiming at fitting a continuous statistical model to the sample data.

B. A model-free approach

As mentioned, the implementation problems provided the idea that a large daily cumulative duration is not a complete description of an exceptional interruption, unless also the number of consumers involved is considered: only days with a SAIDI large with respect to SAIFI ought to be considered potential MEDs. Hence the statistical analysis focused on the annual joint sample distribution of daily SAIFI and daily SAIDI, for each district in the data set. We adopted a model-free, non-parametric, approach aimed at identifying an extreme region, in the SAIFI-SAIDI plane, where MEDs belong to. For the sake of simplicity, the region's boundaries were defined using thresholds defined by functions of the mean and of the standard deviation. These parameters were deemed easier to implement and to understand by parties involved in quality regulation (regulator, distribution companies and consumer associations.) A stricter non-parametric approach might have considered boundaries function of quartiles and interquartiles ranges (IQR).

By observing Italian data, it emerged that an exceptional interruption is well described as one having a long restoration time. This implies a large value for the daily index CAIDI=SAIDI/SAIFI. In fact, CAIDI is interpretable as the average time required for restoring service. This led to excluding from MEDs those days with small or moderate CAIDI. After some simulations on the Italian data, it seemed reasonable to exclude from MEDs those days with CAIDI less than the mean plus one standard deviation of the annual per district sample distribution of daily CAIDIs. Days with CAIDI greater than this threshold are then observed with respect to their SAIDI: the mean and the standard deviation of their distribution is computed and those with SAIDI greater than the mean plus three standard deviations are defined as MEDs.

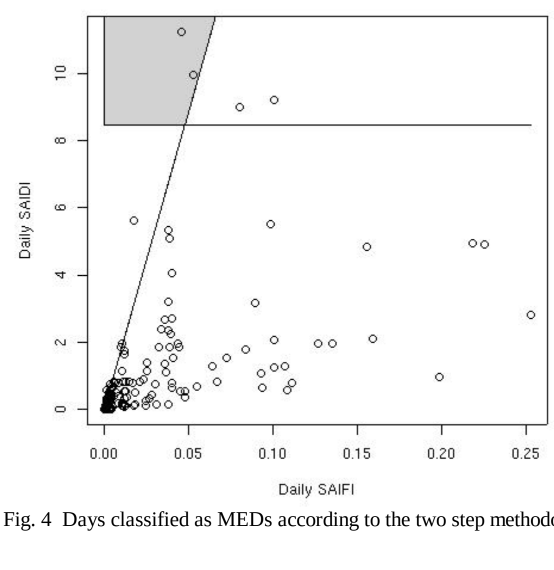

Fig. 4 Days classified as MEDs according to the two step methodology

This two-step procedure is illustrated in Fig. 4 for data relative to a particular district in year 2002. The first step defines a threshold for CAIDI, i.e. a line through the origin in the SAIFI-SAIDI plane. The second step defines a threshold based on the SAIDI distribution of those days that survived in the analysis after the first step, i.e. a horizontal line in the SAIFI-SAIDI plane. The gray area describes the region where MEDs belong to, for the specific district and year considered.

IV. Numerical results

Both the Beta Method and the two-step criterion for identifying MEDs discussed in the previous section, were tested on real data and compared. Before describing the numerical results, we formalize the two procedures.

Let us fix a territorial district A and a year *t*. Let us number the days of the year from 1 to 365 and indicate as SAIDI(*i*) (respectively SAIFI(*i*)) the value of the SAIDI index (SAIFI index) of day *i*, in district A for year *t*. Let N_t be the subset of the set {1,...,365} of days with positive SAIDI, in district A for year *t*.

Criterion 1

A day *k* in N_t is a MED if

$$log(SAIDI(k)) > m(log\{SAIDI(i)\}_{i\in N_t}) + 3sd(log\{SAIDI(i)\}_{i\in N_t}) \quad (2)$$

where *m* stands for the mean and *sd* for the standard deviation.

Criterion 2

First step

Let M_t be the subset of N_t such that day *j* belongs to M_t if and only if

$$CAIDI(j) > m(\{CAIDI(i)\}_{i\in N_t}) + sd(\{CAIDI(i)\}_{i\in N_t}) \quad (3)$$

Second step

A day k in M_t is a MED if

$$SAIDI(k) > m(\{SAIDI(i)\}_{i\in M_t}) + 3sd(\{SAIDI(i)\}_{i\in M_t}) \quad (4)$$

where *m* stands for the mean and *sd* for the standard deviation.

Table I summarizes the results obtained by applying the two proposed criteria to 278 Italian territorial districts in years 2001 and 2002 and compares them to the results (all in minutes of interruptions) obtained by the documental methodology.

TABLE I
Classification Of Cumulative SAIDI For 278 Districts (In Minutes)

Criterion	Year	Company's responsibility	Force Majeure/MEDs
Documental	2001	132.5	16.5 (F.M.)
1	2001	133.5	15.5 (MEDs)
2	2001	130.2	18.8 (MEDs)
Documental	2002	103.3	1.7 (F.M.)
1	2002	101.9	3.1 (MEDs)
2	2002	96.0	9.0 (MEDs)

For each of the three methods and for each year the third column shows the part of the 278 districts cumulative SAIDI attributed to distribution company's responsibility, and the fourth column shows the part of the cumulative SAIDI attributed to *Force Majeure* (documental method) or to MEDs, using Criterion 1 and 2. Note that SAIDI for external causes are not included in the calculation.

Table II compares the two statistical criteria in terms of number of MEDs per year. In particular the table illustrates, for the years 2001 and 2002, the number of MEDs identified per districts. Criterion 1 finds that, in the vast majority of districts, there are no excluded days and, for the remaining districts, the average number of MEDs per district is 1.21 for 2001 and 1.27 for 2002. Criterion 2, instead, finds at least one MED in almost all cases, and for districts with at least one MED, the average number of MEDs per district is 1.50 for 2001 and 1.76 for 2002.

TABLE II
MEDs per district calculated with criteria 1 and 2

Criterion	Year	0 days	1 day	2 days	3 days	4 days	5 days
1	2001	203	62	10	3	0	0
2	2001	37	149	70	17	3	2
1	2002	252	19	7	0	0	0
2	2002	15	132	76	42	12	1

MEDs found applying Criterion 1 were further analyzed and it emerged that a number of them did not present a large CAIDI; in other words, they lacked the identifying feature of an exceptional event indicated by the regulator. For instance, in 2002, out of 33 MEDs identified, 17 presented a CAIDI that, being less than one hour, was not at all exceptional. Hence, if long restoration times are assumed as one of the necessary characteristics for identifying a major event day, Criterion 1 is not always adequate. Preference was thus given to Criterion 2. As better explained below, the consultation process draw attention to the need for further refinements of Criterion 2, mainly dictated by technical and regulatory observations.

V. Regulatory Framework

The described criteria were discussed with electricity distribution utilities and other energy stakeholder within the consultation process that took place in 2003. On the basis of the numerical results illustrated above and of the comments received, the Regulatory Authority decided to include the statistical Criterion 2 in the new regulatory framework for the period 2004-2007 [13]. The adoption required two refinements, one dictated by technical reasons, and one resulting from the regulatory process.

As for the first refinement, it is important to note that interruptions recorded in a given day originate most frequently on the MV network, but they can occur at LV level, or at both levels. A day with only interruptions at LV level presents both small SAIFI and SAIDI (compared to days with faults originated on the MV grid), but a high CAIDI; as a result, including this interruption in the analysis would shift the distribution of the daily CAIDI rightwards, changing its mean and standard deviation, and therefore increasing the first step threshold. In particular, the standard deviation might result so large that data for MEDs will be masked (in the tail of the CAIDI distribution we will find mostly days with only interruptions originated in the LV network). Because it's very unlikely that an event that produces no interruption at MV level is a major event, days without MV interruption have been excluded by the application of the methodology, in the same manner as days with no interruptions are excluded. This refinement leads to a change in the numerical results illustrated in Table II: for instance, in year 2002 the greatest part of districts would have with no MEDs.

Secondly, the two step method has been complemented by the provision that, in case the set of MEDs identified by Criterion 2 is an empty set, the day with the maximum SAIDI among the days that pass the first step test is identified as MED. This second refinement has been introduced in order to take into account the request of distribution companies to have the possibility to always exclude a given number of days per years. The exclusion of one MED per year has thus been granted, unless the methodology finds more. This provision does not modify the quality improvement requirement of the companies: the baseline for each district for the period 2004-2007 is, in fact, calculated excluding MEDs or, in case no MEDs are found, excluding the day with the maximum SAIDI among the days that pass the first step test.

VI. Conclusions

The proposed two-step methodology for identifying major events responds to the objectives defined at the beginning of the study by the regulator. Being based on observable and objective statistical observations, the proposed methodology does not present any ambiguity in the interpretation, and in this, it constitutes an extremely significant simplification over the documental approach; being model free, it is directly applicable to any distribution territory, without the *ex-ante* data fitting procedure that is implicit in the Beta Method; it relies on reliability data of the distribution territory under consideration, resulting in an equitable treatment for all distributors, regardless of the geographical and topological difference in the network design; finally, it is easy to understand and to apply. For these reasons the methodology was included in the quality regulation framework, starting from 2004. Nonetheless, the methodology is well designed under country-specific regulatory conditions, among which the fact that, in Italy, reliability data are observed by the regulator at district level and not at utility level.

The exclusion of MEDs from the incentive regulation should not be interpreted as a lower attention of the regulator and of the utilities to the problem of major events. On the contrary, the adoption of the proposed criterion can be viewed in the context of a continuous learning process in quality regulation. The next step will be in the direction of verifying design requirements for resilient distribution networks as well as introducing procedures for managing emergencies. Other European countries, for instance, United Kingdom and France have already moved in this direction. EdF has introduced new network design criteria, aimed at preventing windstorm effects [14]. The UK Regulatory Authority, Ofgem, has recently proposed a new regulatory framework aimed at providing incentives for a prompt operational response even in severe weather conditions [15].

VII. Acknowledgment

The authors gratefully acknowledge the contribution of Mr. Alessandro Avola, who is with the Italian Regulatory Authority, for his help in data retrieving and warehousing.

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