DISTRIBUTION OF RELIABILITY INDICES IN ELECTRICAL NETWORKS

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ABSTRACT

The quality regulation as part of the since 2009 by the German Federal Regulation Authority applied incentive regulation for electrical networks contains a monetary evaluation of reliability indices. Due to the stochastic character of these indices and the resulting financial risk for the network operators the assessment of the distribution of these reliability indices is necessary. In this paper, a method to determine the distribution of the widely spread reliability indices for electrical networks is presented. In contrast to the established methods of probabilistic reliability calculations this method is based on the underlying statistical data of the reliability indices and other corresponding statistics and can therefore be applied to any network operator based on a basic description of the supplied region and aggregated network data.

INTRODUCTION

Even though the quality regulation in Germany has yet to be finally implemented, it certainly will contain a monetary evaluation of the reliability indices from every distribution network operator affected by the incentive regulation. Because the number of supply interruptions in a period of time as well as the extent and duration of each interruption are subject to a stochastic spreading, the resulting indices for a network operator are samples from a distribution. In order to achieve an effective quality regulation by the Federal Regulation Authority and to manage the resulting financial risks for the network operators the determination of this distribution is required.

Because the necessary statistical data to calculate the reliability indices exist only for a few years, a resilient conclusion about the distribution based on a small sample of indices from a single network operator is not expedient. Given that the characteristics of supply interruption from different network operators show high similarities - i.e. comparable network topologies and their operation - this paper presents an approach to determine the distribution of reliability indices for a single network operator by using existing comprehensive statistical data of supply interruptions from a large variety of network operators for a Monte Carlo simulation. That requires an analysis of both systematic and stochastic influences on the supply interruptions, including in particular the aforementioned number of supply interruptions as well as the extent and duration of each interruption.

RELIABILITY INDICES AND STATISTICAL DATA

In Germany, the reliability of supply for distribution networks is described by the international widely spread DISQUAL indices, which are based on the detected interruptions of supply > 3 min. in one year. The indices are calculated for a number of consumers or, as in this case, a whole network and are defined as following [1]:

- **Interruption Frequency**
  Average number of supply interruptions for a customer
- **Interruption Duration**
  Average duration of one supply interruption
- **Interruption Probability**
  Average duration of a supply interruption for a customer

The acquisition of the required data to calculate these indices started as part of the so called FNN-Availability Statistic in 2004 [2] and is mandatory since 2005 with the beginning of the electricity regulation by the Federal Regulation Authority. Based on these statistics a maximum of six values for the indices of a network operator are available on which the distribution cannot be quantified.

The method described in this paper is based mainly on the FNN-Availability Statistic, which contains information about failures and potential resulting supply interruptions for different voltage levels as well as a technical description of the participating networks. For low voltage networks only supply interruptions with a small range of additional information describing the incident are collected. In medium voltage networks also failures without a resulting supply interruption are collected and the description of the incident is more detailed. Before 2004 the statistic only contains data about failures without the necessary data to calculate the reliability indices.
The DISQUAL indices can be calculated for medium and low voltage networks. For high voltage networks thus transportation networks widely accepted reliability indices are yet to be defined. Up to now there is no quality regulation planned for these networks in Germany. Because the data for low voltage networks is less detailed and information about the number of failures is not available,

the paper focuses on medium voltage networks. Moreover, the DISQUAL-indices are governed by failures in medium voltage networks by some 80%. With information about the number of failures or a realistic assumption, however, the method can be also applied to low voltage networks.

From 2004 on the information collected for each incident (failure with/without supply interruption) includes

- **Occasion for the incident**
  The occasion for the incident such as atmospheric or external influences, often similar to the cause of the incident
- **Location of the incident**
  Affected electrical equipment such as cable, substation or transformer
- **Impact of the incident**
  In case of a supply interruption information about the extent, described by the number of affected customers (low voltage) or the installed capacity of affected transformers (medium voltage) as a customer equivalent, and interruption duration are included

INFLUENCING FACTORS ON THE RELIABILITY INDICES

The influences on the reliability indices can be divided into three main areas as shown in figure 1.

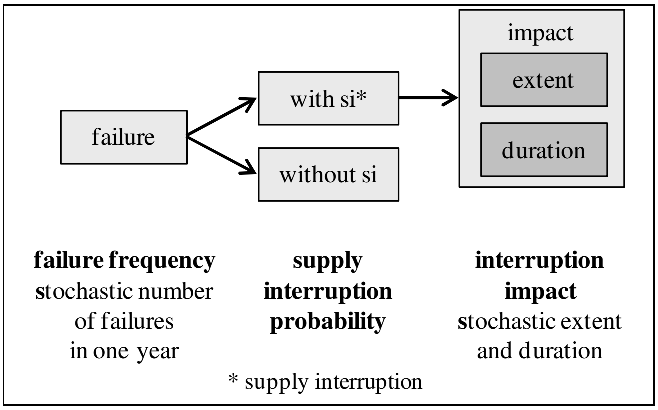

Figure 1: Areas with different stochastic influences

The failure frequency - thus the number of failures in a network in one year - mainly depends on stochastic (external) influences as well as systematic influence like the network structure.

Given the number of failures the supply interruption probability describes the percentage of resulting supply interruptions, depending on the network structure and its function. Since these parameters are systematic parameters as a function of the considered network operator, the probability can basically be modelled as an expected value represented by a number of supply interruptions with no impact.

In case of a resulting supply interruption the impact is influenced by many stochastic effects, which are implied in the available statistical database. By identifying the systematic differentiating parameters between the network operators, a further identification of the numerous stochastic parameters is not necessary.

Failure Frequency

Up to now in most methods the failure frequency is assumed to be an ideal random process and therefore modelled as a Poisson distribution. This assumption is not valid for a significant part of the occurring failures [3].

The stochastic spreading of the failure frequency is a result of the combination of different failure occasions. Figure 2 shows the average configuration of failure occasions as evaluated from the FNN-Statistic (1958 – 2007). For a network operator this configuration varies according to the installed electrical equipment. Failures on overhead lines are affected mostly by atmospheric influences such as storm and/or lightning. Failures on cables are in most cases triggered by engineering work.

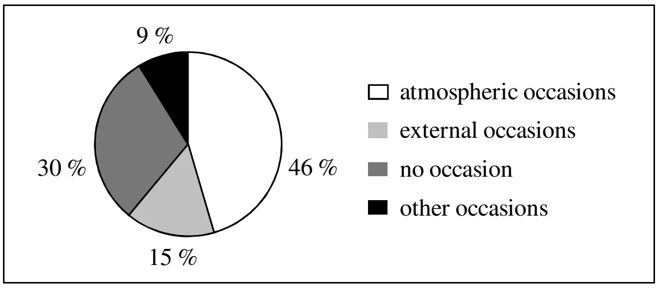

Figure 2: Average configuration of failure occasions

The aforementioned influences - storm, lightning and engineering work - account for approximately 50 % of all failure occasions in an average network structure. For these influences the analysis shows a larger statistical spread than the Poisson distribution. This applies in particular for the atmospheric occasions due to stochastic dependencies of the failures.

Based on additional data from the German Meteorology Institute (DWD) [4], new models for the two dominating atmospheric failure occasions were developed. Besides the amount and type of electrical equipment of the network operator it includes the geographic location and dimension as input parameters. The models describe the systematic influence of these parameters according to the investigated correlation functions between parameters and failure frequency in the past. However, a stochastic part remains, which again depends on the mentioned parameters.

The number of failures due to engineering work is calculated based on a Weibull distribution, where the function parameters depend only on the amount and type of the installed electrical equipment. This model has been derived from the analysis of the empirical distribution of the correspondent failures, but could be replaced, if the extent of civil engineering work in the network region can be quantified, since a strong correlation between this parameter and the failure frequency has been identified at national

level. For all other occasions the Poisson-distribution-approach is maintained, since no contrary evidence is apparent.
Note that the resulting model can also be applied as an input for probabilistic reliability calculation to specify the stochastic behaviour of equipment failure frequencies.

Interruption Impact

The FNN-Statistic contains a huge amount of supply interruptions. Assuming a homogeneous customer density and load as well as predefined network structures, an economic network topology defined only by technical restrictions would be almost identical for all network operators. In combination with an economic operation of the network, a further classification of the supply interruptions would not be necessary. The observed spreading of extent and duration in a random sample would only be caused by stochastic influences.
In reality the network topology and type of installed electrical equipment as well as the network operation depend on the inhomogeneous customer density and variable load, resulting in systematic impact differences of supply interruptions. Therefore the technical information about the networks is taken from the FNN-Statistic in order to identify parameters to classify the supply interruptions. By using statistical tests like the Kolmogorov-Smirnov test for independent distributions [5], the significant differences between impact distributions can be determined. The resulting classification includes the following parameters:

- Failure location
- Voltage level
- Neutral point treatment

As an example for a significant difference figure 3 shows the distribution of the interruption extent, represented by the interrupted installed capacity, on an overhead line at different voltage levels.

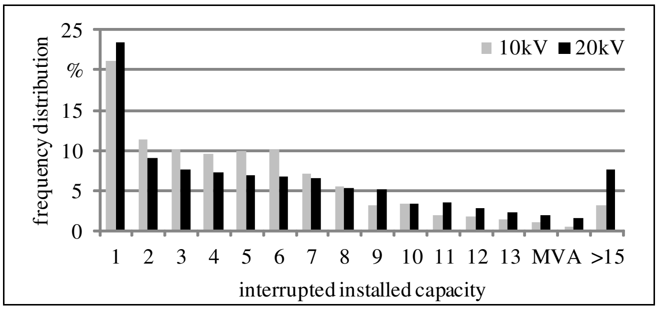

Figure 3: Distribution for the interruption extent of an overhead line at different voltage levels

After the classification the aforementioned supply interruption probability for every class is added by a percentage of interruptions with no impact.

SIMULATION APPROACH

The presented method consists of a two-stage Monte-Carlo simulation based on the different stochastic influences on the reliability indices depicted in figure 4.

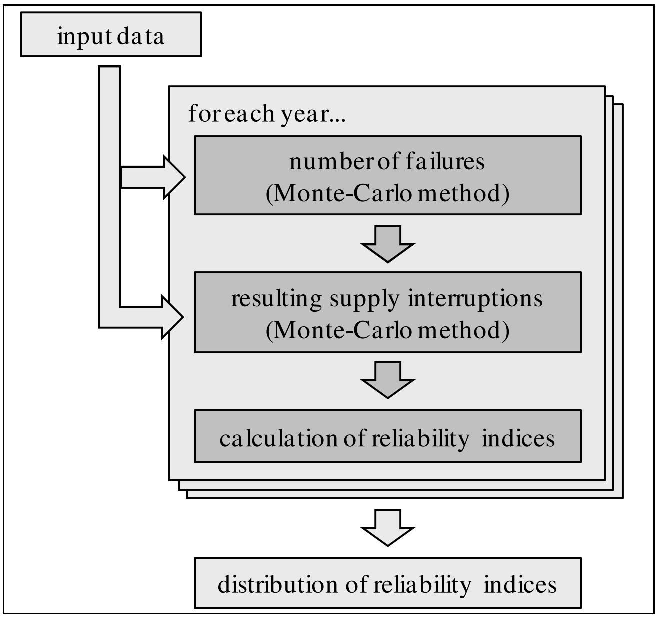

Figure 4: Process overview

The network of a considered network operator is thereby defined by a set of characteristic parameters like the ones mentioned in the previous chapter.
The first stage simulates the number of failures based on a random draw from the different distributions of the influencing factors. The second stage returns the impact for the calculated number of failures by drawing a random sample from the classified supply interruptions. This includes the probability of failures without a supply interruption. The classes for the random draw are chosen depending on the input information about the network structure such as the installed equipment and voltage level. With the determined supply interruptions the reliability indices can be calculated which finalizes the simulation of one year. After a large number of simulated years the distribution of the reliability indices results from the large number of calculated values and the distribution function can be determined by a statistical analysis.

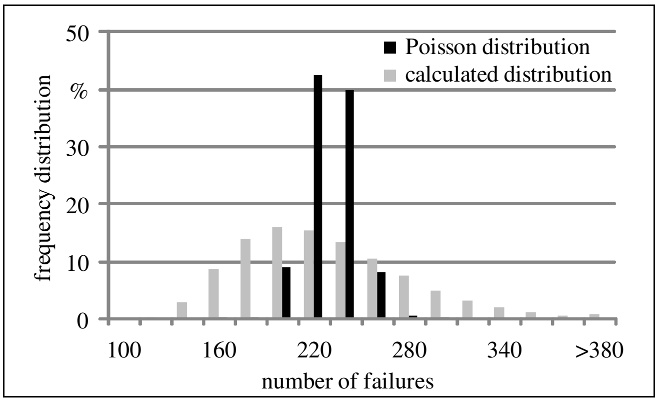

Figure 5: Distribution of the simulated number of failures in comparison to the Poisson distribution

EXEMPLARY RESULTS

As a first step the difference between the simulated failure frequency and the assumed Poisson distribution is presented. The considered network operator has an average medium voltage network with a total circuit length of 3400 km and a share of 25 % overhead lines.
Figure 5 compares the frequency distribution of the calculated failure frequency and the Poisson distribution for the corresponding expected value. The stochastic spreading is significantly higher which is mainly caused by atmospheric influences.

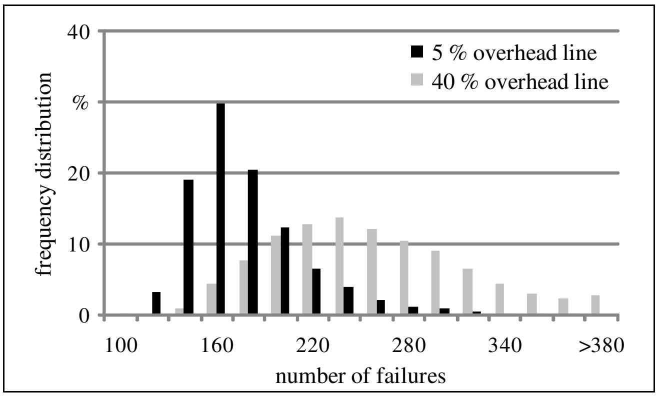

Figure 6: Distribution of the simulated number of failures for different overhead line rates

Figure 6 illustrates the strong atmospheric influences by showing the distribution for different shares of overhead lines. Even though the stochastic spreading is reduced by the reduction of the overhead lines it still exceeds the spreading of a Poisson distribution due to the remaining influence of engineering work. Next to a lower expected value for the number of failures the shape of the distribution changes significantly.

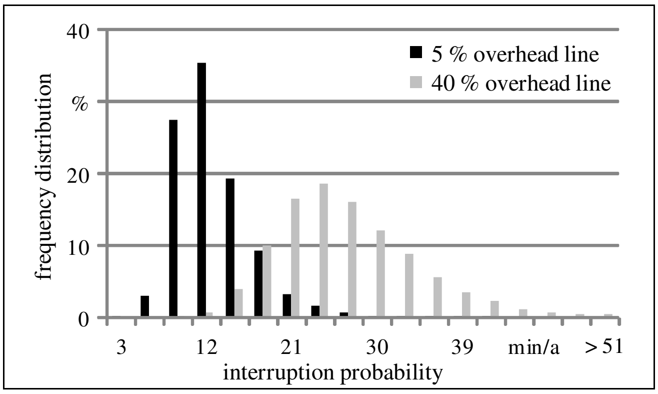

Figure 7: Distribution of the interruption probability for different overhead line rates

As a second step the resulting distribution of the reliability indices is presented. For this example the network structure represents the average network structure from the FNN-Statistic. However, the different share of overhead lines has an effect on the composition of other installed equipment like the substations for example. The size of the network operator in terms of the geographical dimension stays the same whereas the load is changed according to a realistic value of an urban and part rural network. The distribution of the interruption probability for both scenarios is shown in Figure 7. Both distributions show a significant spread around their expected value whereas the spreading for the network with a higher overhead line rate has a wider range. With an expected value for the interruption probability of 25 min/a, the probability of an index higher than 35 min/a is still 10 %. The spreading also increases slightly for each scenario from the interruption frequency to the interruption probability.
With this distribution a network operator is able to quantify the financial risk caused by the expected quality regulation.

CONCLUSION

Based on empiric data from the FNN-Statistic and additional weather statistics a method to determine the distribution of reliability indices was developed, enabling the network operator to evaluate the financial risk emerging from the quality regulation. The number of failures is thereby simulated with an advanced model replacing the widely used Poisson distribution to account for observed higher stochastic spreading. Based on the existing statistical data containing all stochastic influences on supply interruptions and the determination of the systematic differences, the distribution for an individual network operator can be calculated based on a set of describing parameters. The presented method also allows evaluating the effect of a longer period of consideration on the stochastic spreading of the reliability indices. Initial evaluations show a considerable reduction of the spreading up to a period of three years before the reducing effect decreases.

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