# ASSESSMENT OF THE RELIABILITY OF DISTRIBUTION NETWORKS

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## ABSTRACT

This paper describes some approaches to the assessment of the reliability of MV overhead distribution networks. The main accent is put on assessing the reliability by using the guaranteed standards of electricity supply continuity when estimating the penalty payment costs to be paid by the distribution company to individual consumers as a result of breaching these guaranteed standards.

## 1. INTRODUCTION

The level of supply continuity is regulated by national regulatory bodies in the environment of a liberalized electricity market. The aim of the regulation is to ensure that each consumer receives the electricity with a specified minimum level of supply continuity, and that the level of reliability may be successively increased both for individual consumers and at the network as a whole. Regulatory bodies implement various tools for reaching this aim. On the present the most common tools are the overall and guaranteed standards of electricity supply continuity.

For our purpose, analysis is made to a large 22 kV overhead distribution network which consists of 326 feeder lines supplying 513 858 individual consumers (supply points) with electricity. The network is divided into three areas, and measured data from a ten-year period are available.

## 2. STANDARDS FOR ELECTRICITY SUPPLY CONTINUITY

The general standards for electricity supply continuity, based on aggregated indices for the whole system, do not provide sufficient data (information) to evaluate the level of power supply to the individual power consumption points in the network, and for making comparison of the performance of the networks. Therefore, the guaranteed standards of electricity supply continuity are being implemented in some EU countries (e.g. Italy, Spain, Portugal, United Kingdom), but, of course, their concrete form slightly differs in between the individual countries.

The guaranteed standards serve mainly as a protective measure for small consumers and they specify minimum level of quality of electricity supply which must be maintained for each individual customer at the given voltage level. That is the reason why these standards are based on primary reliability indices (non-aggregated indices referred to the individual supply points). For example, the guaranteed standard can include a limit of the annual number of supply interruptions and a limit of their total annual duration. If some of these limits will not be complied with for any customer of the given distribution company, the company will be obliged to pay a certain penalty to the affected customer.

In the Czech Republic, the observation of overall aggregated reliability indices is only required by the Energy Regulatory Office now. Guaranteed standards of the quality of electricity supply and of related services do include e. g. a standard of supply restoration after failure, a standard of not-breaching the planned duration of electricity supply limitation and a standard of replacing the damaged fuse at customer's premises, and have been introduced since 2006. The implementation of a guaranteed standard of the electricity supply continuity with limits of the annual number of supply interruptions and of their total annual duration is foreseen in the amendment of the presently valid regulation [1].

## 3. GUARANTEED STANDARDS OF ELECTRICITY SUPPLY CONTINUITY

There are two main types of guaranteed standards – simple and combined.

In case of a simple guaranteed standard only one limit is observed. It may be e.g. the limit of the annual number of supply interruptions ($L_n$) or the limit of their total annual duration ($L_t$). The guaranteed standard is breached when a given limit is exceeded. In case of the combined guaranteed standard, there are both limits ($L_n$ and $L_t$) observed and standard is breached when one of these standards is exceeded. In this case the distribution company is committed to pay a penalty amounting to $c_p$ to each affected consumer down to the LV level. The value $c_p$ = 1000 Czech crowns (Kč) was chosen for the purpose of study and it does not depend on the extent of exceeding the limit. Penalty payment costs for each feeder may then be determined for the chosen combination of limits.

Penalty payment costs for simple guaranteed standard can be calculated:

$$C_{pv,q} = c_p \cdot o_v \cdot \mathrm{cond}\left(x_{cv,q} \geq L_x\right) \tag{1}$$

where $o_v$ represents the number of consumers connected to $v^{th}$ feeder, $x_{cv,q}$ is the current value of $v^{th}$ feeder and $q^{th}$ year (the annual number of supply interruptions $n_{cv,q}$ or the total annual duration of supply interruptions $t_{scv,q}$ for $v^{th}$ feeder and $q^{th}$ year) and $L_x$ is the limit of current value $x_{cv,q}$ (limit $L_n$ or $L_t$). The cond ( ) expression can attain the value of 1 or 0. If the condition is met cond( ) = 1, if not cond( ) = 0.

The penalty payment costs for combined guaranteed standard can be calculated using the formula:

$$C_{pv,q} = c_p \cdot o_v \cdot \mathrm{cond}\left(n_{cv,q} \geq L_n \vee t_{scv,q} \geq L_t\right) \tag{2}$$

Total penalty payment costs for $q^{th}$ year can be calculated as a summation:

$$C_{p,q} = \sum_{v=1}^{V} C_{pv,q} \tag{3}$$

where $V$ represents the total number of feeders in the network.

As the desired $C_{pp}$ value, which is the total average annual penalty payment costs in the network, the mean of all values $C_{p,q}$ can be accepted.

Because the limits have not been introduced in the Czech Republic yet the analyses must be carried out for a wider spectrum of values, e.g. for: $L_n$ = (4, 5, 6, 7, 8, 9, 10) year$^{-1}$; $L_t$ = (60, 120, 180, 240, 300, 360, 420, 480, 540, 600, 720) min. year$^{-1}$.

### 3.1. SIMPLE GUARANTEED STANDARDS OF ELECTRICITY SUPPLY CONTINUITY

The total average annual penalty payment costs in the network ($C_{pp}$) for different limits $L_n$ or $L_t$ for simple guaranteed standard are shown in **Fig. 1**. These two figures serve for comparing the reliability of our network areas. On the first (left) figure, the estimation costs range from 20 mil. to 88 million Kč per year depending on the strictness of the $L_n$ limit. The worst reliability using this approach covers the Area 2 and the best the Area 1. On the right figure, the estimation penalty payment costs move within the range from 35 mil. to 121 mil. Kč.year$^{-1}$ depending on the strictness of the $L_t$ limit. In this case the Area 1 features the worst reliability and the best reliability is encountered in the Area 2 for limit interval from 60 to 240 min.year$^{-1}$ and Area 3 for interval from 300 to 720 min.year$^{-1}$.

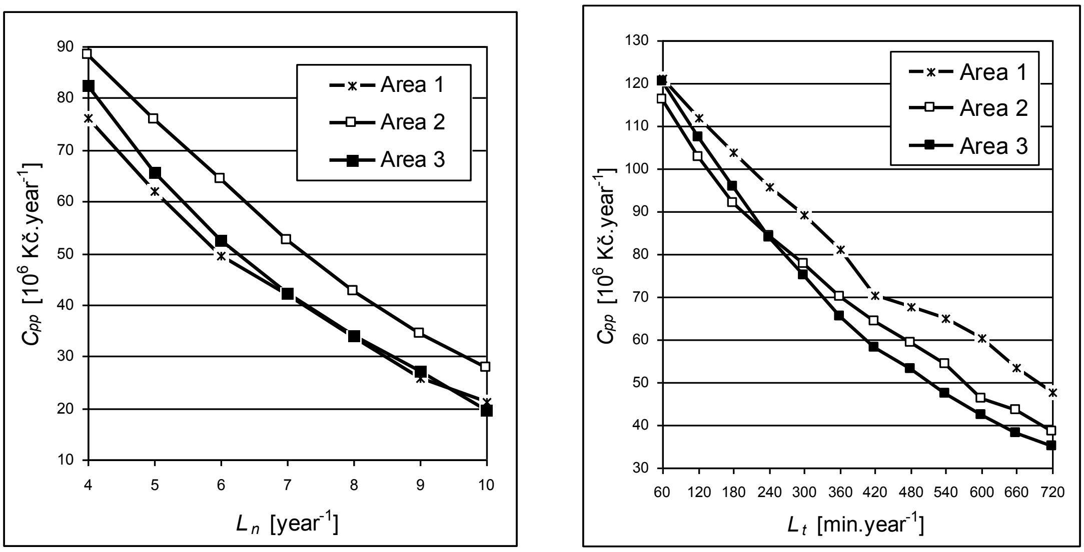


**Fig. 1:** *The total average annual penalty payment costs in the network for different limits $L_n$ or $L_t$ – simple guaranteed standard*

### 3.2. COMBINED GUARANTEED STANDARDS OF ELECTRICITY SUPPLY CONTINUITY

The total average annual penalty payment costs ($C_{pp}$) for combined guaranteed standard are shown in **Fig. 2** and they move within the range from 121 mil. to 369 mil. Kč.year$^{-1}$ depending on the strictness of limits ($L_n$ and $L_t$) combination. As can be seen from **Fig. 2**, the choice of $L_n$ has no significant effect on the height of the $C_{pp}$ costs for about $L_t \leq (60 \div 240)$ min.year$^{-1}$. As a result, the usage of both limits would be of no practical meaning in such cases and it would be sufficient for the evaluation of those $C_{pp}$ costs that exceed the $L_t$ limits, only. At higher values of limit $L_t$, the $C_{pp}$ costs change substantially with the change of the $L_n$ value. As well, the $L_t$ limit (ranging within $L_t \leq (480 \div 720)$ min.year$^{-1}$) becomes insignificant for limits $L_n$ = 4 year$^{-1}$ and $L_n$ = 5 year$^{-1}$.

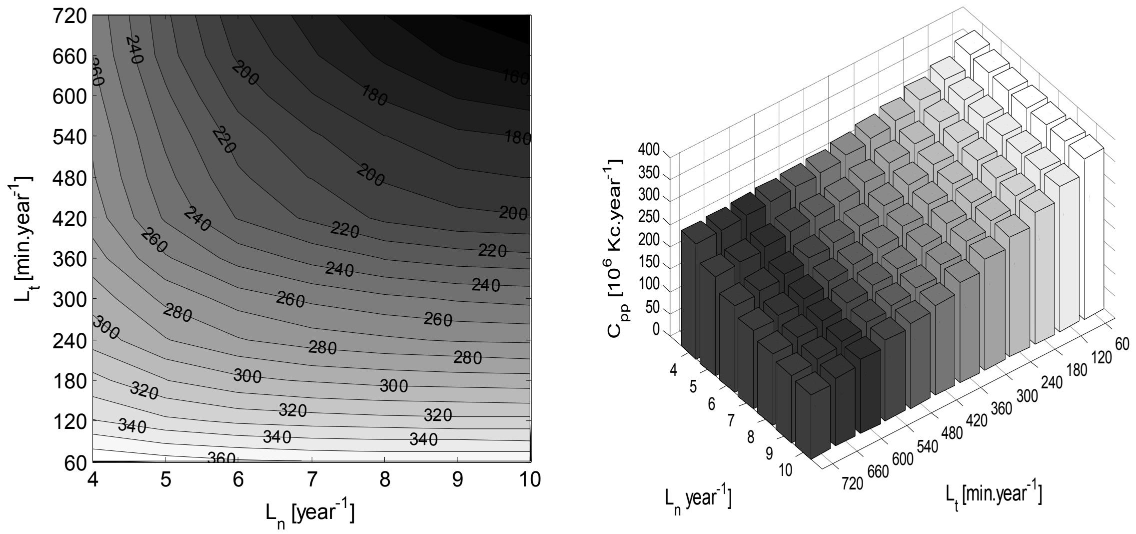


**Fig. 2:** *The $C_{pp}$ total average annual penalty payment costs in the network for a combination of $L_n$ and $L_t$ limits – combined guaranteed standard*

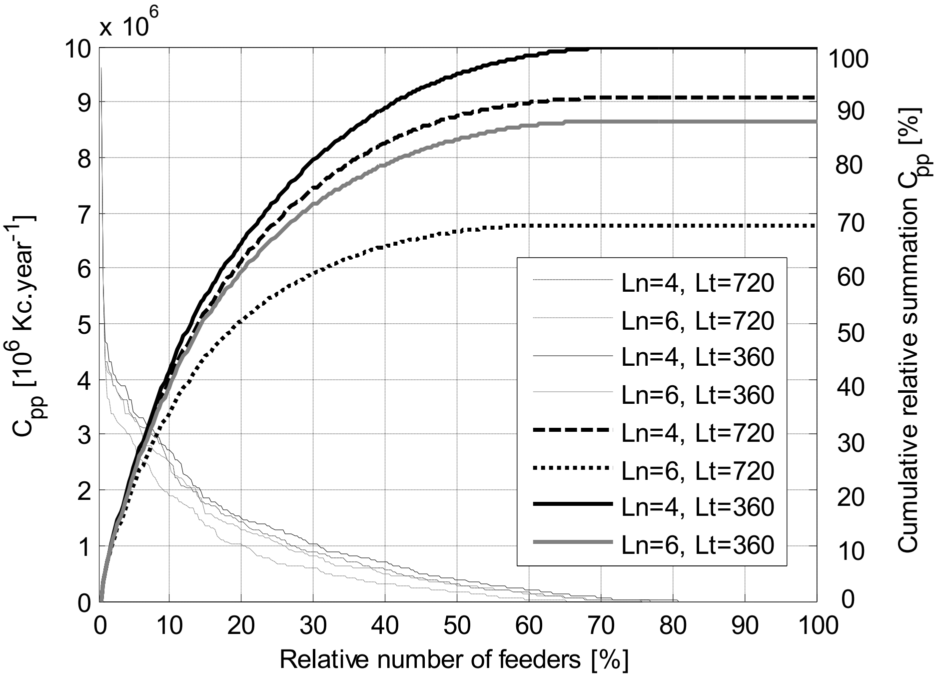


**Fig. 3:** *$C_{pp}$ - total average annual penalty payment costs for individual power feeders and their cumulative relative summation vs. the relative sequence of power outlets (the latter being arranged in the descending order of $C_{pp}$)*

The **Fig. 3** shows the total average annual penalty payment costs for individual feeders and their cumulative relative summation in the descending order. This figure shows that about sixty percent of feeders have been penalized least once during the ten-year period. It can also be seen that ten percent of the worst (least reliable) feeders make up about 40 % of cumulative penalty payment costs. Therefore, it is essential to identify these feeders, since by increasing the reliability of such feeders the distribution company could spare 40 percent of costs on penalization which normally it would have to pay to the affected consumers.

## 4. CONCLUSION

The guaranteed standards of electricity supply continuity and the penalty payments due to power supply interruption could become a useful tool for the evaluation of reliability of a distribution network. A single-type of guaranteed standard can be used for the comparison of the reliability, even if exact limit values are not determined, but such a case depends on choosing the type of limit ($L_n$ or $L_t$). In case of a combined guaranteed standard the situation is quite different because the penalty payment costs depend on setting up the both limits. However, also in this case areas can be identified where the change of one limit has no a relevant impact on the level of the costs, and to operate with both limits specified would be of no practical significance.

Generally, the implementation of these guaranteed standards into practice may represent a significant risk of financial losses for the Czech distribution companies, since these may range within a scope of hundred millions of Czech crowns per year, depending on how rigorously the combination of these limits is defined.

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