EVALUATION OF LONG AND SHORT INTERRUPTIONS INDICES OF POWER SUPPLY IN THE CZECH REPUBLIC

Karel PROCHAZKA
EGC CB s.r.o. – Czech Rep.
kprochazka@egc-cb.cz

Filip BROZ
EGC CB s.r.o. – Czech Rep.
fbroz@egc-cb.cz

Jan SEFRANEK
Energy Regulatory Office – Czech Rep.
Jan.Sefranek@eru.cz

Michal KONC
CEZ Distribuce – Czech Rep.
michal.konc@cezdistribuce.cz

Martin KASPIREK
E.ON Ceska republika – Czech Rep.
Martin.Kaspirek@eon.cz

Jiri HRADECKY
PREdistribuce – Czech Rep.
jiri.hradecky@pre.cz

ABSTRACT

The paper describes various model examples from the calculation of indicators point of view, with individual operations steps for location of the faults, isolation of the faulted network section, supply restoration and assessment of their SAIDI and SAIFI indicators.

Further report deals with evaluation of the customer short-term interruptions in detail. For LV customer it is based on monitoring the LV side of MV/LV transformer, in which we consider as important to evaluate both their duration as well frequency. Evaluation of the comprehensive set of measurements, containing data from more than 10 thousand MV/LV TR during the year 2015, demonstrates duration and frequency of short interruptions for LV customers.

INTRODUCTION

CEER questionnaire for 6th Benchmarking Report on Quality of Electricity Supply elaborated in the year 2015, was the main impulse for analysis and eventual unification of the individual DSOs approach in the Czech Republic to the evaluation of long interruptions indices SAIDI and SAIFI in more complex cases. At the same time the questionnaire was together with complaints of sensitive customers on dips and interruptions an incentive to seek the appropriate approach for evaluation these short-term phenomena (MAIFI).

To monitor long-term power supply interruptions/ phenomena in 110 kV and MV networks, DSOs use SCADA, together with comprehensive monitoring of voltage quality parameters according to EN 50160 in all delivery points of the TSO/DSO, in most substations 110 kV/MV and at selected customers 110 kV and MV. For evaluation of the supply continuity in low voltage networks we recommend using primarily power quality analysers installed in MV/LV transformer stations and in the future the AMM directly (if applicable).

EXAMPLES OF CALCULATION OF SAIFI, SAIDI CONTINUITY INDICATORS IN DISTRIBUTION SYSTEMS

The following chapter provides examples of calculation of basic continuity indicators (SAIFI, SAIDI) in distribution systems. The impulse for drafting this chapter resulted from one of the questions raised during the preparation of this benchmarking, as the responses implied that the approach to continuity indicators calculation in individual countries may be different. Simultaneously, it is important to realise that different approach (or perception) may occur even among individual operators of distribution systems who are responsible (in many countries) for calculation of indicators or for reporting data necessary for such calculation. Nevertheless, the unification calculation method is the key prerequisite for further analyses or comparison of individual companies or countries. This chapter because of above mentioned reasons intends to present instruction for calculation of basic continuity indicators (SAIFI, SAIDI) on the selected model example.

Model example of calculation

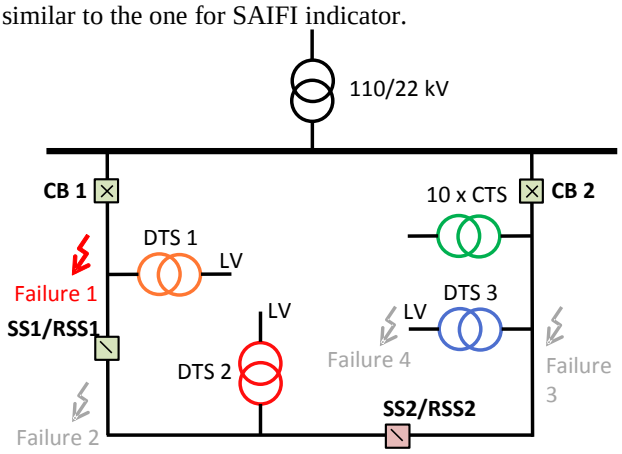
Presented example describes the procedure for calculation of the SAIDI, SAIFI indicators in more complicated cases where the operation steps during failure localization usually interrupt electricity distribution to different groups of customers in the system for the period exceeding 3 minutes. At the same time, we would like to emphasize that described example aims to facilitate understanding of indicators calculation and doesn't intend comparing advantages brought by different types of switching elements.

Model example covers four different failures in different parts of a distribution system. Regarding to the extent the paper includes the failure n. 1. See [7] for full scale calculation of this example. To allow for presenting calculation of not only the system indicators but even for the voltage level indicators, the customers are connected to the LV – low voltage and MV – medium voltage levels. At the same time the stated transformer stations (TS) are not interconnected on the LV side, hence the substitute

feeding cannot be provided through operation on the LV level (utilised mainly in urban cable networks).

The example is provided for two alternatives of switching elements in the line (section switch and remotely controlled section switch). It is presumed that the first dispatcher´s operation could not be executed in less than 3 minutes, regardless of the switching element type. We anticipate that the operations done by dispatcher in order to reconfigure the system into the pre-failure state would be finalised within 3 minutes, as in such case the dispatcher is ready for these operation steps and can carry them out in immediate sequence. Although in real operation the remotely controlled section switches can be used for operation also when the line is energized the operations within the example are considered only for no voltage state, i.e. after the feeder circuit-breaker would be switched off.

To illustrate this point, individual alternatives are supplemented with graphical courses of interruption evaluation, including the method for detecting the failure location. Only the long-term interruptions, i.e. with the duration exceeding three minutes are used for calculation of the SAIFI, SAIDI indicators. The hatched areas of these courses are not included into the calculation, as their duration is shorter or equal to three minutes. Such interruptions would be potentially used for calculation of indicators that evaluate short-term interruptions (e.g. MAIFI), where the way of calculation applied would be similar to the one for SAIFI indicator.



Distribution transformer station (DTS)
Customer transformer station (CTS)

DTS 1 = 150 customers at LV
DTS 2 = 50 customers at LV
DTS 3 = 100 customers at LV
10 x CTS = 10 customers at MV

$N_{SLV} = 150 + 50 + 100 = 300$
$N_{SMV} = 10$
$N_S = N_{SLV} + N_{SMV} = 310$

CB – power circuit-breaker
SS – section switch
RSS – remotely controlled section switch

Switched on
Switched off

Figure 1

Alternative with section switch (SS)

Process	Time elapsed from failure (min)
Triggering the CB 1 protection	t = 0
Switching off the SS 1, switching on the CB 1, triggering the CB 1 protection – **detecting the location of failure**	t = 6
Switching off the CB 2, switching on SS 2	t = 8
Switching on the CB 2 – **partial restoration of supply**	t = 12
Switching on the CB 1 – **failure reparation finished**	t = 22
Switching off the CB 1 – **operations in order to reconfigure the system into the pre-failure state**	t = 23
Switching off the CB 2, switching off the SS 2, switching on the SS 1	t = 24
Switching on the CB 2	t = 26
Switching on the CB 1	t = 27

Table 1: Course of operations in case of failure n. 1

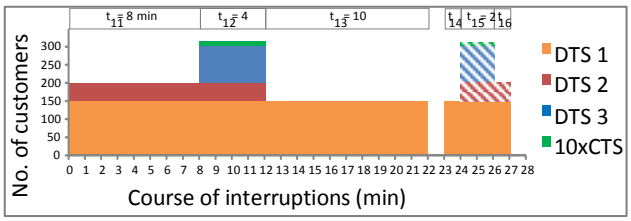


Figure 2: Graphic course of interruptions in case of failure n. 1

Calculation of system indicators in case of failure n. 1:

$$SAIFI_S = \frac{\sum_{h=(LV,MV,\ldots)} \sum_j n_{jh}}{N_S} = \frac{n_{1LV} + n_{1MV}}{N_S} = \frac{(150+50+100)+(10)}{310} = 1 \ [1/\text{year}]$$

$$SAIDI_S = \frac{\sum_{h=(LV,MV,\ldots)} \sum_j t_{sj}}{N_S} = \frac{\sum_{h=(LV,MV,\ldots)} \sum_j \sum_i t_{ji} \cdot n_{jhi}}{N_S} = \frac{t_{s1LV} + t_{s1MV}}{N_S} =$$

$$= \frac{(t_{11}.n_{1LV1} + t_{12}.n_{1LV2} + t_{13}.n_{1LV3} + t_{14}.n_{1LV4} + t_{15}.n_{1LV5} + t_{16}.n_{1LV6}) + (t_{12}.n_{1MV2})}{N_S} =$$

$$= \frac{[8 \cdot (150+50)+4 \cdot (150+50+100)+10 \cdot 150+1 \cdot 150+2 \cdot 150+1 \cdot 150]+[4 \cdot 10]}{310}$$

$$= 15{,}94 \ [\text{min/year}]$$

where
h *indicates the voltage level (low voltage = LV, medium voltage = MV, …),*
j *indicates the event (failure),*
n_{jh} *is the total number of customers directly fed from the voltage level h, who were affected by interruption of electricity distribution as a result of the j event,*
t_{sj} *is the total duration of all electricity distribution interruptions resulting from the j event at individual customers directly fed from the voltage level h, for whom the electricity distribution was interrupted,*
t_{ji} *is the duration of the i operation step within the j event,*

n_{jhi} is the number of customers directly fed from the voltage h, who were affected by interruption of the electricity distribution in the given category in the i operation step of the j event,
i is the sequence number of the operation step within the j event.

Voltage level indicators in case of failure n. 1:

$$SAIFI_{LV} = \frac{\sum_j n_{jLV}}{N_{SLV}} = \frac{n_{1LV}}{N_{SLV}} = \frac{(150+50+100)}{300} = 1 \ [1/\text{year}]$$

$$SAIDI_{LV} = \frac{\sum_j t_{sj}}{N_{SLV}} = \frac{\sum_j \sum_i t_{ji} \cdot n_{jLVi}}{N_{SLV}} = \frac{t_{s1LV}}{N_{SLV}} =$$

$$= \frac{(t_{11}.n_{1LV1} + t_{12}.n_{1LV2} + t_{13}.n_{1LV3} + t_{14}.n_{1LV4} + t_{15}.n_{1LV5} + t_{16}.n_{1LV6})}{N_{SLV}} =$$

$$= \frac{8 \cdot (150+50) + 4 \cdot (150+50+100) + 10 \cdot 150 + 1 \cdot 150 + 2 \cdot 150 + 1 \cdot 150}{300} =$$

$$= 16{,}33 \ [\text{min/year}]$$

$$SAIFI_{MV} = \frac{\sum_j n_{jMV}}{N_{SMV}} = \frac{n_{1MV}}{N_{SMV}} = \frac{10}{10} = 1 \ [1/\text{year}]$$

$$SAIDI_{MV} = \frac{\sum_j t_{sj}}{N_{SMV}} = \frac{\sum_j \sum_i t_{ji} \cdot n_{jMVi}}{N_{SMV}} = \frac{t_{s1MV}}{N_{SMV}} = \frac{t_{12}.n_{1MV2}}{N_{SMV}} = \frac{4 \cdot 10}{10} = 4 \ [\text{min/year}]$$

Alternative with remotely controlled section switch (RSS)

Process	Time elapsed from failure (min)
Triggering the CB 1 protection	t = 0
Switching off RSS 1, switching on CB 1, triggering the CB 1 protection - **detecting the location of failure**	t = 4
Switching off CB 2, switching on RSS 2	t = 7
Switching on CB 2 - **partial restoration of supply**	t = 10
Switching on CB 1 - **failure reparation finished**	t = 20
Switching off CB 1, switching off CB 2, switching off RSS 2, switching on RSS 1 - **operations in order to reconfigure the system into the pre-failure state**	t = 24
Switching on CB 2	t = 25
Switching on CB 1	t = 26

Table 2: Course of operations in case of failure n. 1

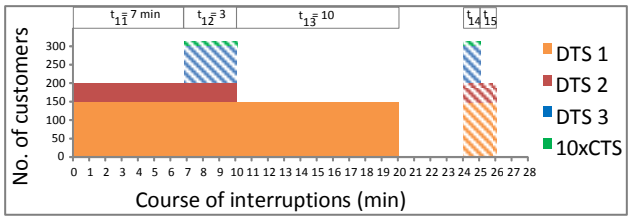


Figure 3: Graphic course of interruptions in case of failure n. 1

Calculation of system indicators in case of failure n. 1:

$$SAIFI_S = \frac{\sum_{h=(LV,MV,...)} \sum_j n_{jh}}{N_S} = \frac{n_{1LV}}{N_S} = \frac{150+50}{310} = 0{,}65 \ [1/\text{year}]$$

$$SAIDI_S = \frac{\sum_{h=(LV,MV,...)} \sum_j t_{sj}}{N_S} = \frac{\sum_{h=(LV,MV,...)} \sum_j \sum_i t_{ji} \cdot n_{jhi}}{N_S} = \frac{t_{s1LV}}{N_S} = \frac{t_{11}.n_{1LV1} + t_{12}.n_{1LV2} + t_{13}.n_{1LV3}}{N_S} =$$

$$= \frac{7 \cdot (150+50) + 3 \cdot (150+50) + 10 \cdot 150}{310} = 11{,}29 \ [\text{min/year}]$$

Voltage level indicators in case of failure n. 1:

$$SAIFI_{nn} = \frac{\sum_j n_{jLV}}{N_{SLV}} = \frac{n_{1LV}}{N_{SLV}} = \frac{(150+50)}{300} = 0{,}67 \ [1/\text{year}]$$

$$SAIDI_{nn} = \frac{\sum_j t_{sj}}{N_{SLV}} = \frac{\sum_j \sum_i t_{ji} \cdot n_{jLVi}}{N_{SLV}} = \frac{t_{s1LV}}{N_{SLV}} = \frac{t_{11}.n_{1LV1} + t_{12}.n_{1LV2} + t_{13}.n_{1LV3}}{N_{SLV}} =$$

$$= \frac{7 \cdot (150+50) + 3 \cdot (150+50) + 10 \cdot 150}{300} = 11{,}67 \ [\text{min/year}]$$

EVALUATION OF SHORT-TERM INTERRUPTIONS OF LV CONSUMERS

Additionally this paper deals with evaluation of LV consumers short-term interruptions based on monitoring of voltage on the distribution transformer (MV/LV TR) output. It is important to evaluate both the frequency and the duration of these interruptions.

The short-term interruptions result from transient short-circuits and restorations caused by reclosing and by change of DS connection status during operations. There is no reclosing on LV level thus the short-term interruptions are originated from MV or HV levels. The interruption on MV or HV level results in restraining all consumers supplied by relevant MV/LV TR.

Short-term interruptions

The evaluation of interruption of distribution for LV level customers is based on permanent analyzers measurements of power quality on MV/LV TR in 2015. The permanent measurement evaluation was made on large sample consists of more than 10 000 MV/LV TR.
Used voltage analyzers record even the fast voltage phenomena lasting longer than 0.01 second. Thus the evaluation includes every short-term interruption lasting from 0.01 second to 3 minutes.
According to [1], the interruption of power supply is considered the case in which the voltage of each phase drops below 5 percent. The evaluation includes all distribution interruptions even the long-term interruptions of power supply lasting longer than 3 minutes. Long- and short-term interruptions are evaluated independently. The short-term interruptions are additionally classified according to their duration. Time periods for this resolution are taken from evaluation of short-term voltage drops (see Distribution Code, Appendix 3 [6]).
There are 5.3 short-term interruptions per MV/LV TR per year. Representation of individual time range can be seen in figure 4.
Notice: listed calculation does not take into account the number of restricted customers and shows the raw number of distribution interruptions only.

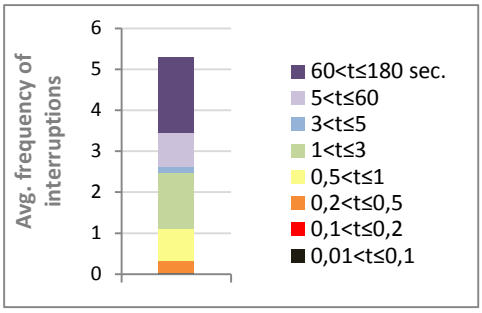


Figure 4

MAIFI

MAIFI indicator takes into account the number of restricted customers. Number of customers at selected MV/LV TR is shown in diagram in figure 5. Transformers are listed based on customers in descending order. The diagram shows 10.2 thousands of MV/LV TR supplying more than 1.2 million of customers (about 20 percent of all customers in the Czech Republic). There are 119 customers per each transformer in average.

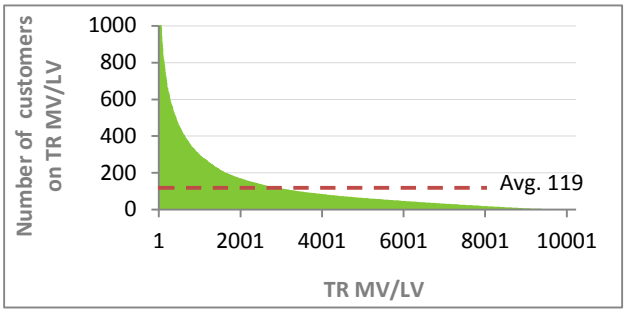


Figure 5

MAIFI was set through the association of short-term interruptions with relevant number of affected customers. The overall MAIFI value is 3.6. Figure 6 shows the MAIFI including individual time groups. To allow the direct comparison of interruptions frequency the display format and axis scale are the same for figure 6 and figure 4.

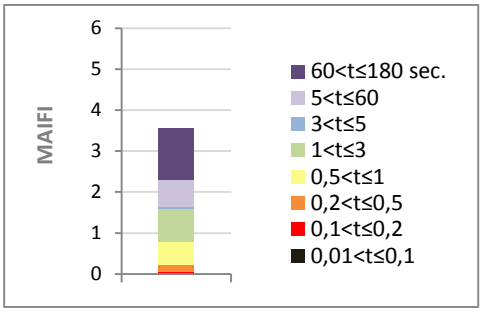


Figure 6

Interruption sequences

Usually the short-term interruptions do not occur separately but are grouped together in sequences. This part of report introduces the aggregation rule that considers repetitive interruptions as one if they are within defined threshold. The threshold starts at the end of last interruption, see figure 7. First interruption can be both short- and long-term.

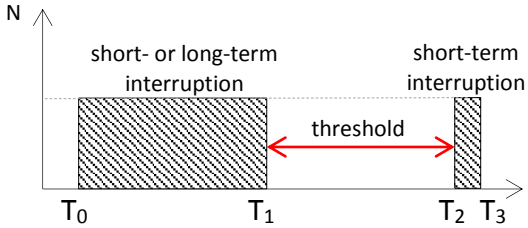


Figure 7

The threshold is considered in range of 3, 20, 60 and 120 minutes. The aggregation influence on MAIFI is shown in figure 8. The aggregation of interruption has a huge impact on MAIFI level. In example in case of 1 hour aggregation the MAIFI decreases of 33 percent.

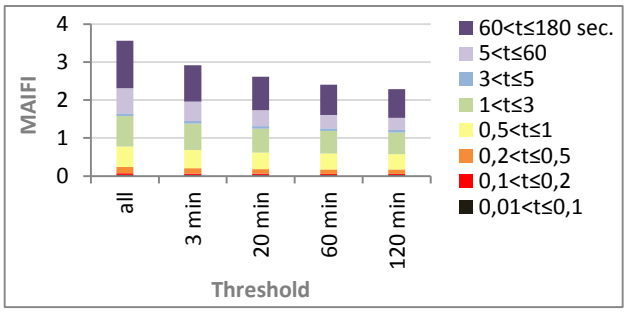


Figure 8

"Cityparts" MAIFI

The number of short-term interruption logged on each MV/LV TR was compared with number of customers supplied by associated transformers. This dependency is shown in figure 9. Each point in figure represents one transformer. For example TR #1122 supplies 628 customers and there were two interruptions recorded on that TR in 2015. This distribution transformer is shown as a red dot in diagram under 628 on x-axis (number of customers) and 2 on y-axis (number of interruptions). This way, all ten thousand distribution transformers are represented in diagram.

Usually the higher the number of customers supplied by MV/LV TR the lower number of interruptions. This result corresponds with the assumption that MV/LV TRs supplying more consumers are located in areas with higher population density. Municipal areas are usually supplied through cable network that is more durable regarding the distribution interruption.

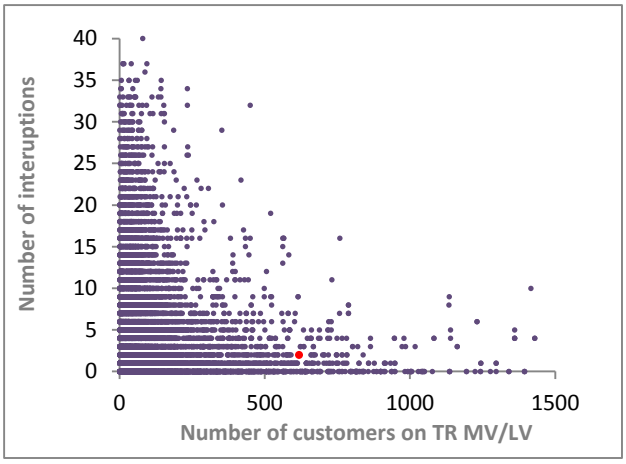


Figure 9

Taking into account of this characteristic in MAIFI calculation we introduced the feature similar to the so called cityparts which evaluates local parameters on the number of citizens on municipality basis.

Related MAIFI calculation is updated so it uses the number of customers supplied through MV/LV TR instead of the number of citizens in cityparts evaluation. Evaluated transformers are classified in 5 groups based on the number of supplied consumers. The definition of each group is listed in following table. The limits were set so each group includes approximately the same number of customers.

TR group	Total number of customers	TR number
1≥N<100	262434	6629
100≥N<200	252077	1796
200≥N<400	282774	1008
400≥N<800	274569	505
800≥N<2500	142116	131

Table 3

Figure 10 shows individual MAIFI evaluation of each transformer group. MAIFI value is about three times higher for transformer supplying low number of customers (i.e. less than 100 customers per transformer) than in municipal areas with more than 400 customers per transformer.

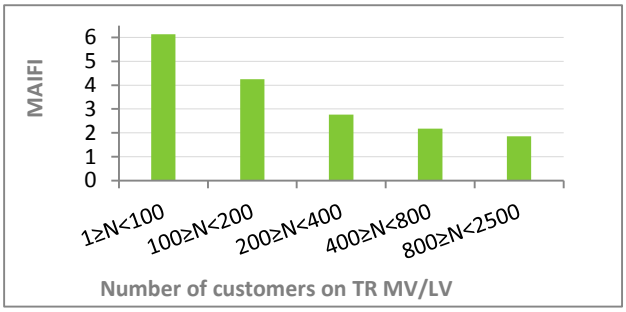


Figure 10

CONCLUSION

Long-term interruptions in the Czech Republic are reported to the Regulatory Office through SAIFI, SAIDI and CAIDI continuity indicators. These indicators are used for quality comparison across the Member States [7]. But as can be seen the calculation methodology of each indicator can vary not only for each Member State but even for each system operator in the same State. This paper introduces the calculation methodology for SAIFI and SAIDI in the Czech Republic that could be standardized through the EU. Recommendation of standardization of calculation methodology for each indicator in order to improve the comparison of each Member State is one of CEER recommendations.

Nowadays there are neither short-term interruptions presented to the Regulatory Office nor there is evaluation standardization in the Czech Republic. Not only the short-term interruptions can be dangerous for sensitive customers but they become more important. Therefore there are tasks in progress in the Czech Republic analyzing the short-term interruptions and they will result in methods for their evaluation and presentation.

The average value of short-term interruption rate 5.3 and MAIFI 3.6 was defined based on the wide series of permanent measurements on the LV level. Additionally the attention was payed to interruption sequences where significant number of interruption repeats during period lasting less than three minutes.

Though short-term interruptions are monitored in many Member States the non-uniform approach hampers the comparison between States. Hence there is a need for standardization of calculation methodology within system operators and Member States.

REFERENCES

[1] EN 50160 Ed.3 2010: Voltage characteristics of electricity supplied by public distribution networks

[2] TR 50555 Interruption indexes, 2010

[3] Directive n. 540/2005 in form of Directive n. 41/2010 series of Energy Regulatory Office about power quality and associated services in power industry

[5] Distribution Code, Annex 2, 2014: Methodology for power continuity and distribution network elements determination

[6] Distribution Code, Annex 3, 2011: Distribution system power quality and methods of its determination and evaluation

[7] 6th Benchmarking Report on Quality of Electricity Supply, CEER