Global Reliability Indices Calculation Using Monte Carlo Simulation

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Abstract The paper deals with comparison of classical and global indices of electrical energy supply reliability. Analysis of indicators according to UNIPEDE is performed. A comparison of these classical and global reliability indicators is performed in the contribution. Calculation analysis is performed, i.e. how is it possible to calculate global indicators of reliability at common reliability calculation.

Keywords: Reliability, Electric Distribution Networks, Global Reliability Indices, Monte Carlo Simulation

1 Introduction

At present, the reliability of electrical energy supply is a matter more and more discussed. Reliability calculations in the area of electric networks are constantly more frequent nowadays. With the growing importance of reliability calculations, the quantification of reliability changes as well. In the past, classical reliability quantities were used. These days, so-called global indices of reliability are applied increasingly. These global indices can be understood more easily from the electrical energy customer's point of view. The global indices of reliability are, altogether, easy-to-determine from the analysis of individual power outages. At present the collection of data on failures and outages from almost all utilities in the Czech Republic is in progress at the Department of Electric Power Engineering of VŠB - Technical University of Ostrava. In virtue of this database it will be possible not only to determine the global indices of reliability, but also the reliability of important elements of the electric power system, i.e. classical indices of reliability.

2 Classical Reliability Indices

The quantification of reliability may be various according to input data and a methodology employed. The most common expression of reliability is as follows:

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– failure rate λ ($year^{-1}$)
– mean failure duration τ (h)
– probability of failure-free operation R (-)
– probability of failure Q (-)
– mean time between failures t_S (h)

The failure rate is usually expressed as number of failures per time unit (in electric power engineering usually per year). The mean failure duration is given in hours or days. The probability of failure-free operation as well as the probability of failure is given as a proportional number (decimal fraction) or is given in per cents. These values are related to the time, for which the probability is being determined. The mean time between failures is stated in days or years and is a ratio of the total time of operation to the total number of failures during this time. The mean time between failures is proportional to the inverse value of the rate of failures. These classical indices of reliability are used mainly in reliability calculations, when reliability indices of individual elements of the reliability diagram are known and the calculation of resultant reliability of the whole system is executed.

3 Global Reliability Indices of Electrical Energy Supply

Calculation methods of the reliability of supply usually leads to the determination of the reliability of electrical energy supply in a certain point (or more points) of the electric network. To enable the quantification of the reliability of electrical energy supply to a given area, so-called global indices of the reliability of electrical energy supply must be applied. In the Czech Republic, the professional group called in English “Reliability” at ČK (Czech Committee) of CIRED worked out a document named in English “A methodology for the determination of both the reliability of electrical energy supply and that of elements of the distribution systems”. In the framework of this document, global indices of the reliability of electrical energy supply are defined too. The global indices of supply reliability are as follows:

– outage frequency (number of outages/year/customer)
– the total duration of all outages (min/year/customer)
– the duration of one outage (minutes/outage)

These indices recommended for this purpose by UNIPEDE characterise the mean average reliability of delivery and its effects from the customer’s point of view. They will be exploited especially in relation to consultation firms, authorities and mutual comparisons between utilities. In relation to common power customers, important limits, however, exist within which these indices move in utility (or in some of its part) and also the distribution of their frequencies. The subject of observation is, within the meaning of EN 50160, events of the duration more than 3 minutes (so-called long interruptions of delivery). Events of shorter duration belong to the area of electromagnetic compatibility (EMC) and their observation is not included in this directive. For the calculation of the global indices of the reliability of electrical energy supply, it is necessary to have the following data on each event (outage):

T_0 Date and time of the beginning of the event (failure).

T_1 Date and time of the beginning of manipulation.

T_2 Date and time of the end of manipulation for failure detection.

T_3 Date and time of supply restoration in the section affected by the event.

T_4 Date and time of the end of the event, i.e. time of restoration of equipment ability to fulfil its function.

T_Z Date and time of earth fault.

Z_1 The number of customers being without voltage at the time T_0.

Z_2 The number of customers being without voltage at the time T_2.

There are three basic approaches to the determination of global indices of the reliability of supply from the distribution networks caused by random or planned interruptions of supply, namely:

– outage effects are related to the number of customers affected by the outage

– outage effects are related to the undelivered power (installed or agreed power)

– outage effects are related to the number of affected stations or transformers

It is expected that for the purposes of inter-annual comparisons any selected approach can ensure sufficient accuracy. From the standpoint of long-term point of view, the observation of proposed indices (related to the customer) should gradually pass to the observation of the number of affected customers. The indices can be calculated for specific voltage levels according to one of ways given below. In the assessment, the method employed for the calculation must be stated. One event in the distribution system can lead to several outages that will affect some or all originally affected customers, in some cases, however, also other customers. All relevant outages and their effects on customers must be considered in the calculation of the indices.

3.1 The variant of customer limitation

This is the variant when the number of affected customers and the duration of the outage are recorded or can be estimated. For this variant, the following relations are valid:

The frequency of outages λ_G

$$\lambda_G = \frac{\sum_j n_j}{N_S} \qquad (\text{outage} \cdot \text{year}^{-1}) \tag{1}$$

The total duration of all outages related to one customer τ_{GV}

$$\tau_{GV} = \frac{\sum_j (n_j \cdot t_j)}{N_S} \qquad (\text{min} \cdot \text{year}^{-1}) \tag{2}$$

The duration of one outage τ_G

$$\tau_G = \frac{\sum_j (n_j \cdot t_j)}{\sum_j n_j} \qquad (\min \cdot \text{outage}^{-1}) \tag{3}$$

n_j – the number of customers in the group of affected customers j (-),
t_j – the mean duration of outage for the customer of the group j (min),
N_s – the total number of customers supplied (-).

The mean duration is given by the following relation:

$$t_j = \frac{Z_1(T_1 - T_0) + (Z_1 + Z_2) \cdot (T_2 - T_1)/2 - Z_2(T_3 - T_2)}{Z_1} \tag{4}$$

The philosophy of relation 4 is as follows:

– The mean duration of outage is related to all affected customers Z_1, i.e. to customers that were affected at the beginning of the event (Z_1 is the largest number of affected customers during the given event; any increase in the number of affected customers in the course of manipulation is not expected).

– The expression in the numerator determines the time limitation of customers and is divided into the following three parts:

– The first part is the time from failure occurrence to the beginning of manipulation. During this period, the most customers are being affected, i.e. Z_1.

– The second part is the time of manipulation till the failure detection. Within this period, the number of affected customers is expected to decrease from the value Z_1 to the value Z_2. Relation 4 presupposes that the decrease in the number of affected customers is linear in time.

– The third part is the period of time from failure detection to the complete restoration of power supply. In this period, Z_2 customers are being affected.

If no change in the number of affected customers occurs in the course of failure detection, the duration of outage is equal to the time difference T_3–T_0. The relation between the global reliability indices and the basic reliability quantities is clear from the following example.

4 The Relation Between Global and Classical Reliability Indices

On the basis of analysis of definitions of the global and classical reliability indices it is possible to make their comparing. As already stated, it is possible to use the global reliability indices that are related to the number of limited customers, or to the limited power, or to the limited distribution transformer substations. For the purpose of comparison with the classical reliability quantities, the global indices will be taken that are related to the number of limited customers. From the comparison of the definitions, the following relations can be written:

$$\mathrm{SAIFI} \equiv \lambda_G = \frac{\sum\limits_{i=1}^{n} (\lambda_i \cdot N_i)}{\sum\limits_{i=1}^{n} N_i} \qquad (\mathrm{outage} \cdot \mathrm{year}^{-1}) \tag{5}$$

$$\mathrm{SAIDI} \equiv \tau_{GV} = \frac{\sum\limits_{i=1}^{n} (\lambda_i \cdot \tau_i \cdot N_i)}{\sum\limits_{i=1}^{n} N_i} \qquad (\mathrm{min} \cdot \mathrm{year}^{-1}) \tag{6}$$

$$\mathrm{CAIDI} \equiv \tau_G = \frac{\sum\limits_{i=1}^{n} (\lambda_i \cdot \tau_i \cdot N_i)}{\sum\limits_{i=1}^{n} \lambda_i \cdot N_i} \qquad (\mathrm{min} \cdot \mathrm{outage}^{-1}) \tag{7}$$

λ_i – outage rate at the point i of the network (year^{-1}),
τ_i – the mean duration of outage at the point i of the network (min),
N_i – the number of connected customers at the point i of the network ($\sum\limits_{i=1}^{n} N_i = N_S$),
SAIFI – system average interription frequency index,
SAIDI – system average interription duration index,
CAIDI – customer average interruption duration index.

Relation 5, in principle, coincides with relation 1. The frequency of outages can be also expressed as a ratio of the number of customers affected by one outage per year to the total number of customers. Relation 6 is basically equal to relation 2. The value of this index can also be defined as a ratio of the number of customers affected by a minute's outage per year to the total number of customers. Relation 7 is in the main equal to relation 3. The value of the index is also defined as a ratio of the number of customers affected by a minute's outage per year to the number of customers affected by the outage. The definitions of reliability indices that are given in this chapter express the basic relations between the classical reliability quantities and the global reliability indices.

5 Calculation of Reliability Indices Using Monte Carlo Simulation

For Monte Carlo simulation of electric power networks we are using at the Department of Electric Power Engineering program named KomplexSPOLEH[1,2,3,4]. The input data are reliability parameters of particular nodes and branches (failure rate and duration, maintenance rate and duration, power indices such as node load and branch maximum capacity...). Since program implies in calculation also power balance, it is necessary to set to every node the consuming/generating power and to every branch its rated power. The branches can be classical ones, further there can be two types of backup branches (that means two types of cold reserves), and also T-joint line. Program KomplexSPOLEH allows also setting the whole network including redundant areas and performing the reliability calculation. The outcome of calculation is then overall balance of solved network and outcoming reliability parameters of all nodes.

As a simulation result in the KomplexSPOLEH program are calculated (among others) local reliability parameters for particular nodes. These parameters areλ_i (outage rate) τ_i (mean duration of outage). Since one of parameters for simulation calculation is also N_i (number of customers connecteted to i-th node), the global reliability indices SAIFI, SAIDI and CAIDI can be calculated according to equations number 5, 6 and 7 respectively.

6 CONCLUSION

It is possible to express reliability in various ways. For reliability calculations, classical reliability indices of network elements are stated. When determining the reliability of electricity supply to customers, global reliability indices are used almost ever at present. At the observation of outages of electrical energy supply that has been introduced in the Czech Republic lately, it is possible to quantify merely the global reliability indices either. An effort is devoted to the gradual extension of outage databases so that the reliability of specific elements may be assessed as well. In this contribution a methodology for the calculation of global reliability indices from classical reliability indices is described briefly. This methodology is very important and is employed mainly in the determination of global reliability indices of wholesale customers connected newly, when no real data on outages is available. In this case classical reliability calculations must be applied and resultant values must be converted into global indices.

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