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Evaluation of an urban medium-voltage network by using reliability indices

Elisabeth Hufnagl, Maria Aigner, Ernst Schmautzer

Graz University of Technology, Institute of Electrical Power Systems – IFEA
Inffeldgasse 18/1, 8010 Graz, Austria
E-mail: elisabeth.hufnagl@tugraz.at

Abstract. The paper proposes a procedure to assess the reliability indices needed in evaluating an urban medium-voltage network. There are several ways of determining the reliability indices describing the network in its current state as well as the potential changes caused by reinforcing the electrical installations, implementing restructuring measures or increased generation and demand in the network structure. For the calculations to be efficient the input data for the created reliability datatypes and values should be used correctly. By employing the reliability indices, an impartial comparison between various here given options is possible.

Keywords: reliability analysis, reliability, network calculation software, network expansion

Ovrednotenje zanesljivosti srednjenapetostnega omrežja v urbanem okolju z uporabo sistemskih kazalnikov

Članek predlaga postopek določanja sistemskih kazalnikov zanesljivosti, ki so potrebni za ovrednotenje zanesljivosti srednjenapetostnega omrežja v urbanem okolju. Pri tem obstaja več načinov za določitev sistemskih kazalnikov. Z njimi lahko opišemo zanesljivost omrežja v obstoječem stanju in po potencialni nadgradnji z ojačitvami in spremembami strukture omrežja, kot tudi s povečanjem proizvodnje na zahtevo. Za učinkovito izvajanje izračunov je potrebno uporabiti vhodne podatke, ki ustrezajo tipu in vrednosti ustvarjenih kazalnikov zanesljivosti. Uporaba sistemskih kazalnikov zanesljivosti omogoča nepristransko primerjavo med različnimi možnostmi za povečanje zanesljivosti srednjenapetostnega omrežja.

1 INTRODUCTION

In general, an impartial technical comparison of electric grids is difficult to accomplish, considering that multiple factors have an impact on the node voltages, load and reliability. The average system performance can be measured by the duration and frequency of customer interruptions, but it must be kept in mind, that these average values give only general trends which entail a loss of detail. This means that the interruption duration for any specific customer can not be determined on the basis of statistic reliability indices. [1]

However, using these indices enables electric grids to be compared in terms of average interruption duration and frequency. In this paper, the use of the statistic reliability indices provides a basis for evaluating two sub-networks[1] of an Austrian urban medium-voltage network. To calculate the reliability indices (in our case according to IEEE standard [1]), the network reliability is assessed. The network calculation software NEPLAN® is used. For the determination of every possible interruption combination to be fully automated in NEPLAN®, each of these switching options are added to the network simulation model. [2]

Concerning interruption combinations a differentiation between single and multiple interruptions is made. Multiple interruptions are basically a superposition of single interruptions. A detailed explanation can be found in [2].

2 RELIABILITY ASSESSMENT

As mentioned above, it is important to know the difference between the input data (interruption duration and frequency for each grid element) and the computed reliability value. The former characterizes the interruption behaviour of the grid equipment. For this paper, the statistical data of the »FNN-Interruption-Statistics« is used in creating reliability datatypes, used as a global input for NEPLAN®. By using these datatypes combined with the switching options and switching times after an interruption, the reliability values for each grid element are computed and then used in calculating the reliability indices and evaluating

[1] The evaluated medium-voltage network consists of five sub-networks (north, west, south, east and centre). Each sub-network is supplied by a transformer station and shows a partly meshed structure. For this paper, the sub-networks north and west are analyzed. Further explanations are given in [7] and [4].

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the network reliability (average system performance). The reliability values discussed in this paper are described in Table 1.

Table 1: Reliability values computed by NEPLAN®, [2]

Acronym	Reliability value	Unit	Description
F	Expected value of the interruption frequency	1/a	Expected interruption frequency per year
Q	Non-availability	min/a or h/a	Probability of the expected interruptions per year
T	Expected value of the interruption duration	min or h	Expected interruption duration

2.1 *Reliability Indices*

With the NEPLAN®-computed reliability values for the network nodes and the installed transformer capacity (or the number of customers), the described reliability indices are:

- **S**ystem **A**verage **I**nterruption **D**uration **I**ndex (SAIDI)
  ...indicates the total interruption duration for the average customer. Usually, this index is measured in minutes or hours of an interruption.
- **S**ystem **A**verage **I**nterruption **F**requency **I**ndex (SAIFI)
  ...indicates how often the average customer is affected by an interruption.
- **C**ustomer **A**verage **I**nterruption **D**uration **I**ndex (CAIDI)
  ...indicates the average time required to restore the service. This index is commonly measured in minutes or hours of an interruption.
- **A**verage **S**ystem **I**nterruption **D**uration **I**ndex (ASIDI)
  ...corresponds to SAIDI, but refers to the interrupted load rather than to the average customer.
- **A**verage **S**ystem **I**nterruption **F**requency **I**ndex (ASIFI)
  ...indicates the load which can't be supplied due to interruptions. It is sometimes used to measure the performance in areas with a large load concentration but rather few customers.

The process chart for calculating the reliability indices is shown in Fig. 1.

The Austrian 2013 reliability indices are given in Table 2 and show the interruption rates. They are used as reference values for the calculated network-specific indices.

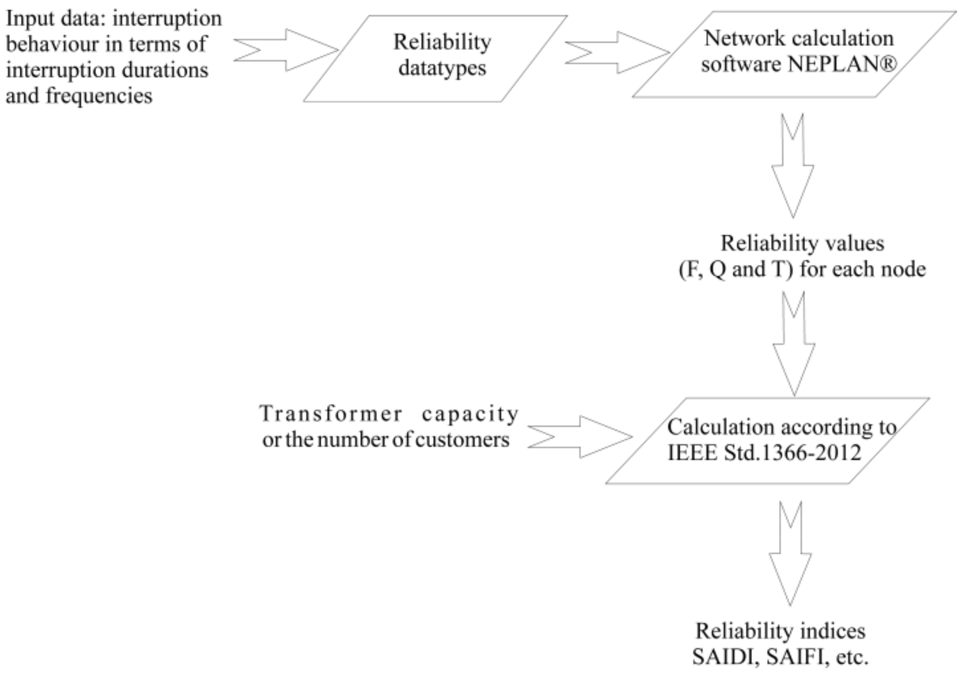

Fig. 1. Process chart for Calculating the reliability indices

Table 2: The Austrian 2013 reliability indices, [3]

System Average Interruption Duration Index	SAIDI	47.58 minutes
Average System Interruption Duration Index	ASIDI	50.18 minutes
System Average Interruption Frequency Index	SAIFI	0.96 (dimensionless)
Average System Interruption Frequency Index	ASIFI	1.03 (dimensionless)
Customer Average Interruption Duration Index	CAIDI	49.37 minutes

To explain the term »reliability datatype«, Fig. 2 shows a circuit breaker of which the values given for F and T are not the ones used for this paper. The values figuring in it are just examples.

Finally, the missing links between the reliability values and reliability indices are given by equations ((1) - (5)). They describe the output values supplied by NEPLAN® for the total number of customers served and the NEPLAN® simulation results for the total transformer capacity.

$$SAIDI = \frac{\sum Q_i \cdot K_i}{N_T} \quad (1)$$

where:

Q_i - non-availability in minutes per year in node i,

K_i - number of the customers supplied by node i,

N_T - total number of the customers served

$$SAIFI = \frac{\sum F_i \cdot K_i}{N_T} \quad (2)$$

where:

F_i - expected value of the interruption frequency in node i

$$CAIDI = \frac{SAIDI}{SAIFI} \quad (3)$$

$$ASIDI = \frac{\sum Q_i \cdot S_i}{L_T} \quad (4)$$

where:

S_i - transformer capacity in node i,

L_T - total transformer capacity

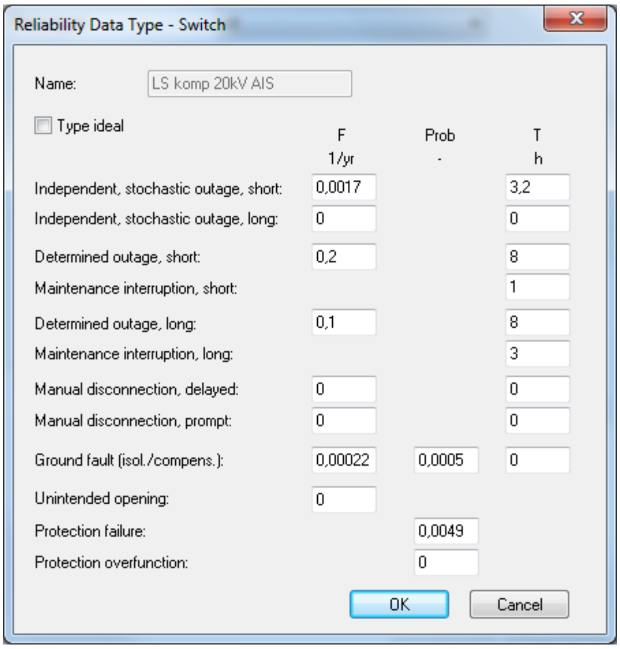

Fig. 2. Reliability datatype of a circuit breaker

$$ASIFI = \frac{\sum F_i \cdot S_i}{L_T} \quad (5)$$

3 Restructuring an Urban Medium-Voltage Network

In this chapter, the impact of restructuring a medium-voltage network is described. For the heavy-load state (an increase by 20 % is assumed), the load of some of the cables in the sub-network north is more than 50 % of their capacity. To reduce their load, some restructuring measures are proposed and their impact is analysed.

3.1 Changing the switching status

The circuit breaker's present open switching status is now changed to close. This closes the parallel circuit and some of the heavy-loaded cables (> 50 % of the nominal load) are released. By changing the circuit breaker's switching status the load of these cables is reduced by 20 %. Of course, by taking this measure some lines are put into operation, but their maximum load is only 33 % of their capacity. Fig. 3 shows the restructuring results (underlined values) and the initial values.

The load is reduced on the most heavily loaded cable. The voltage does not exceed its set limits when closing the circuit breaker. The impact of restructuring on the network reliability is shown in Table 3.

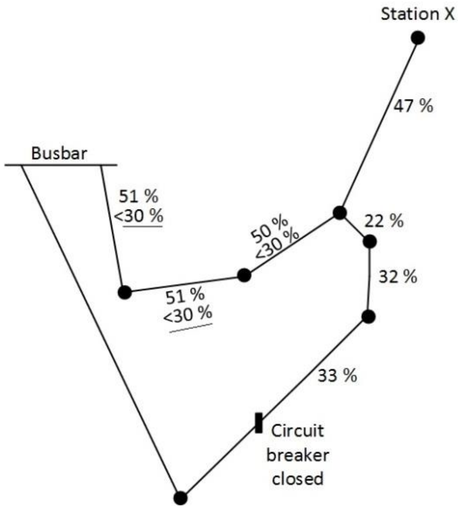

Fig. 3. Closing the circuit breaker, present cable load, underlined values: the load after changing the circuit breaker's switching status from open to closed, [4]

3.2 *Additional cable connection*

The next measure to reduce the heavy cable load is adding a new cable connection, i.e. closing the bypass between the busbar and station x. The resulting impact on the load flow is shown in Fig. 4 and, on the reliability indices in Table 3.

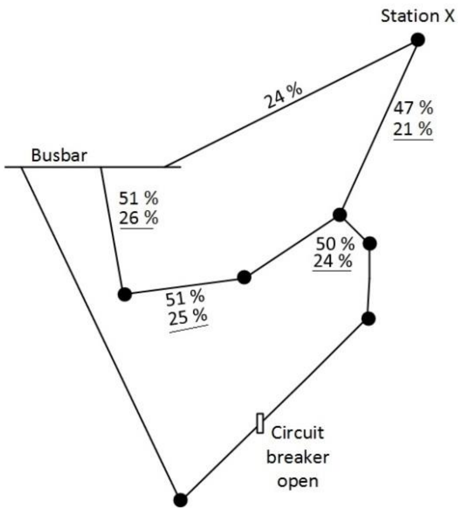

Fig. 4. Adding a new cable connection, the present cable load, underlined values: the load after adding a cable connection, [4]

3.3 *An additional cable connection cross-connected with the existing stations*

Adding a cable cross-connected with the existing stations involves a much higher technical and financial effort but the resulting positive impact on the network reliability is considerable. The impact of this measure on the reliability indices is given in Table 3.

The restructuring measure shown in Fig. 5 (in case of open circuit breakers) has no impact on the load flow compared to the measure described in section 3.2.

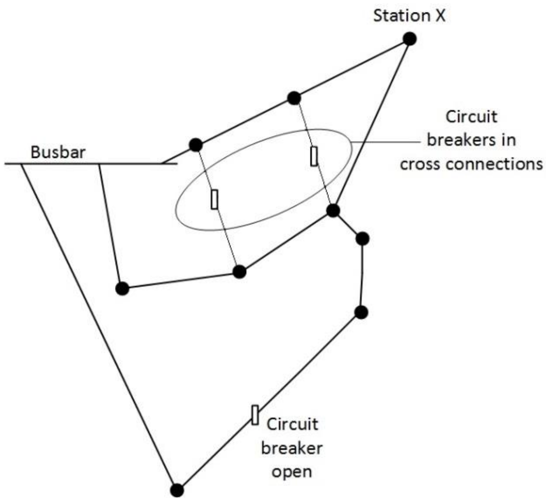

Fig. 5. Additional cable connection cross-connected with the existing stations, [4]

4 RESULTS OF THE RELIABILITY ASSESSMENT

To simulate single interruptions, the reliability datatypes are created with »FNN-Interruption-Statistics« data [5]. Table 3 shows the results of analyzing the subgrids north and west at single interruptions. Presently, in the examined sub-networks the interruptions are very short and their frequencies are low (Table 3, simulation numbers 1 and 2), meaning that the network is very well developed. Moreover, as the structure of the network is partly meshed, its reliability is high. So, the interruptions being of a short duration, the non-availability can only be reduced marginally by taking the proposed restructuring measures in the sub-network north. Releasing the heavily-loaded cables can be accomplished by implementing any of the proposed measures, without exceeding the set voltage limits or equipment capacities. As there is no need to propose a restructuring measure for the sub-network west, only its present state is evaluated (Table 3).

To allow for a comparison, for each sub-network one restructuring measure is evaluated for the case of multiple interruptions. The results are given in Table 4. As clearly seen, there are no significant differences between the results of simulations for single and multiple interruptions. This is due to the partly meshed network structure of the analyzed network.

The results of this analysis are also confirmed by the experiences of the distribution-system operator.

Table 3: Reliability-assessment results for single interruptions, [4]

Simulation	Description	SAIDI	SAIFI	CAIDI	ASIDI	ASIFI
#	-	min/a	1	min/a	min/a	1
1	Sub-grid west: present state	5.593	0.066	84.736	5.885	0.067
2	Sub-grid north: present state	6.590	0.096	68.791	6.273	0.094
3	Sub-grid north: circuit breaker closed	4.754	0.072	66.025	4.530	0.072
4	Sub-grid north: additional cable connection	6.955	0.090	76.901	6.534	0.089
5	Sub-grid north: combination of #3 and #4	4.838	0.0674	71.752	4.597	0.0664
6	Sub-grid north: additional cable connection + cross-connections (circuit breakers open)	4.841	0.067	71.835	4.599	0.066

Table 4: Reliability-assessment results for multiple interruptions, [4]

Simulation	Description	SAIDI	SAIFI	CAIDI	ASIDI	ASIFI
#	-	min/a	1	min/a	min/a	1
7	Sub grid west: present state	5.378	0.066	81.455	5.642	0.067
8	Sub grid north: additional cable connection + cross connections (circuit breakers open)	4.814	0.068	70.616	4.573	0.067

5 CONCLUSIONS

The paper shows that by using the NEPLAN® network calculation software and the »FNN-Interruption-Statistics« data [5], the reliability indices can be highly accurately assessed, as confirmed also by experiences of the distribution system operator.

Assuming a future 20 % load increase, some of the cables in the sub-network north will be loaded up to 50 % of their capacity. By applying the proposed restructuring measures (e.g. an additional cable connection) the loadflow can be split, thus reducing equipment load and improving the network reliability.
The results show, that even in a well-developed (partly meshed) network, additional equipment can increase the non-availability, whereas further switching options can positive affect the network reliability.

Comparing the single and multiple interruptions shows that the multiple interruptions can be neglected.

Finally it should be noted, that it is difficult to make a general assessment of the impact of restructuring measures on the network. Generally their efficiency depends on the structure of the particular network and has to be calculated and evaluated individually. According to the experiences of the distribution-system operator, evaluating the restructuring measures by using the reliability indices before an actual implementation can be beneficial.

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Elisabeth Hufnagl received her diploma degree in electrical engineering from Graz University of Technology in 2014. Since then she has been a scientific assistant at the Institute of Electrical Power Systems, at the same university.

Maria Aigner received her diploma degree in electrical engineering in 2008 and her PhD degree in 2015 from Graz University of Technology where she has been a project assistant at the Institute of Electrical Power Systems.

Ernst Schmautzer is a senior researcher at the Institute of Electrical Power Systems, Graz University of Technology. His main research interests are in efficient use of electric energy, smart grids, smart building installations, low-frequency electromagnetic fields, EMC, EMI, grounding problems and protection measures.