EVALUATION OF AN URBAN MEDIUM VOLTAGE NETWORK USING RELIABILITY INDICES

Elisabeth HUFNAGL, Maria AIGNER, Ernst SCHMAUTZER

ABSTRACT

This article deals with the assessment of reliability indices of a medium voltage network. In order to evaluate an urban medium voltage network, several steps can be taken to determine the reliability indices describing the network in its current state, as well as for potential changes caused by e.g. reinforcement of the electrical installation, restructuring measures, increased generation and demand in the network structure. To successfully conduct the following calculations, the correct use of the input data for the created reliability datatypes and reliability values is essential. By using reliability indices an impartial comparison between various options (referring to the cited measures) is possible.

1 INTRODUCTION

In general, an impartial technical comparison of electric grids is difficult to accomplish, considering that multiple factors have an impact on node voltages, load and reliability. The average system performance can be measured by duration and frequency of customer interruptions, but it must be kept in mind, that 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, the use of these indices still offers the opportunity to compare electric grids in terms of average interruption duration and frequency, which motivates their use in this paper for the evaluation of two sub-networks[1] of an urban medium voltage network. To calculate reliability indices (according to IEEE standard [1]), a reliability assessment has to be done. In this case, the network calculation software NEPLAN® has been used. In order to accomplish a fully automated determination of every possible interruption combination, all switching options of the evaluated medium voltage grid have to be added to the network simulation model. [2]

Concerning interruption combinations a distinction between single interruptions and multiple interruptions is necessary. Multiple interruptions basically describe a superposition of single interruptions – a detailed explanation can be found in [2].

[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 were analysed. Further explanations are given in [7] and [4].

2 RELIABILITY ASSESSMENT

As implied in chapter 1, it is of importance to know the difference between input data in form of interruption durations and frequencies and the computed reliability values. The former characterize the interruption behaviour of the grid equipment. For this paper the statistical data of »FNN-Interruption-Statistics« was utilised to create reliability datatypes, which are used as global input for the network calculation software NEPLAN®. By using these datatypes combined with the given switching options and switching times after an interruption, the reliability values for each grid element can be computed, which are necessary for the calculation of reliability indices and for the evaluation of 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 interruption frequency	1/a	Frequency of expected interruptions per year
Q	Non-availability	min/a or h/a	Probability of expected interruptions per year
T	Expected value of duration of interruption	min or h	Expected duration of interruption

2.1 Reliability Indices

With the obtained reliability values, computed by NEPLAN®, for the network nodes and the installed transformer capacity (respectively number of customers), the described reliability indices (according to IEEE standard [1]) can be calculated:

- **S**ystem **A**verage **I**nterruption **D**uration **I**ndex (SAIDI)
  ...indicates the total duration of interruption for the average customer. Usually this index is measured in minutes or hours of 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)
  ...represents the average time required to restore service. This index is commonly measured in minutes or hours.

- **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)
  ...is based on the load which can't be supplied due to interruptions. This index is sometimes used to measure performance in areas with large concentrations of load but rather few customers.

The process chart of calculating reliability indices is illustrated in Fig. 1.

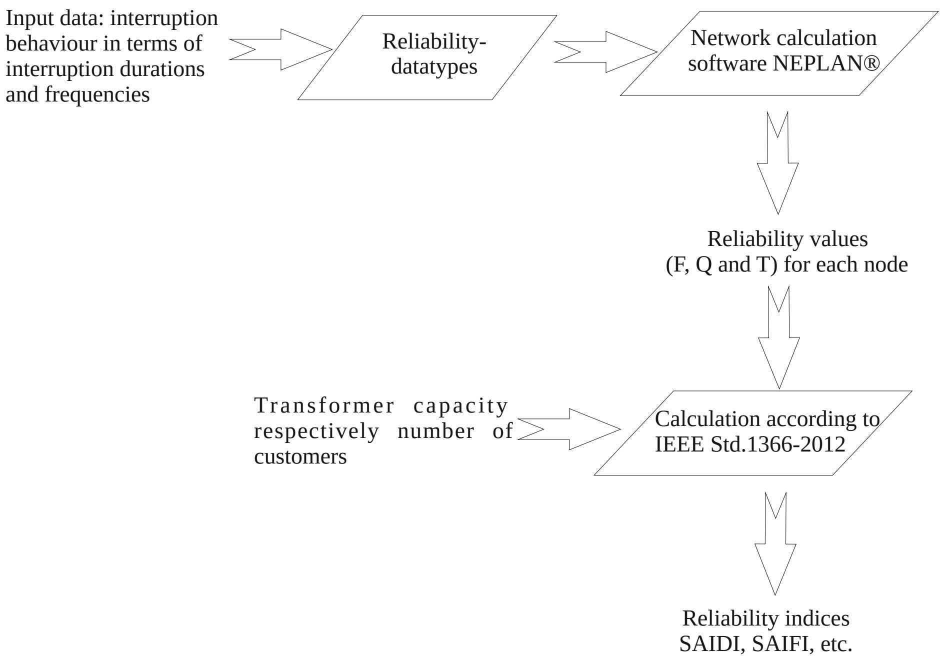

Fig. 1. Calculation process chart for reliability indices

The reliability indices of Austria 2013 are given in Table 2 and provide a good impression concerning the range. They can be used as reference values for the calculated network specific indices.

Table 2: Reliability indices of Austria in 2013, [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 clarify the term »reliability datatype« a circuit breaker is given in Fig. 2, whereas the given values for F and T don't match the ones used for this paper, as only example values were inserted.

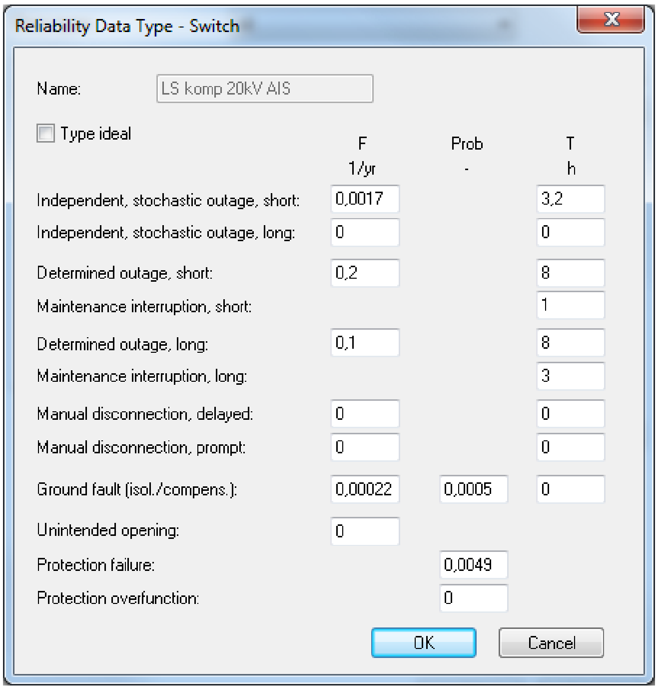

Fig. 2. Reliability datatype of a circuit breaker

Finally the missing links between reliability values and reliability indices are given by equations ((1) - (5)), which describe on the one hand the output values supplied by NEPLAN® by the total number of customers served in the considered network and on the other hand the NEPLAN simulation results by the total transformer capacity in the considered network.

$$\mathrm{SAIDI} = \frac{\sum Q_i \cdot K_i}{N_T} \tag{1}$$

where: Q_i - Non-availability in minutes per year in node i,

K_i - Number of customers supplied by node i,

N_T - Total number of customers served in the considered network

$$\mathrm{SAIFI} = \frac{\sum F_i \cdot K_i}{N_T} \tag{2}$$

where: F_i - Expected value of interruption frequency in node i

$$\mathrm{CAIDI} = \frac{SAIDI}{\mathrm{SAIFI}} \tag{3}$$

$$\text{ASIDI} = \frac{\sum Q_i \cdot S_i}{L_T} \tag{4}$$

where: S_i - Transformer capacity in node *i*,

L_T - Total transformer capacity in the considered network

$$\text{ASIFI} = \frac{\sum F_i \cdot S_i}{L_T} \tag{5}$$

3 RESTRUCTURING OF AN URBAN MEDIUM VOLTAGE NETWORK

In the following chapter the effects of restructuring measures in a medium voltage grid are described. Under the assumption of heavy load conditions (for this load profile an increase of the present heavy load by 20 % has been applied), a few cables in the investigated sub-network north are loaded with more than 50 % of their capacity. In order to reduce the load of these cables, some steps of restructuring are suggested and their efficiency is analysed.

3.1 Change of switching status

A circuit breaker, whose present switching status is »open«, is closed. For this reason, a parallel circuit is closed and some of the heavy loaded cables (> 50 % of nominal load) are released. By changing the status of this circuit breaker a load reduction of 20 % can be achieved. Of course a couple of lines are put into operation by taking this measure but they are loaded at a maximum load of 33 % only, what can be accepted. In Fig. 3 the results of this restructuring measure are given in blue, the initial values are illustrated in red.

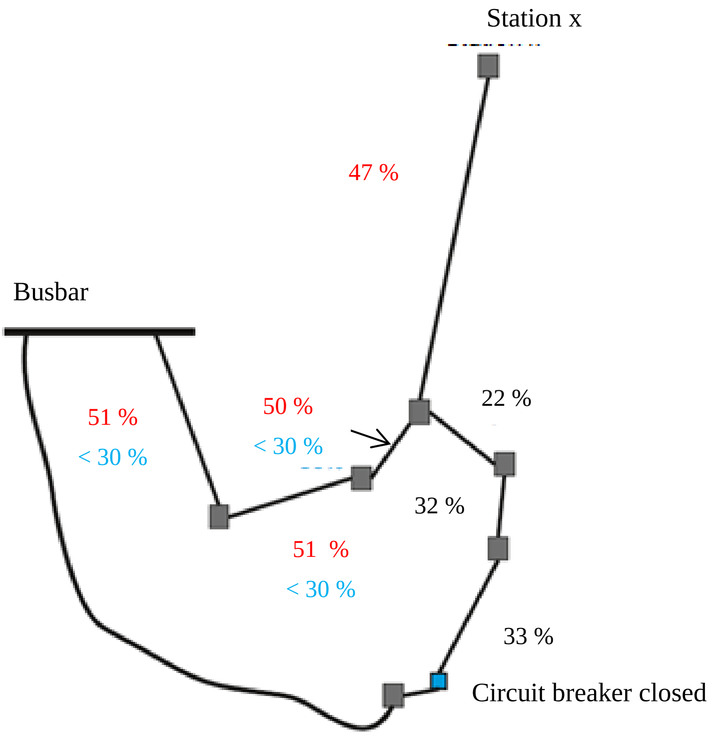

Fig. 3. Closing of a circuit breaker, red: present load of the cables, blue: load after changing the switching status of the circuit breaker marked in blue to closed, [4]

The most heaviliy loaded cable obviously receives the highest load removal. The voltage range does not exit its given limits due to closing the circuit breaker. The impact of this restructuring measure on the network reliability is demonstrated in Table 3.

3.2 Additional cable connection

A further measure of releasing the heavy loaded cables is adding a new cable connection, closing a bypass path between the busbar and station x. The impact of this change on the load flow is illustrated in Fig. 4. The effect on the reliability indices is given in Table 3.

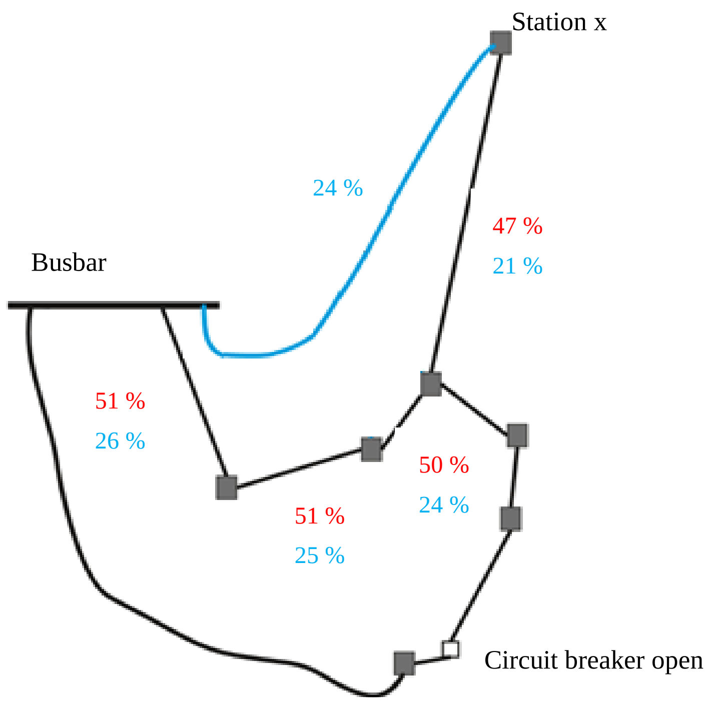

Fig. 4. Adding a new cable connection (blue), red: present load of the cables, blue: load after the addition of a cable, [4]

3.3 Additional cable with cross connections to existing stations

The addition of a cable with further cross connections leads to considerably higher technical and financial efforts but the resulting benefits on the network reliability are noteworthy. The impact on reliability indices of this measure is given in Table 3.

The restructuring measure shown in Fig. 5 does (in case of open circuit breakers) not change the load flow in comparison to the measure described in 3.2.

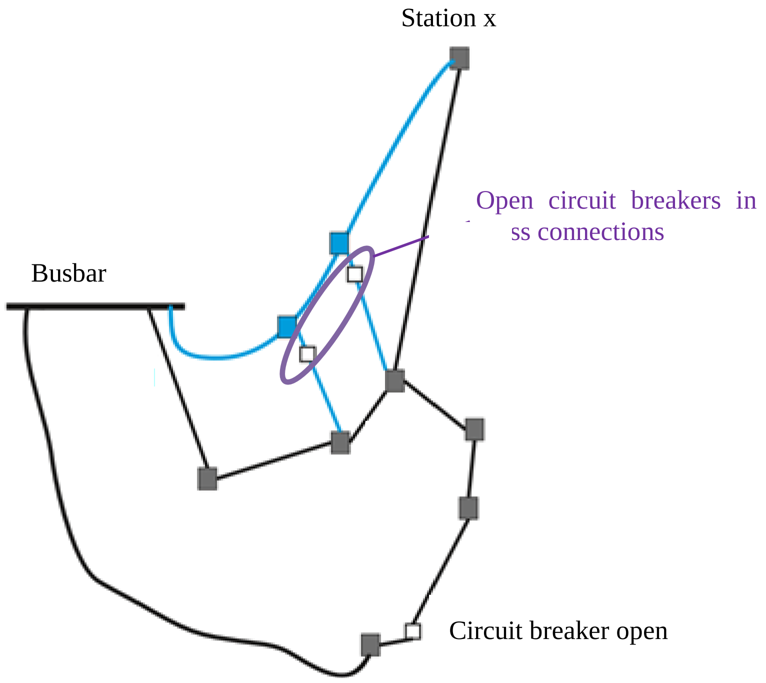

Fig. 5. Additional cable connection with cross connections to existing stations, [4]

4 RESULTS OF RELIABILITY ASSESSMENT

For the simulation of single interruptions the reliability datatypes were created with the given data of the »FNN-Interruption-Statistics« [5]. In Table 3 the results of the analyses of subgrids north and west of the urban network under the consideration of single interruptions are shown.

The examined sub-networks of a medium voltage urban power network already show very short interruption durations and low interruption frequencies at their present state (Table 3, simulation number 1 and 2). This indicates a very well developed network. The assessed medium voltage network also has a partly meshed structure, which leads to a high network reliability.

Based on these low interruption durations, the non-availability can only be reduced marginally by the suggested measures of restructuring in sub-network north. A release of the heavily loaded cables can be accomplished with all the proposed measures in this paper, without exiting the given voltage limits or equipment capacities. As there was no cause to suggest restructuring measures in sub-network west, only its present state was evaluated in this work – see Table 3.

Table 3: Results of the reliability assessment under consideration of 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: closing a circuit breaker	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 #2 and #3	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

To meet comparison purposes, for each assessed sub-network one restructuring measure was evaluated under consideration of multiple interruptions. The results of this analysis are given in Table 4. It becomes clear that, referring to the medium voltage network assessed in this article, no significant differences between the results of simulations under consideraton of single interruptions and simulations under consideration of multiple interruptions occur. This can be explained by the partly meshed network structure of this specific urban network.

Table 4: Results of reliability assessment under consideration of 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

The results of these analyses are confirmed by the experiences of the distribution system operator.

5 CONCLUSIONS

As a part of the network restructuring project the analyses have shown, that by the use of the network calculation software NEPLAN® and data of the »FNN-Interruption-Statistics« [5] an assessment of reliability indices can be accomplished with high accuracy - the results of this analyses have been confirmed by the experiences of the distribution system operator in a very high level.

If a future increase of the present heavy load by 20 % is assumed, a couple of cables in sub-network north are loaded higher than 50 %. By applying restructuring measures suggested in this paper (e.g. an additional cable connection, additional circuit breakers) the loadflow can be splitted, so the load of the equipment can be reduced and the network reliability is improved.

The achieved results imply, that even in a well-developed network (partly meshed), additional equipment can increase the non-availability, whereas including further switching options can have a positive effect on the network reliability.

The comparison of single interruptions and multiple interruptions shows that, due to this medium voltage network’s structure, a negligence of multiple interruptions is valid.

Finally it should be acknowledged, that simplifying statements regarding the impact of network restructuring measures, are difficult to make. Generally the efficiency of such measures depends on the network structure and has to be calculated and evaluated individually. The network distribution operator’s experiences confirm that the evaluation of restructuring measures using reliability indices before the actual implementation can be beneficial.

6 REFERENCES

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AUTHORS' ADDRESS

Dipl.-Ing. Elisabeth HUFNAGL

Graz University of Technology, Institute of Electrical Power Systems – IFEA

Inffeldgasse 18/1, 8010 Graz, Austria

Tel: + 43 316 873 7552 Fax: + 43 316 873 7553

http://www.ifea.tugraz.at