Reliability and Maintenance of Electrical Power System

Invited lecture

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***Abstract*—Paper deals with the analyses of electrical power network reliability parameters connected to maintenance. Knowledge of the component reliability parameters in power networks is necessary for the reliability computation and also for reliability-centered maintenance system. Component reliability parameters are possible to retrieve only with accurate databases of distribution companies. Such a database includes records of outages and interruptions in power networks. Maintenance influence the indicators evaluating interruptions - maintenance time in fact means unavailability. There are analyses of interruption indicators improvement, modern techniques like Live Working and Reliability Centered Maintenance in this paper.**

Keywords—reliability indicators; distribution network; database; maintenance; RCM; live working

I. Introduction

Reliability of Supply describes the ability of the network to transport energy, possibly free of interruption and meeting the product quality [1]. This work deals with the reliability distribution networks. It is necessary to observe outages and interruptions of electrical energy for retrieving the reliability indicators [2]. A larger database would describe the real condition of the network more accurately. Therefore, it is necessary to merge databases of various distributors and distribution areas. These databases are used for maintenance optimization of electric distribution network devices.

II. Reliability of Components

The basic reliability data of particular elements may be computed from the database of outages and interruptions stored at the VSB – Technical University of Ostrava. The results include the rates and mean durations of equipment outages. The actual data collection includes outage data from distributors from the Czech Republic and one from the Slovak Republic. We have retrieved data from eight distribution areas. Today database contains more than 400 thousand records (from 2000 to 2016) on voltage levels 110 kV, MV and partially LV.

The graphic representation of all distribution regions reliability indices from the above-mentioned data for the 22 kV cable is given in Fig. 1. From the significant differences in particular years it is possible to observe the contribution of our analyses. The divergence of reliability indices is eliminated during long-term observation.

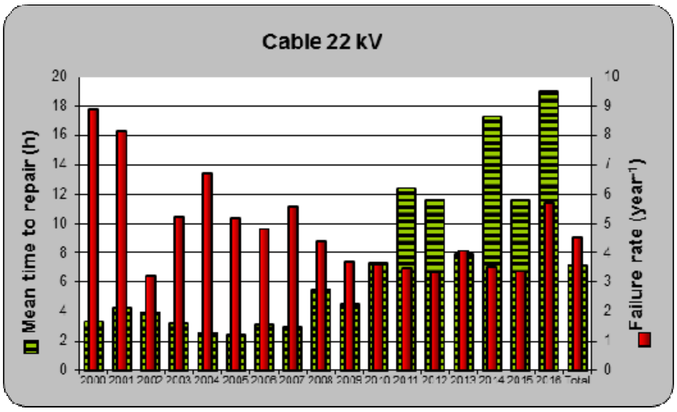

Fig. 1. The value tendency of reliability indices of the 22 kV cable.

These parameters could update reliability indices from old Regulations 2/74 [3]. There is a comparison of both databases, 1975 - 1979 and 2000 - 2016, in Table I.

TABLE I. COMPARISON WITH METHODOLOGY ČEZ 22/80

Equipment		ČEZ 22/80	2000 - 2016
22 kV cable	λ (year^{-1})	14.5	4.541
	τ (h)	215	6.923
22 kV overhead line	λ (year^{-1})	14	2.384
	τ (h)	3	4.618
110 kV overhead line	λ (year^{-1})	5.2	0.242
	τ (h)	3.5	3.552
MV/LV transformer	λ (year^{-1})	0.03	0.006
	τ (h)	2500	5.141
110 kV/MV transformer	λ (year^{-1})	0.04	0.054
	τ (h)	1300	0.218
22 kV circuit breaker	λ (year^{-1})	0.015	0.012
	τ (h)	30	30.005
110 kV circuit breaker	λ (year^{-1})	0.01	0.021
	τ (h)	100	24.139

In Table I, we can observe that the current reliability indices are rather more superior.

This research was partially supported by the SGS grant from VSB-Technical University of Ostrava (No. SP2017/54) and by the project TUCENET (No. LO1404).

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One of the results of analyses is structuring failures according to their causes (Fig. 2). The most common cause of outages is "Operation and maintenance causes".

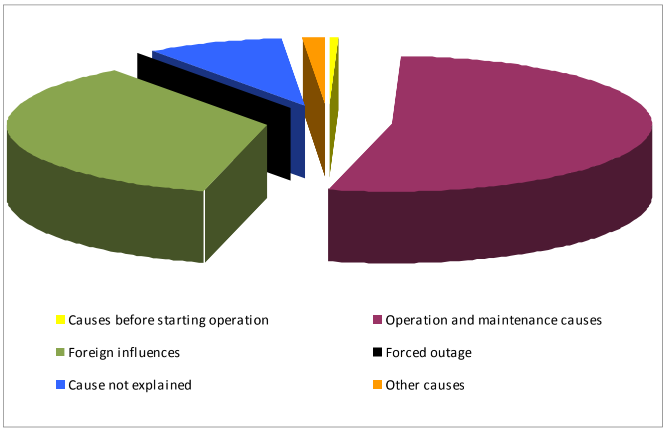

Fig. 2. Division of failures according to their cause.

An analysis of event durations was carried out for comparison. The resulting data are illustrated in the bar chart bellow (Fig. 3). The most of outages are longer than 1 hour and shorter than 1 month.

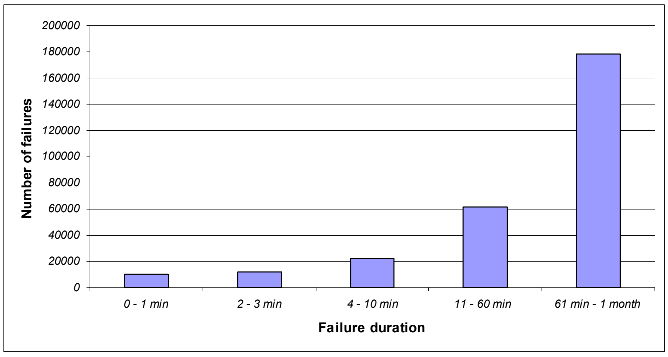

Fig. 3. Division of failures according to their duration.

There was no database of failures using data from local industrial distribution system (LDS) to enable calculation of the indicators. Industrial grids differ by pattern, the method for connection into the grid or even geographical conditions. Furthermore, power grids in heavy industry are also exposed to many adverse effects, e.g. presence of water, jolts, shaking, vibrations, heavier dust formation, high ambient temperatures or even occurrence of corrosive, chemical or other contaminating materials. That is why the component reliability results are very valuable. Gathering and analysis of a large amount of materials referring to operation of the industrial LDS in the period of 2010 – 2014 allowed us compiling the database to document the overall behavior of the system with respect to its operation, maintenance and failures, including time stamps for each occurrence. That enabled enumeration of the reliability indices for significant elements and their comparison with old Regulations 2/74 in Table II [4].

TABLE II. COMPARISON WITH INDUSTRIAL DISTRIBUTION SYSTEM

Equipment		ČEZ 22/80	LDS
Cable 6 kV	λ (year^{-1})	not included	3.2
	τ (h)	in database	8.104
Cable 22 kV	λ (year^{-1})	14.5	2.2
	τ (h)	215	11.417
Transformer 110 kV / MV	λ (year^{-1})	0.04	0.333
	τ (h)	1300	4.403
Transformer MV / MV	λ (year^{-1})	not included	0.130
	τ (h)	in database	0.481
Transformer MV / LV	λ (year^{-1})	0.03	0.200
	τ (h)	2 500	0.361
Circuit breaker 6 kV	λ (year^{-1})	not included	0.025
	τ (h)	in database	5.538
Circuit breaker 22 kV	λ (year^{-1})	0.015	0.039
	τ (h)	30	5.702

III. INDICATORS EVALUATING INTERRUPTIONS

Comparison indicators evaluating power supply interruptions [5] of the Czech Republic and Slovakia ZSD with other European countries for unplanned (Fig. 4 and 5) and planned interruptions comes from report CEER [6].

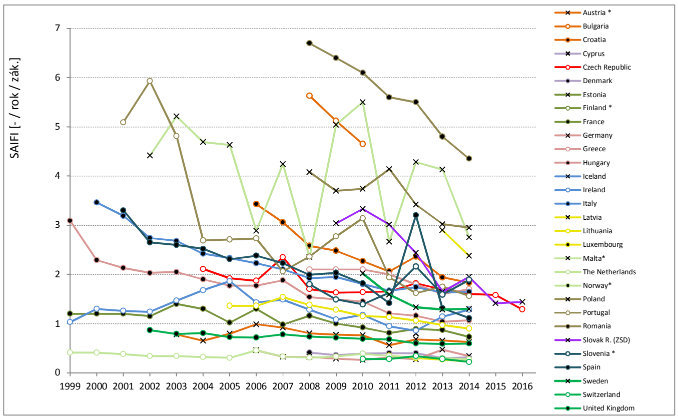

Fig. 4. S A I F I - unplanned (excluding exceptional events).

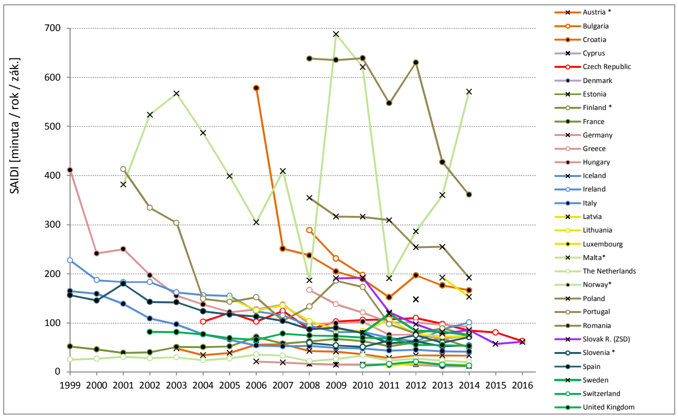

Fig. 5. S A I D I - unplanned (excluding exceptional events).

IV. MAINTENANCE

Maintenance influence the indicators evaluating interruptions - maintenance time in fact means unavailability. German Ordinance for Incentive Regulation sets rules for quality requirements. It affected network operators with 30.000 customers or more. We can see effects of Live Working at cost comparison on MV Flying Section in Fig. 6. Interruption could be reduced by better coordination and could be almost completely avoided by Live Working

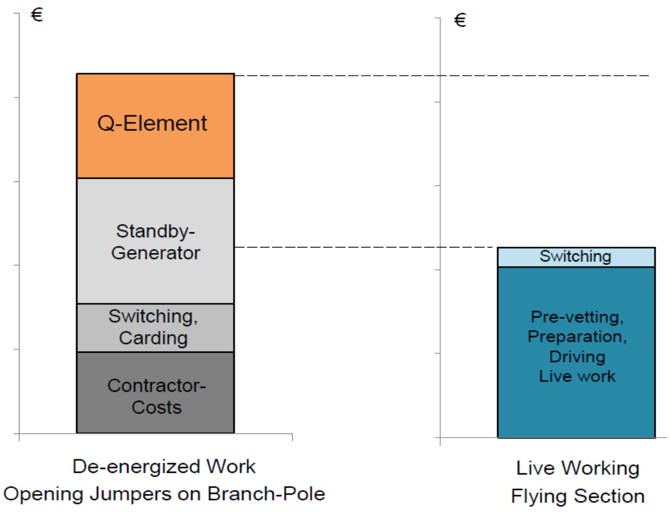

Fig. 6. Cost comparison MV flying section.

Live Working in low and medium voltage networks is a safe and well proven method for reducing planned interruptions of supply. Without considering the costs of avoided interruptions, live work was cost-effective in many cases already in the past. With the introduction of quality regulation, Live Working has become even more interesting, because it is an important tool for meeting the quality goals set by the regulators [7].

V. RELIABILITY-CENTRED MAINTENANCE

Reliability centered maintenance (RCM) is a term that appeared in the area of electrical power engineering as late as the nineties of last century. The goal of RCM is to shorten maintenance-based outages of pieces of equipment to ensure the given reliability. Thus it is a case of the principle of maintenance depending not on time but on the real state of the item of equipment.

We have already been concerned with the development of methodology and software for RCM since 2004. Our main objective is its practical utilization and inclusion into the maintenance system of the electrical power system operator. On that account are developed algorithms and calculation procedures for individual components of the distribution network.

We chose two basic approaches to RCM implementation. One approach leads to the optimization of the maintenance cycle for all components of the given type or groups of components of the same type. The other approach leads to the optimization of condition based maintenance (on-condition maintenance), i.e. to the determination of optimum order of maintenance of particular components of the same type.

The comparison of the approaches is as follows:

- Optimization of the maintenance cycle - the number of components of the given type is high; generally, each component of the given type has low importance, costs of the specific component of the given type cannot be obtained, at the analysis of the event (failure, outage) the specific component cannot be found.
- Determination of the order of components for maintenance - the boundary must be defined from when performing maintenance is reasonable not only from the economical point of view, equipment monitoring is possible (e.g. on-line monitoring), we must be able to determine the condition and importance of equipment.

The goal of RCM is to formulate such a maintenance strategy so that the total operating costs may be minimized at keeping the necessary degree of the reliability, safety and environmental soundness of equipment operated. For the first approach it means that for each item of equipment the equation of total operating costs [8] will be formed and its local maximum will be searched for and comparison of condition and importance of components for the second approach should be done [9].

The input data for the first approach are given by the cost function. The main problem consists in the fact that it is not possible to get the financial values for each separate element. Also any “importance” cannot be assigned to any specific component. That is why it is necessary to proceed to data division into groups. Then, maintenance intervals of the groups will be different.

Input data for the division of components into groups by importance are as follows:

- For all components of the given type - coefficient for consumer evaluation, the number of groups for division and their limits and the type of component.
- Separately for each component - identification number, the number of connected consumers by type, possible another division of the component.

The result of the division of components into groups by importance is the determination of the amounts of components in particular groups and the assignation of a group number to each component.

Even this division is rather inaccurate because the failure rate of the element may also depend on the element “load”, i.e. on the element position in the network. Likewise, the repair and maintenance costs may depend on e.g. element accessibility with regard to technical facilities, i.e. on the element location as well. At the very accurate analysis all input data should be considered to be dependent both on the type and the location of the element in the network.

Input data for the RCM analysis itself are maintenance costs, repair costs, failure rate, total time of failures, time of scheduled outage, number of all consumers, including their types, number of outages at not obeying the standards, penalties, price of undelivered electrical energy for specific types of consumers, relationship between costs of undelivered energy by particular types of consumers, relationship between costs of outage by specific groups, maintenance rate and the average power passing through the given component. The given data are related to the period under consideration of one year.

Sources of these input data are exports from technical records, failure databases and financial databases, or the data are entered directly by the keyboard and are stored in a special file.

The result of optimization of the Distribution transformer stations (DTS) maintenance cycle is a cost curve for DTS particular groups shown in the Fig. 7. On the basis of this curve, the optimum value of maintenance rate that is given in the lower part of the graph, is then mathematically determined.

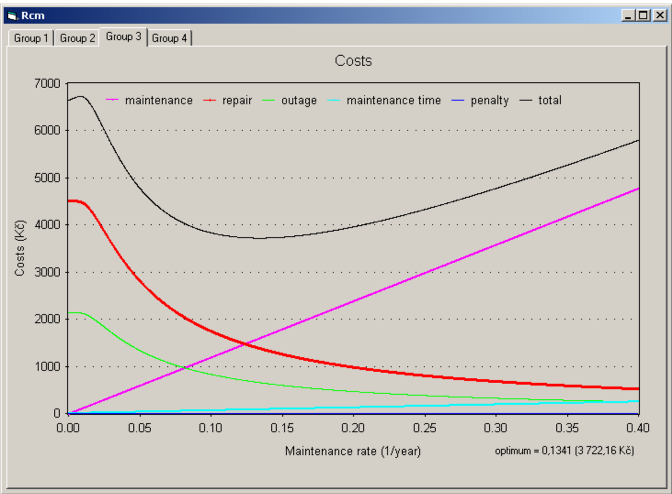

Fig. 7. Optimization of the maintenance cycle – cost curves.

Input of the second approach are technical conditions, evaluation of diagnostic tests, weights of particular influences and importance.

The result of RCM by the determination of optimum order of maintenance is a graph in the Fig. 8 with the layout of particular pieces of equipment. On the basis of this graph, the optimum order of components for maintenance is then determined. You can see also four levels of maintenance activity.

This system was applied to:

- Distribution transformer stations MV / LV
- Overhead line 22 kV
- 110 kV / MV Transformers,
- 110 kV circuit breakers,
- 110 kV overhead lines.

VI. Conclusion

This paper describes the results of reliability evaluation of interruptions in distribution networks including industrial. These results were acquired by processing data on failures and outages collected during years 2000-2016 at our department. It is possible to see influence of maintenance on reliability in this paper - reduction of interruption indicators value, cost drop Live Working and optimization by Reliability Centered Maintenance.

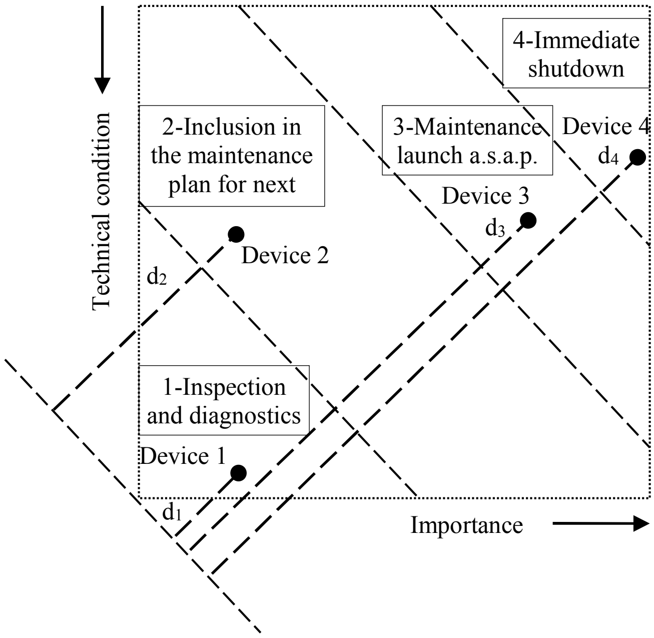

Fig. 8. Determination of the order of components for maintenance.

References

[1] P. Krejčí, P. Santarius, R. Hájovský, R. Velička and R. Čumpelík, PQ monitoring in selected networks of Czech Republic. Przeglad Elektrotechniczny, vol. 88, 7b/2012, pp. 183-185, 2012.

[2] Z. Martínek, T. Klor and J. Holý, Reliability of the electrical power system, Proceedings of the 2014 15th International Scientific Conference on Electric Power Engineering, EPE 2014, vol. 1, IEEE, pp. 81-84, 2014.

[3] J. Piskac and J. Marko, Regulations for electric power system no. 2 – failure statistics at electricity distribution, Prague, ČEZ, 1974.

[4] J. Drholec and R. Gono, Reliability database of industrial local distribution system, Advances in Intelligent Systems and Computing, vol. 451, pp. 481-489, 2016.

[5] Distribution companies of the Czech Republic, Distribution network grid code, appendix no. 2 - Methodology of reliability determination of electric power supply and distribution network equipments, Prague, ERÚ, 2016.

[6] 6th CEER benchmarking report on the quality of electricity and gas supply 2016.

[7] K. Dütsch, Quality regulation in german distribution networks – effects on Live Working, 4th International Conference on Live Working, Sokolnice 2015.

[8] J. Szkutnik and A. Gawlak, Optimalization-based method of dividing the network development costs. Electrical Engineering, vol. 93/3, pp. 137-146, 2011.

[9] V. Kral, S. Rusek and R. Gono, Software determining optimum order for maintenance, Advances in Intelligent Systems and Computing, 423, Springer, pp. 159-169, 2016.