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Input parameters for restoration method for 110 kV power line

***Abstract**. The article analyzes the input parameters for RCM software for restoration of 110 kV power lines. It describes the ranking system for technical condition and the importance of power line. In the final part of the paper there is a design method for the determination of restoration of 110 kV power lines by the input data.*

***Streszczenie.** W artykule analizowano dane wejściowe programu RCM (reliability centered maintenance) do utrzymania niezawodnośći linii 110 kV. Zaproponowano metodę projektowania linii bazująca na tych danych (**Parametry wejściowe niezbędne do odtwarzania linii 110 kV po jej uszkodzeniu**)*

Keywords: maintenance, reliability, RCM, effect of failure, distributed power
Słowa kluczowe: utrzymanie linii przesyłu energii, niezawodność

Introduction

In the present time most power-supply companies carry out the maintenance by scheduled periodic inspections (e.g. routine maintenance) specified by for example order of preventive maintenance.

Reliability centred maintenance (RCM), which we deal with in this paper, optimises maintenance cycle or determines so-called maintenance priority by technical condition and operational importance, thereby it reduces the maintenance costs while the demanded reliability of operational equipment are preserved.

From the principle view it is possible to choose two different approaches to apply RCM onto distribution network elements.

First approach Optimisation of maintenance cycle (also called periodic RCM) leads to optimisation of maintenance cycle for all elements of a certain type or for group of elements of the same type. Optimisation of maintenance cycle is performed by the principle of finding the minimum of cost function. Maintenance, outage and failure repair cost are expressed as a function of maintenance rate. Optimisation of maintenance cycle is suitable for type of elements, which are high number in distribution network and which have not high importance (e.g. distribution transformers and MV lines [6].

Second approach Determination of maintenance priority (also called RCM according the condition) leads to determination of appropriate equipment maintenance priority, which further leads to determine either the optimal order of elements to maintenance or the adequate maintenance activity for particular element. The maintenance priority is determined according to evaluation of technical diagnostic, technical condition and operational importance. Maintenance priority determination is suitable for type of elements, which number is not such high in distribution network and its importance is quite high, so it is suitable for 110 kV voltage level elements (namely 110 kV power breakers, power lines and 110 kV/MV transformers).

RCM is based on the technical condition and importance of an element of the distribution system [1]. Such maintenance helps to optimise existing preventive maintenance and ensures safe and reliable operation of an element decreasing overall maintenance costs [2].

At the Department of Electrical Power Engineering, VŠB-TUO methods for different elements of distribution system have been developed: distribution substations, exterior 22 kV power lines, and 110 kV power circuit breakers. Currently, we are working on the restoration method for 110 kV power lines and optimisation of 110 kV/MV transformer maintenance.

Restoration of 110 kV power lines

This paper deals with application of RCM to 110 kV power lines, so in the next chapters there is used approach determination of maintenance priority and designed the algorithm for application of RCM to this type of power lines.

Appropriately performed maintenance can enhance reliability of power lines. The operators follow the Schedule of preventive maintenance (ŘPÚ) to ensure safe and reliable operation of the distribution system. Preventive maintenance, such as inspection, thermovision or earthing measurement is performed in a precisely planned period of time.

Reliability centred maintenance is generally applied on different elements in the same way. Firstly, importance and technical condition of a given element must be assessed. The assessment of these parameters differs from an element to element.

In case of 110 kV power lines, the technical condition is assessed from the failure database of the particular distribution area. The importance of a power line is assessed on the basis of two parameters: distributed power and the effect of a line failure. To our benefit, all the mentioned parameters are monitored and recorded in some way by the distribution network operators. The above mentioned parameters shall be elaborated in the following paragraphs [3].

Database of faults

For determine the technical condition is used database of faults. The one of most important record is priority of fault in database. Priority of fault tells when it's necessary to remove the fault. There are four priorities of faults in the database, today (Tab. 2.). Based on the priorities of fault was made basic evaluation. More details and descriptions of the database of faults were published in another paper [3].

Table 1. Categories for quantity

Quantity - category			
Meters		Pieces	
To 25 m	1	To 10 pcs	1
From 25 to 50 m	2	From 10 to 30 pcs	2
Above 50 m	3	Above 30 pcs	3

Table 2. Evaluation of priority of faults with quantity

	Quantity		
Priority of Fault	1	2	3
1 - Urgent	127	1	
3 - Month	78		
4 - Year	688	63	30
5 – Control at ŘPÚ	327	65	39

The basic evaluation showed that the failures are recorded in metres and in some cases also in pieces. In particular, the failed element is a line or a cable and then the value is in metres. Hence, it says how long the affected section is. However, when the failed item is pole, fittings, or isolator, then the number means pieces (failed rivets, warning plates, isolators). After independent evaluation of identical items, three categories for quantity were determined (Table 1).

Thus, evaluation of failures was increased with one more parameter - the parameter of quantity. The quantity category is the same for both - the data in meters and in pieces. This is advantageous in the final evaluation of technical condition of lines, especially for the future RCM software. The evaluation in Table 2 shows that the category of quantity number 1 is the most frequent.

Concerning failures, it must be noted that they are not recorded with respect to a particular line but a technical spot. Technical spot is a section of a line – in other words its maintenance section. Some lines have one maintenance section, some have more of them. In total, there are 388 maintenance sections in the database.

Concerning technical condition, only quantity is categorized. There can be more individual records with only one priority in one maintenance section, therefore we need to know the total number of failures with the same priority for the same quantity category. This can be easily determined from the 110 kV power lines failure database for each maintenance section. We use contingency table of MS EXCEL for the determination of failure quantity.

Technical condition

To directly determine the technical condition TS after the evaluation of quantity, priority and maintenance section would be very complicated concerning the development of future software. Therefore a 'points of technical condition' BTS was introduced. This can be calculated in the following equation (1):

$$BTS = \sum VP_x \sum \left(p_{M1x} + k_2 p_{M2x} + k_3 p_{M3x}\right) \quad (1)$$

where: *BTS* – points of technical condition, VP_x – value of the weight for priority number x, p_{M1x} – count of faults for priority x and quantity category 1, similarly for p_{M2x} and p_{m3x} (for quantity category 2 respectively 3), k_2, k_3 - coefficients for increase BTS for higher quantity categories.

From total value of BTS the TS technical condition can be determined. The initial method design counts with five categories (Tab.3). To debug the method, a functional file for MS EXCEL was created, whereby all weight values and coefficients can be modified. Hereby given values are not to be considered terminal. They are meant to explain the whole system for the evaluation of the technical condition of power lines which will enter the future software for the restoration of 110 kV power lines on the principles of RCM.

Table 3. Table for determination TS from BTS

Value ranking for *BTS*				
50	100	200	400	>400
Technical condition *TS*				
95 %	80 %	70 %	60 %	40 %

Effect of failure

Assessment of line importance was theorized about in a previously published paper [4]. There, back-up alternatives and their ranking were designed with the method of reliability schemes. This theoretical analysis gave us a short overview of 110 kV power lines back-up alternatives and has been used to evaluate one distribution area.

The term "backup alternative" has been replaced by the term "effect of failure", as the latter directly denotes the consequence which takes place if a 110 kV power line fails, meaning what the type of its backup is. The distribution field experts helped us to evaluate a hundred and sixty-eight 110 kV power lines in total from one distribution area. For each failed line there is one effect of failure to be selected out of seven alternatives. The evaluation (Tab.4) shows that approx. 56 % of lines require no manipulation. In fact, these lines are backed up by parallel lines which are permanently connected. Theoretically, we speak about a hot reserve. There are 72 lines which require manipulation after a failure, and after that full load can be transmitted. Only two lines are backed up by lines which carry reduced load. There are nine lines that are backed up by MV lines. Also, during manipulation, lines can only carry reduced load and therefore the duration of manipulation is important. Backup via HV line needs max. 20 minutes manipulation and backup via lower voltage lines may need as much as 45 minutes manipulation.

Distributed power

The assessment of 110 kV power lines importance on the basis of solely on the effect of failure would be incomplete without counting in the power distributed by the line. This parameter is easy to determine from the power outputs measured in a distribution area. [5]

To calculate the distributed power we used data measured in 2010 which were at our disposal. These are 365 XLS files of 20.1 MB each. A file of a day record comprises measured active power, voltage, current, reactive power and other system data. The values are recorded hourly and their average, maximum and minimum levels are given. We used the average values. The daily record contains measurement on 110 kV power lines plus the measurements on 22 kV lines, substation taps, and transformers etc.

The calculation of total energy had several steps. Fist, total energy in one day was calculated and saved in a new file. The energy from the following day was recorded in a column next to the first one in the same file and the procedure was repeated on and on. In order to check the numbers, the evaluation was divided into two terms which were subsequently added. All these operations had been programmed as macro in the MS EXCEL table processor. In all these operations the absolute value was added because the power flow changes direction on some power lines. The calculation was carried out at all the measured values, i.e. voltage, current etc. The correct value of energy is where the active power is measured. In all sums the absolute value was added because the current flow changes in some lines.

When evaluating distributed energy, it is very important to verify the accuracy of calculated numbers. Abnormalities occurred during the calculation of energy for particular lines. Gradually, a control system was devised using functions in MS EXCEL

Importance of line

For the future design of RCM software it is not important to know the exact value of distributed energy. Four categories of the energy distributed in a year were selected.

1. < 50 GWh,
2. 50 ÷ 150 GWh,
3. 150 ÷ 250 GWh,
4. > 250 GWh.

When evaluating distributed energy, it is very important to verify the accuracy of calculated numbers. Abnormalities occurred during the calculation of energy for particular lines. Gradually, a control system was devised using functions in MS EXCEL

Table 4. Effect of failure

Effect of failure	Count (-)	Count (%)	Name of Effect
1	93	55.95 %	“No effect” no manipulation necessary
2	52	30.36 %	Back-up by 110 kV line of approx. the same length
3	1	0.60 %	Back-up by 110 kV line of approx. the same length – limited power
4	12	7.14 %	Back-up by a longer 110 kV line
5	1	0.60 %	Back-up by a longer 110 kV line – limited power
6	9	5.36 %	Back-up by MV line
7	0	0.00 %	Back-up by MV line – limited power

Table 5. Evaluation of distributed power with effect of failure

Distributed power		Effect of failure						
Value range	Category	1	2	3	4	5	6	7
To 50 GWh	1	20	21		3		3	
From 50 to 150 GWh	2	34	17	1	4		5	
From 150 to 250 GWh	3	26	7				1	
Above 250 GWh	4	9	5		5	1		

Table 6. Evaluation of distributed power

Distributed power	Count ()	Count (%)
To 50 GWh	47	29.01 %
From 50 to 150 GWh	61	37.65 %
From 150 to 250 GWh	34	20.99 %
Above 250 GWh	20	12.35 %

As mentioned above, the final importance of a line is determined from the distributed energy and effect of a failure. With these two pieces of input information - both of them categorized – we can use a matrix in Table 7. This can give on the basis of categories the value of line importance DV to be used in the final calculation of restoration (2).

The values in the matrix are selected on the basis of previous analyses of input importance and theoretical analysis. It is evident that the power line backups which transmit reduced power have considerably higher values. Also, MV line backups have higher values compared with HV line backups. The same holds for the length of the line backup. Concerning distributed energy, the higher the value of distributed energy, the higher the final value of line importance.

Table 7. Importance of line - Matrix

Matrix Importance of line		Distributed power			
		1	2	3	4
Effect of failure	1	0%	5%	10%	20%
	2	5%	10%	15%	25%
	3	15%	25%	30%	45%
	4	7%	12%	17%	27%
	5	25%	35%	40%	50%
	6	20%	25%	30%	40%
	7	35%	45%	55%	70%

Priority of restoration

Several methods for final evaluation were experimentally tested, but none of them was substantial enough. Initially, the methods had directly input values (category): distributed energy, effect of failure, number of failures with respect to priority. Those methods did not require independent calculation of technical condition, or more precisely importance of a line. Relative ratios between individual input parameters were determined by the weights of these entries.

Those methods were abandoned and the rule of subsequent calculation was introduced, which means determining the technical condition and importance before evaluating the priority of restoration - ‘PO‘. The priority of restoration is per cent. The higher the priority, the sooner the restoration of the line should take place. The relation used for the calculation of priority (2).

(2) $$PO = (100 - TS) \cdot (1 - k_{\text{TSDV}}) + DV \cdot k_{\text{TSDV}}$$

Where: *PO* – value of priority of restoration per cent, *TS* – value of technical condition per cent, *DV* - value of importance of line per cent, k_{TSDV} – coefficient for prioritizing technical condition or importance of line.

Coefficient k_{TSDV} divide influence between technical condition and importance of line. If the coefficient is lower then 0,5, technical condition is prioritized and vice versa. Both the technical condition and importance are per cent. The best (lowest) priority of restoration is when technical condition is 100% and the importance of 0 %.

Conclusion

The maintenance priority is determined by evaluation of technical condition and operational importance. The introduction of this paper describes the issues of the restoration of 110 kV power lines on the principle of reliability centred maintenance. In the second section input parameters needed for the evaluation of the line importance are analyzed, mostly distributed energy which was evaluated last. The check system for verification of distributed energy figures is analysed. Also, we related and evaluated distributed energy and effect of failure on a particular line. After thorough evaluation and analysis of the findings we categorized distributed energy into four groups. This section also describes the problems that occurred during the evaluation of distributed energy.

Next chapter outlines the evaluation of the input parameters for technical condition. A more detailed description of the issues of failure database and priority of failure is to be found in other papers. However, here an evaluation of quantity for every failure was carried out. Again, categories were crated as in case of distributed energy.

The final section describes the first design of the method using all the previous analyses of input parameters. A final algorithm for the calculation of ‘priority of restoration’ was determined. Restoration priority determines the sequence of the 110 kV power lines to restoration. Next, we describe the method of evaluation of both input parameters employed in the final algorithm. To get the power line importance we combine the category of distributed energy and effect of failure from the matrix value. Concerning technical condition, a relation for partial values of technical condition and description of weights are included.

Our further aim is to accurately analyze our method, as well as the weight system for both input values and create a functional file for MS EXCEL to analyze and design type power lines.

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