Backup Alternatives for 110 kV Lines

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Abstract. *The paper describes backup alternatives for 110 kV lines. Line backup is one of input parameters used to optimise the renovation of 110 kV lines. The optimisation is based on the principle of reliability centred maintenance (RCM) which depends on the technical condition and importance of a particular element. The paper starts with illustrating the method of reliability schemes. This method enables the evaluation of failure-free operation probability. The probability of a failure-free operation can be estimated for all backup types of 110 kV lines existing in the distribution network. To compare different backup alternatives, type lines were selected and calculated with. The results of the method helped estimate the effects of a line failure for a particular distribution district.*

Keywords

Backup, effect of failure, maintenance, RCM, reliability.

1. Introduction

For a today's consumer, a reliable and failure-free operation of electricity network is a vital and natural thing. However, for a distributing company responsible for the safety and reliability of network, meeting this need is a complicated task liable to the "Regulations for distribution network operation". If the power supply is interrupted, the distribution company loses profit on distribution and power supply. Moreover, the distributor can be fined for the energy unsupplied to consumers.

To maintain the reliability and safety of operation, a distribution network must be regularly serviced as per the "Schedule of preventive maintenance" [1]. To optimise maintenance, reliability centered maintenance (RCM) seems to be the most appropriate tool [2]. It is based on the technical condition and importance of the equipment. There are two input parameters which help assess the importance of a line. Firstly, this paper outlines the back-up alternatives for a failed line. Another input parameter is transmitted energy [3]. Also, we present an evaluation of one distribution district.

2. Importance of Line

The possibility of a line backup informs best on the importance of a line [4]. However, importance of a 110 kV line can be also determined by its losses, load or carrying capacity. Backup alternatives for a failed line must be specified - power can be supplied by another 110 kV line or an MV line. However, some 110 kV lines have no backup. If a line fails, localization of a failure and manipulations to deal with failure, either manual or remote, must be carried out. In terms of reliability, duration of manipulation is essential.

2.1. Reliability Scheme Method

To evaluate backup, we use probability of failure-free operation R calculated in the following equation [5]:

$$R = 1 - \frac{\lambda\tau}{8760}. \quad (1)$$

To calculate the probability of a failure-free operation, failure rate λ (year^{-1}) and mean failure time τ (hour) must be determined. The calculation is run as per CEZ 22/80, but the maintenance downtimes are neglected. The method diversifies three basic types of connecting two elements:

- series connection of elements,
- parallel connection of elements – hot reserve,
- parallel connection of elements – cold reserve.

1) Series Connection of Elements

In series connection of elements failure of one element causes a failure of the whole system, e.g. transformer and line connection:

$$\lambda = \lambda_1 + \lambda_2, \quad (2)$$

$$\tau = \frac{\lambda_1 \tau_1 + \lambda_2 \tau_2}{\lambda}. \quad (3)$$

Fig. 1: Serial connection of elements.

2) Parallel Connection of Elements – Hot Reserve

Hot reserve is a parallel connection without the use of manipulation. If one element fails, another element takes over its function, e.g. two parallel transformers. Total failure rate and mean failure time are determined as follows:

$$\lambda = \frac{1}{8760} \left(\lambda_1 \lambda_2 \left(\tau_1 + \tau_2 \right) \right), \quad (4)$$

$$\tau = \frac{\lambda_1 \lambda_2 \tau_1 \tau_2}{8760 \lambda}. \quad (5)$$

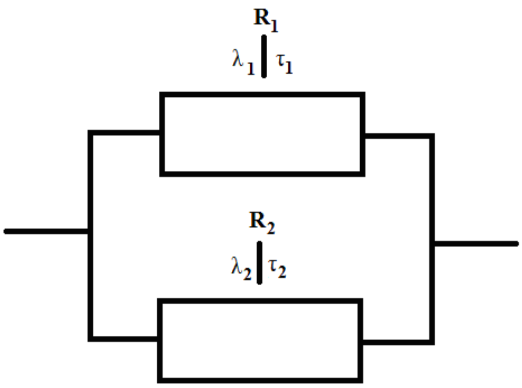

Fig. 2: Parallel connection of elements – hot reserve.

3) Parallel Connection of Elements – Cold Reserve

Cold reserve is a connection identical with the hot reserve. The connection is parallel and with manipulation, so manipulation time must be included in the calculation. Schematically, the connection is serial-parallel. However, in case of a failure, the reserve element does not switch on immediately but with a delay.

The failure rate of manipulation corresponds with the failure rate of the first element. The manipulation takes place if the first element fails. Cold reserve equations are a combination of relations for parallel hot reserve and series combination.

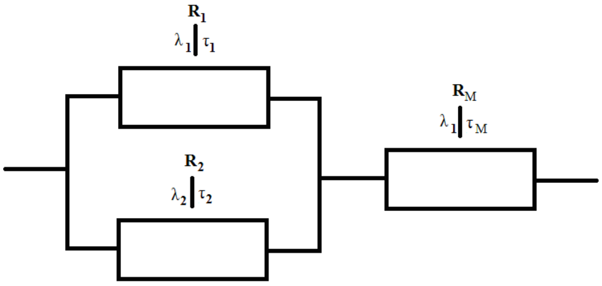

Fig. 3: Parallel connection of elements – cold reserve.

2.2. Probability of Failure-Free Operation

Input parameters for the calculation itself [6], failure rate and mean failure time, have been updated in a long-term monitoring of failures. The updated values are in the following Tab. 1 [7]:

Tab. 1: Input parameters.

	λ (year^{-1})	τ (hour)
HV line 100 km	0,282	3,155
MV line 100 km	3,623	18,759
HV/MV transformer	0,048	74,892

Five different types of connections were used. As we solve HV lines, there are several conditions we must deal with:

- no backup,
- backup by HV line of the same length,
- backup by HV line of 1,5 multiple of its length,
- backup by MV line of the same length,
- backup by MV line of 1,5 multiple of its length.

Every backup has two alternatives – one without manipulation (hot reserve), the other with manipulation (cold reserve). Manipulation times are 7 minutes for HV backup lines and 20 minutes for MV backup lines. HV lines of a type were calculated, the length of the original line is 100 km. The backup line is either of the same length or of the 1,5 multiple of its length for both HV and MV. Altogether, nine alternatives were calculated. The calculation is of the same length or longer, i.e. 150 km.

1) No Backup

The scheme has one element. To calculate the probability of failure-free operation, parameters of 110 kV line must be substituted in relation $R = 0,999898434$, 1.

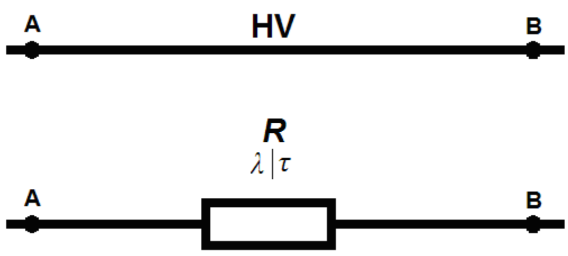

Fig. 4: No backup – power and reliability scheme.

2) Backup by HV Line of the Same Length

In this case, parallel connection is available. This alternative can be with or without manipulation. Reliability scheme is used for the calculation of probability (Fig. 5). First, parallel combination is calculated and then manipulation is added to total calculation, depending on the alternative:

- no manipulation: $R = 0,999999989$,
- with manipulation: $R = 0,999996234$.

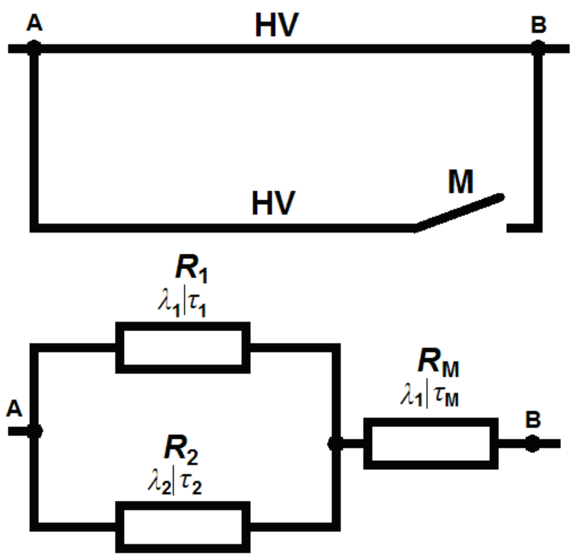

Fig. 5: Backup by HV line – power and reliability scheme.

3) Backup by HV Line of 1,5 Multiple of its Length

Schemes are identical with the previous alternative (Fig. 5), backup line is longer:

- no manipulation: $R = 0,999999985$,
- with manipulation: $R = 0,999996229$.

4) Backup by MV Line of the Same Length

In this connection (Fig. 6) there are two transformers in the backup line in the serial combination. This combination is solved first, later the parallel line is calculated and finally the manipulation depending on the alternative:

- no manipulation: $R = 0,999999129$,
- with manipulation: $R = 0,999988398$.

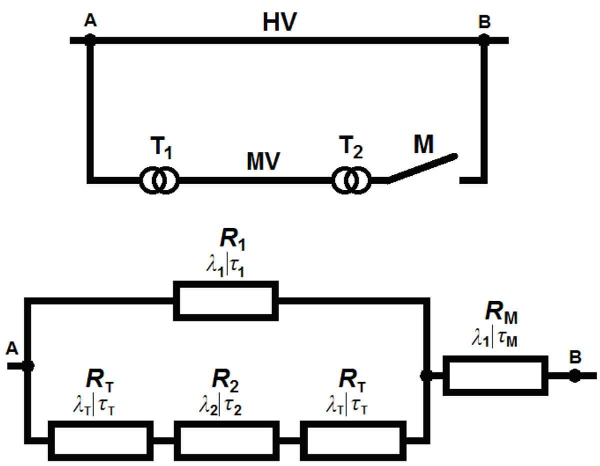

Fig. 6: Backup by MV line - power and reliability scheme.

5) Backup by MV Line of 1,5 Multiple of its Length

The calculation is identical to the previous one (Fig. 6):

- no manipulation: $R = 0,999998735$,
- with manipulation: $R = 0,999988004$.

3. Backup Ranking

With the help of probability of failure-free operation, all the alternatives of backup were ranked (Tab. 2). The best backup is provided by backup without manipulation – hot reserve. The second is backup with manipulation - cold reserve. The worst option is a line with no backup. The ranking illustrates theoretical assumptions, however for the final evaluation of optimisation accurate data on probability of failure-free operation is needed. Former relative values of backup alternatives were imprecise and therefore replaced by new ones.

The HV abbreviation in Tab. 2 means that the backup is via HV line, $l_1 = l_2$ means that the lengths of

Tab. 2: Backup ranking.

Ranking	Identification	Backup type
No manipulation – hot reserve		
1.	HV $l_1 = l_2$	HV line of same length
2.	HV $l_1 < l_2$	HV line of 1,5 multiple of its length
3.	MV $l_1 = l_2$	MV line of same length
4.	MV $l_1 < l_2$	MV line of 1,5 multiple of its length
Without manipulation – cold reserve		
5.	HV $l_1 = l_2$ MAN	HV line of same length
6.	HV $l_1 < l_2$ MAN	HV line of 1,5 multiple of its length
7.	MV $l_1 = l_2$ MAN	MV line of same length
8.	MV $l_1 < l_2$ MAN	MV line of 1,5 multiple of its length
Other		
9.	No	No backup

the backed up line and the backup lines are the same, $l_1 < l_2$ means that the length of the backup line is 1,5 longer than that of the backed up line. Backups using MV lines are marked MV. The MAN abbreviation means that the backup is with manipulation. Theoretical findings of ranking of all backup alternatives can be used to determine line importance of a particular network. Primarily it can be used as a weight criterion of the final algorithm.

4. Effect of Line Failure

To optimise renovation of 110 kV in, algorithms on the basis of reliability centered maintenance must be determined. Backup alternatives were determined for every line in a distribution district. The above mentioned method was used to do that. The possibility of backup was substituted by the effect of a line failure. This effect of failure tells us what happens after a line fails. In theoretical analysis reduced transmitted power was neglected. However, in a final field evaluation this parameter must be taken into account. Another reason for using the effect of failure is that it gives a better picture of the line backup.

The effects of failure were discussed and determined by the technicians operating in the distribution district and they correspond with the field practice. There are no existing lines without a backup in the area. Altogether, seven types of effects of failure exist:

- 1: "No effect" – no manipulation necessary,
- 2: Back-up by 110 kV line of approx. the same length,
- 3: Back-up by 110 kV line of approx. the same length with limited power,
- 4: Back-up by a longer 110 kV line,
- 5: Back-up by a longer 110 kV line - limited power,
- 6: Back-up by MV line,
- 7: Back-up by MV line - limited power.

There are total of 168 power lines in one distribution network. The results of evaluation are shown in Tab. 3 and in bar graph (Fig. 7). Bar graph does not show the effect number 7, because the value is zero.

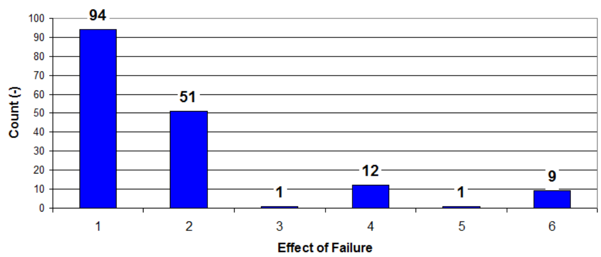

Fig. 7: Effect of line failure – bar graph.

The evaluation 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.

Tab. 3: Input parameters.

Effect of Failure	Count [-]	Count [%]
1	94	55,95
2	51	30,36
3	1	0,60
4	12	7,14
5	1	0,60
6	9	5,36
7	0	0,00
Total of:	168	

Also, during manipulation, lines can only carry reduced load and therefore the duration of manipulation is important. Backup via HV line needs max. 20 min. manipulation and backup via lower voltage lines may need as much as minutes manipulation.

5. Conclusion

Theoretical assessment of sequencing different backups will be used as a weight criterion in the algorithm for optimised renovation of 110 kV line. The line backup is expressed by the effect of a failure.

The weight will show how important a particular value of a failure effect is. In case of the best backup alternative 1, this parameter is insignificant. On the contrary, the value is vital in case of backup alternative 5. The technical condition is assessed on the basis of the failure database. Importance of a line is determined by transmitted energy and possibility of backup.

The paper outlines backup alternatives for 110 kV lines in one distribution area. This area was evaluated in the previous section. Overall, approximately 56 % of lines have adequate backup and therefore require no manipulation in the distribution network. On the contrary, lines with decreased load backup are few.

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