OPTIMAL FAULT LOCATION IN OVERHEAD RADIAL DISTRIBUTION NETWORKS EQUIPED WITH SWITCHES AND FAULT DETECTORS

J. Nahman, Faculty of Electrical Engineering, Belgrade, Serbia
J. Spirić, EPS PD “Jugoistok” - branch Leskovac, Serbia

1. Introduction

The fault location in distribution networks is a very important task directly affecting the fault duration and the energy not supplied to the consumers, being among the main operation performance indices of a network. In a previous paper [1] a procedure for fault tracking based upon the probability of fault location and manipulation time needed has been proposed for networks equipped with switches along the main feeder line. The feeder lateral branches are checked for faults by opening their switches, if available, or by removing the corresponding ties on line poles. This tracking procedure has shown to provide the shortest expected time of fault location when compared with the sequential or halving tracking methods in all investigated practical cases [1].

2. Optimal location of fault detectors

Optimization goal. Fault detectors reveal if the fault has occurred upstream or downstream of the detector on base of indicated current flow. In such a way, from the standpoint of fault location, detectors split the feeder into sections between source substation and adjacent detector, between adjacent detectors and between detectors and terminal feeder points. Optimal location of fault detectors for a given number of detectors is determinable by minimizing the mathematical expectation of the total time of fault location wherever it has occurred

$$T = \sum_{k=1}^{n+1} T_k \tag{1}$$

Here are

T – mathematical expectation of the total time of fault location

T_k – mathematical expectation of the time spent in locating the fault within feeder section *k*

n – number of fault detectors

The optimization could be limited to find the best location of the detectors, if their number is fixed based upon the cost consideration. In general case, the optimization can be conducted for various *n* beginning from 1 to the total number of feeder branches to obtain a clear idea on the benefits that could be achieved.

MPMT index based approach. To determine T_k , the optimal sequence of manipulations with switches of the considered feeder section should be determined. The method “maximum probability of fault location for minimum time” selects the switch to be manipulated next by calculating the index

$$MPMT = \frac{\min(p_u, p_d)}{t} \qquad (2)$$

with p_u and p_d denoting the probability that the fault occurred upstream and downstream of the switch under consideration. By *t* the time to travel from the current location to and manipulate with this switch is denoted. The switch having the highest MPMT value should be manipulated in the next step. The numerator in (2) is the probability that the manipulation by the switch will reveal the faulted part of the feeder. *Min* sign indicates that the pessimistic, on the safe side, value of this probability is taken as relevant.
Probabilities p_u and p_d are basically conditional probabilities, i.e. probabilities that the fault will be upstream or downstream of the switch, given the fault has occurred.If we presume that the failure rates of line branches per unit length are the same for all branches, then we can write

$$p_u = \frac{\sum_u L}{L} \qquad (3)$$

$$p_d = \frac{\sum_d L}{L} \qquad (4)$$

with L designating the total feeder length. Numerators in (3) and (4) are sums of the length of branches upstream and downstream of the switch that have not been checked for fault in previous calculation steps. Bearing in mind (2) – (4), index MPMT can be simplified to the form

$$MPMT = \frac{\min(\sum_u L, \sum_d L)}{t} \qquad (5)$$

that facilitates the calculations.
By applying (5) the optimal sequence of manipulations is determined. This sequence gives the time t_i, which would be spent to locate fault at each branch, given it occurred. Then, the expected time of fault location for the considered feeder section will be

$$T_k = \frac{\sum_i L_i \, t_i}{L} \qquad (6)$$

with index *i* including all branches belonging to the feeder section *k*.

Shortcut calculation of time T. The best location of fault detectors can be determined by probation using the approach explained above. However, such an approach implies a considerable number of time T_k calculations. To reduce the calculation burden, the following approximate shortcut expression has been found to provide a fair assessment of time T in one step

$$T = \frac{\sum_i L_i \tau_i}{L} \quad (7)$$

with τ_i being the sum of times of traveling from source node to and manipulation with switches adjacent to and/or being in branch *i* by whose manipulation this branch is insulated from other feeder branches. Index *i* should not include switches with fault detectors as these remotely provide their information on fault location.
An alternative expression for *T*, giving the same results as (7) is

$$T = \frac{\sum_i (L_{ui} + L_{di}) t_i}{L} \quad (8)$$

L_{ui} is the length of the branch immediately upstream to switch *i* while L_{di} is the length of the branch in which the switch is positioned. By t_i the time is denoted of visiting and manipulating with switch *i* starting from the source node. The summation in (8) includes all switches not equipped with fault detectors.

3. Application

Sample overhead line feeder. The calculation procedures outlined in the previous text will be demonstrated on a practical example.
Figure 1 displays a feeder having six branches. The lengths of branches are given in Table 1. Table 2 displays the times needed to travel among feeder switches. Symbol *S0* denotes the source station with circuit breaker. The data presented include manipulation time with switches and the circuit breaker.

TABLE 1. - Branch lengths, km

L_0	L_1	L_2	L_3	L_4	L_5
5	6	10	5	10	4

Let us consider the case with a single fault detector located at switch S2. In this case the feeder is split in a section containing branch 2 only and the other section containing the remaining feeder branches.

TABLE 2. - Traveling and manipulation times among switches, hours

Switch	S0	S1	S2	S3	S4	S5
S1	0.35	0	0.15	0.50	0.45	0.45
S2	0.40	0.15	0	0.55	0.50	0.50
S3	0.70	0.50	0.55	0	0.15	0.15
S4	0.65	0.45	0.50	0.15	0	0.15
S5	0.65	0.45	0.50	0.15	0.15	0

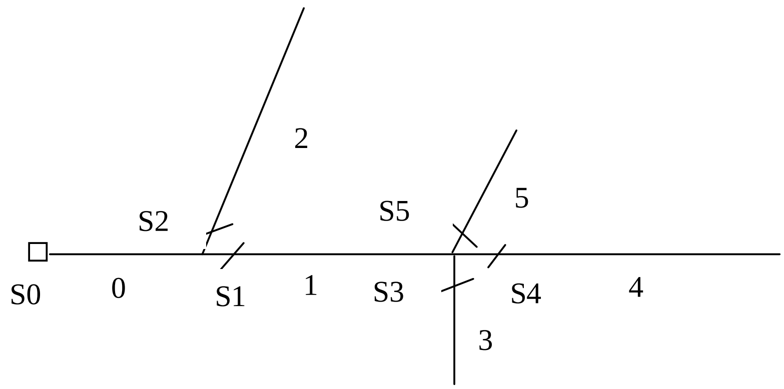

Fig.1 Sample distribution feeder

MPMT based approach. If the fault is located on branch 2, detector at switch S2 will immediately indicate this. If the fault occurred somewhere in the other feeder section, using the MPMT indices the sequence of visiting the switches of this section should be determined. Index MPMT for switches under consideration is, according to the data in Table 1 and Table2:

Switch S1: $\mathrm{MPMT} = \frac{\min(5,25)}{0.35} = 14.29$

Switch S3: $\mathrm{MPMT} = \frac{\min(25,5)}{0.7} = 7.14$

Switch S4: $\mathrm{MPMT} = \frac{\min(20,10)}{0.65} = 15.38$

Switch S5: $\mathrm{MPMT} = \frac{\min(26,4)}{0.65} = 6.15$

The highest MPTM value is for switch S4 and this switch should be visited first. If by manipulation of S4 the fault is revealed on branch 4 the fault location procedure will be terminated. Otherwise, the fault is located on the left-hand side of S4 and search procedure should be continued by determining the switch to be visited next in this area.

The MPMT index values for this area are:

For S1: $\mathrm{MPMT} = \frac{\min(5,15)}{0.45} = 11.11$

For S3: $\mathrm{MPTM} = \frac{\min(15,5)}{0.15} = 33.33$

For S5: $\text{MPTM} = \dfrac{\min(16,4)}{0.15} = 26.67$

Switch S3 has the highest MPTM value and has to be visited next. If branch 3 is faulted, the manipulation of S3 reveals it and the location procedure is ended. Otherwise, the fault is somewhere in the remaining not explored feeder part. The next switch to be visited in this case is again determined by calculating MPMT index values for remaining switches:

For S1: $\text{MPTM} = \dfrac{\min(5,10)}{0.50} = 10$

For S5: $\text{MPMT} = \dfrac{\min(11,4)}{0.15} = 26.67$

As can be concluded, switch S5 should be visited after S3. If branch 5 is faulted, manipulation with S5 will indicate this. If this is not the case, the fault has occurred on branches L_0 or L_1 that will be resolved by manipulating with switch S1.
Figure 2 presents the search flow advocated by MPMT index and indicates the times of location of faulted branches if this search sequence is applied. Time *T* for the feeder is obtainable by summing the calculated times weighted by the quotients of branch and total feeder lengths giving the probabilities of branch faults. For the case being studied the following result is obtained

$T = 0.7425$ h

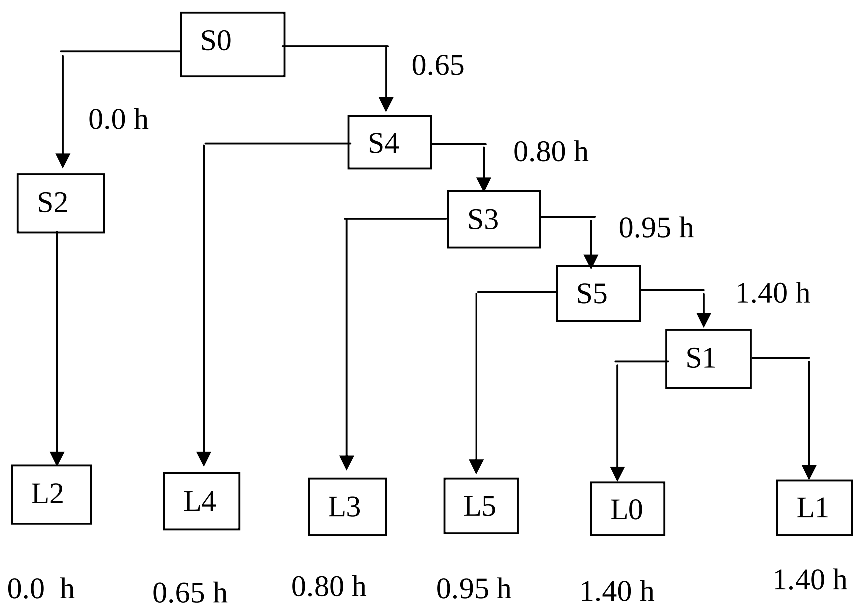

Fig.2 MPMT index based fault tracking scheme

Shortcut approaches. By applying (7) we obtain

$$T = \frac{1}{40}\left[L_0\, t_1 + L_1\,(t_1 + t_3 + t_4 + t_5) + L_3\, t_3 + L_4\, t_4 + L_5\, t_5\right] = 0.711\,h$$

Expression (8) gives the same result

$$T = \frac{1}{40}\left[(L_0 + L_1)\,t_1 + (L_1 + L_3)\,t_3 + (L_1 + L_4)\,t_4 + (L_1 + L_5)\,t_5\right] = 0.711\,h$$

The result obtained using the shortcut approaches differs from the result obtained by time based upon the MPMT approach for less than 5%.

Expected fault location time for the feeder under consideration has been calculated for various locations of fault detectors both using the complete MPMT approach and expressions (7) and (8). These results are presented in Table 3.

TABLE 3 -Time T for various detector locations, hours

Detector location	S1	S2	S3	S4	S5
MPMT approach	0.650	0.742	0.612	0.544	0.694
Expressions (7) , (8)	0.765	0.711	0.669	0.601	0.699

As can be seen, both approaches yield similar results indicating that the best fault detector location is at switch S4.

The analysis with both MPMT and shortcut methods was performed to find for the feeder under consideration the best location of two, three and four detectors. In all cases the shortcut approach has indicated the same best location of fault detectors as the MPMT approach. Table 4 gives the expected fault location times for various numbers of optimally positioned fault detectors for the feeder under consideration, determined by the MPMT and the shortcut approaches. These data provide the basis for a cost/benefit consideration.

The best locations for two detectors are at S3 and S4, for three detectors at S3, S4 and S5, for four detectors at S2, S3, S4 and S5.

TABLE 4.- Expected fault location time for optimally positioned detectors, min.

Number of detectors	0	1	2	3	4
MPMT approach	44.6	32.6	23.3	15.1	5.8
Shortcut approach	45.7	36.1	24.5	14.8	5.8

4. Conclusions

Calculation procedures are described to determine the optimal placement of fault detectors along a branching feeder to minimize the time of identifying faulted branches by taking into account the probability of fault occurrence. One of the procedures uses the stepwise fault location search based upon the values of the MPMT index for switches. The other two alternative shortcut procedures approximately calculate the expected fault location time in one step and considerably reduce the computational effort in searching for the optimal detector

locations. It was found for several typical overhead line feeder samples analyzed that these shortcut procedures can be with confidence used for optimizing the location of fault detectors. The feeder studied in this paper served as a simple demonstration of the procedures considered and benefits provided by suggested shortcut approaches.

Key Words: Fault location, fault detectors, expected location time, optimization, shortcut search

References

1. J. Nahman, J. Spirić, Optimally fault tracking in radial overhead line distribution networks (in Serbian), 1998 Savetovanje JUKO CIRED, R.6.10, Zlatibor,
2. R. Brown, *Electric Power Distribution Reliability* , 2002 M.Dekker, Inc. New York.
3. H. Lee Willis, 2004, *Power Distribution Planning Reference Book,* (Second Edition) M.Dekker, Inc. New York,
4. J. Nahman, *Dependability of Engineering Systems,* 2002. Springer Verlag, Berlin

OPTIMAL FAULT LOCATION IN OVERHEAD RADIAL DISTRIBUTION NETWORKS EQUIPED WITH SWITCHES AND FAULT DETECTORS

J. Nahman, Faculty of Electrical Engineering, Belgrade, Serbia
J. Spirić, EPS PD “Jugoistok” - branch Leskovac, Serbia

The paper outlines an approach for the optimal selection of the number and location of fault detectors in an overhead radial distribution network equiped with a number of switches. The optimization goal is to minimize the expected fault location time by taking into account the probability of fault occurrence on various feeder branches.
The method is based upon the recently published heuristic optimization method using the “maksimum probability of fault location for minimal time” approach, which was elaborated if only switches are installed. New heuristic, single step approaches for shortcut determination of the expected fault location time are also proposed considerably reducing the computational burden in searching for optimal solutions.