RELIABILITY COSTS IN DISTRIBUTION NETWORKS AND THE APPLICATION OF SWITCHING DEVICES

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SUMMARY

A new approach in determination of the costs due to supply interruptions to the customers of distribution networks and the way for assessing the reliability of supply are proposed. A critical comment on the way of collecting and assessing the costs of customers due to supply interruptions conducted in various countries is given. The way for a more appropriate determination of interruption costs for a customer is indicated that takes into account the frequency and duration of customer's activities and their overlapping with supply interruptions. The paper proposes a comparatively simple practical method to consider the reliability aspects in reinforcement and expansion planning of distribution networks. A simple distribution network example is usedfor the illustration of the method proposed and to show the impacts the various switching devices may have upon the network costs and reliability indices.

Key words: Reliability, distribution network, costs

1. SUPPLY INTERRUPTION COST

The assessment of the supply interruption cost is a very laborius and complex task as it implies the analysis of various scenarios concerning the activities which are interrupted and the costs/damages caused by various interruption durations. The mentioned costs have been assessed in the past using data obtained by inquires conducted for characteristic types of customers for a specified scenario of outages concerning the season, day and hour when the interruption occurs. A survey of such data for various countries and typical customer types has been publishhed in [1]. It was shown that the cost that are usually given per kW of peak consumption value differ significantly among the countries depending on the climate and different energy resources used for various activities, but also on the scenarious asumed for assessing the interruption costs. Namely, the adopted scenarious have usuallypresumed that the interruption will occure at a fixed day of the year and at a fixed hour, usually at the peak consumption. The main drawback of such an approiach lies in the fact that the interuuptions can happen at any instant during a day, with different cosequences causing different costs, if any. A more complex approach in assessing the supply interruption costs for residental sector has been proposed in [2]. This approach considers each household activity and supplying network behaviour as Markov stochastic processes that interact. The probability and the duration of the interruption of a considered activity due to supply failure is calculated from the block-diagram presented in Fig.1 with λ_j and λ_i designating the rate of failure and of activity occurrence, andr_j and d_i being the fault and activity durations, respectively.

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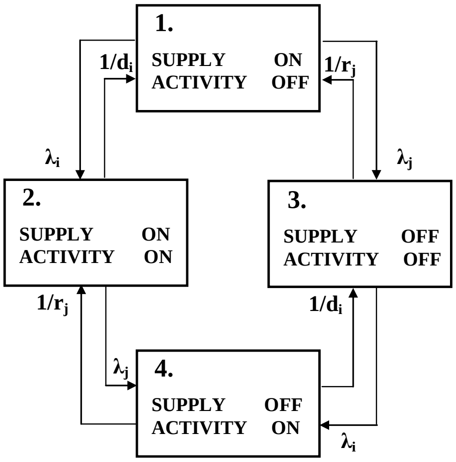

Fig.1 State transition diagram

Mean duration of the state No.4, which determines the cost caused by the supply interruption, equals, as it follows from Fig.1,

$$D_{ji} = \frac{r_j \cdot d_i}{r_j + d_i} \qquad (1)$$

The frequency of the state No.4 is

$$f_{ij} = \frac{\lambda_j \lambda_i (r_j + d_i)}{(1+\lambda_j r_j)(1+\lambda_i d_i)} \qquad (2)$$

Using expressions (1) and (2) the costs of interrupting due ty supply failures can be determined for all activities. A similar approach has been used to assess also the costs of posponable activities [2].. Such an approach has been used for assessing the supply interruption costs for domestic customers in some Belgrade districts by taking into account the scenarious of daily home activities in characteritic seasons of the year and by making a difference between workingdays and hollydays.

The application of the above mentioned approach in determining the costs for various types of customers in every day engineering practice is a reckomendable but a very laborious and costly task.On the other side, as discussed before, the consumer cost data obtained for a fixed time of upply interruption occurence, offer only a very crude and usually overestimated outcome. Therefore, they can not be used with great confidence in any distribution system operation and planning study. In the text that follows a practical approach for assessing the reliability impacts in dustribution systems will be presented.

2. ASSESSMENT OF THE RELIABILITY OF SUPPLY

The alternative approach for accounting for the reliability issues in any system analysis could be the foloowing:
a. Prescribe the maximum allowable values of indices SAIDI and SAIFI.
b. Deterimine the amount lost of the incomes of the electrical energy providersin selling the electrical energybecause of supply interruptions. The providers are, generally, the distribution network utility and the distributed generators owners.

The mathematical model for calculating the reliability costs for a distribution network is as follows

$$C = \sum_k \lambda_k \alpha \left(\sum_{ki} c_i P_{ki} D_{ki} \right) + \sum_j g_j C_j \qquad (3)$$

with λ_k, α , P_{ki}, c_i ,D_{ki} , $g_j$and $C_j$designating failure rate of network branch *k,* load factor, peak load of customer at the end of branch *ki*switched out due to failure of branch *k*, income lost of energy suppliers of the network per unit of energy not delivered, duration of supply interruption of branch *ki*due to outage of branch *k*, annual capital and maintenance cost factor of switching device *j* and cost of it, respectively.

The reliability indices that should be determined for the distribution network are, as well known,

$$SAIDI = \frac{\sum_k \lambda_k \left(\sum_{ki} D_{ki} N_{ki} \right)}{N} \qquad (4)$$

$$SAIFI = \frac{\sum_k \lambda_k \left(\sum_{ki} N_{ki} \right)}{N} \qquad (5)$$

with N_{ki}designating the number of customers supplied by branch *ki* curtailed by the failure of branck *k* and *N* being the total number of network customers. These two indices provide a measure of the disturbances caused to the customers. Their maximum allowable values should be defined and applied as constraints in any reinforcement and further development activities for a network. In accordance to Europian expirience [3] the preferable values that in 2016. have been achieved by many countries of Europian Union are SAIDI< 400 min./cust.yr. and SAIFI < 3 inter./cust.yr.In practical applications, if only one reliability index is considered, *SAIDI* index is usually taken to be more informative [4].

3. ILLUSTRATIVE APPLICATION OF THE PROPOSED APPROACH

The proposed approach for assessing the reliability cost and achieved availability in supplying the customers will be illustrated using a simple 35 kV network example presented in Fig.2

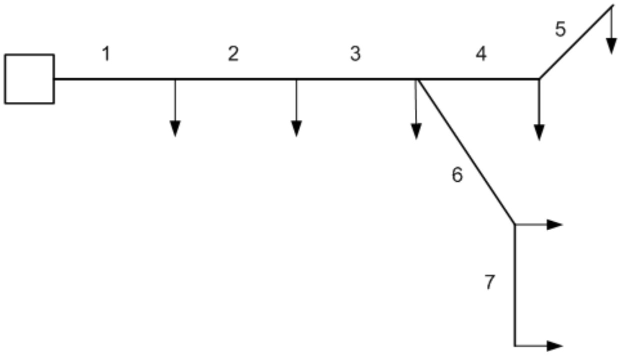

Fig.2 Considered 35 kV distribution network

Table 1 provides the data on branch failure rates, peak power consumption of customers at the ends of network branches and numbers of them. The reliability associated costs and indices have been calculated for various combinations of switching devices. The main idea was only to show the effects of various possible solutions in sellection and location of available switching devices upon the network reliability parameters.

TABLE 1. NETWORK DATA

Branch, k	1	2	3	4	5	6	7
λ_k 1/year	0.56	0.42	0.60	0.20	1.00	0.24	0.30
N_k	107	50	55	67	100	25	45
P, kVA	150	80	90	110	110	50	75

The following solutionsare examined:
A= Circuit breaker in source substation;
B = A +switches at sending ends of branches 4 and 6
C=A+sectionalizer at the end of branch 3,
D = A + recloser at sending end of branch 2 + sectionalizers at sending ends of branches 3, 4, 6; E = A + remote controlled switches at sending ends of branches 4 and 6

Assumed interruption durations for considered solutions:
A = All customers 4 h.
B = Customers switched out during repai 3.5 h, other customers 0.5 h
C and D = Customers switched out during repair 3.5 h, other customers 0 h.
E = Customers switched out during repair 3.5 h, other customers 0.3 h.

Annual capital and maintenance costs for switching devices are presented in Table 2 [4]. The lost income for the energy suppliers and load factor are assumed to be c_i = 0.1 US$/kW and α = 0.8.

TABLE 2. ANNUAL COSTS OF SWITCHING DEVICES

Device	Switch	Sectionalizer	Recloser	Remote-controlled switch
Cost , US$/year	1000	1500	4000	4000

Results of the calculation of total reliability costs for all considered solutions are presented in Table 3.

TABLE 3. CALCULATION RESULTS

Solution	SAIDI min./cust. yr.	SAIFI num./cust. yr.	Cost US$/yr.
A	796	3.32	706
B	496	2.12	2434
C	524	2.50	1962
D	378	1.80	8830
E	474	2.12	8284

As can be seen from Table 3, only the most expensive solution D offers the desirable SAIDI and SAIFI values mentioned before. The least expensive solution A can not be taken as satisfactory by regarding both considered reliability indices. As the second best solution with respect to the reliability indices and annual cost can be considered the solution B. It provides reliability indices close to these achievable by solution E but with considerably less annual cost.

4. CONCLUSIONS

The paper presents a new approach in determining the reliability cost and its assessment in operation and planning of distribution networks. The effects of various switching devices upon the reliability cost and SAIDI and SAIFI indices have been also demonstrated on a simple example, as illustration.

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