Electric Power Systems Research xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Switch and recloser placement in distribution system considering uncertainties in loads, failure rates and repair rates

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ARTICLE INFO

Article history:
Received 19 November 2015
Received in revised form 27 April 2016
Accepted 11 May 2016
Available online xxx

Keywords:
Differential evolution
MINLP
Reclosers
Switches
Uncertainty

ABSTRACT

For maximizing the customer satisfaction and retention, improvement of service reliability is a major concern for electric utilities. Service reliability can be improved by placing switches and reclosers at appropriate locations in the distribution system so that supply from the main substation to the healthy load points can be maintained after isolating the faulted section. This paper presents a formulation for an optimal placement of switches and reclosers in a distribution system for maximizing system reliability while minimizing the associated investment and outage costs considering uncertainties in load data, system failure and repair rates. The uncertainties have been incorporated in the formulation using point estimate method (PEM). The proposed formulation has been tested on 13, 58 and IEEE 123-bus test systems using differential evolution (DE) and mixed integer nonlinear programming (MINLP) method. The obtained results establish the effectiveness of the consideration of data uncertainties in improving the distribution system reliability and maximizing utilities' profits.

1. Introduction

In a power grid, faults are more frequent in distribution system as compared to other parts of the system leading to supply interruptions of the customers [1]. For maximizing the customer satisfaction and retention, improvement of service reliability while minimizing the associated cost is a major concern for electric utilities. In distribution systems, switches and reclosers are primarily used for the isolation of the faulted feeder section, network reconfiguration and reliability improvement [2]. Service reliability can be improved by placing switches and reclosers at appropriate locations in the distribution system so that healthy parts of the system can be energised after isolating the faulted section of the system.

Therefore, for improving the service reliability, a strategy for optimal placement of the switches and reclosers needs to be evolved.

In the literature, studies have been carried out to investigate the problem of optimal placement of switching devices in a distribution system. In [2] the problem of sectionalizing switch placement problem has been solved using simulated annealing (SA) method to find the optimal number and locations of the switches. In [3] a graph-based switch placement scheme is proposed to support the priority customers by single or multiple distributed generators in the event of faults. An immune algorithm (IA) based approach is proposed in [4] for optimal switch placement in a distribution system to minimize the investment and outage cost considering different customer classes. A particle swarm optimization (PSO) based three-state approach is presented in [5] to simultaneously find the optimal number and locations of sectionalizer and breaker switches in a distribution system. In [6] an ant colony optimization (ACO) based methodology is proposed for optimal placement of sectionalizing switches in a distribution system with distributed generation (DG) to improve system reliability while minimizing the cost of switches. Another ACO based multiobjective optimization approach is presented in [7] for placement of switches and protective devices in distribution system for reliability improvement. In [8] a multiobjective switching device placement problem has been solved using non-dominated sorting genetic algorithm II (NSGA-II) considering DG unavailability, equipment cost and network reliability with no island network operation. A mixed-integer linear programming (MILP) based approach is proposed in [9] for placement of sectionalizing switches in a distribution system considering customer outage cost and the costs associated with switch installation, operation and maintenance. Another method to determine the optimal number and locations of sectionalizing switches using MILP approach has been proposed in [10]. In this work, the problem of switch placement in distribution network was considered in the presence of DG for minimizing the total associated cost in order to achieve a specified level of reliability. In [11] a PSO based multiobjective optimization problem is proposed for

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http://dx.doi.org/10.1016/j.epsr.2016.05.012
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Please cite this article in press as: A. Alam, et al., Switch and recloser placement in distribution system considering uncertainties in loads, failure rates and repair rates, Electr. Power Syst. Res. (2016), http://dx.doi.org/10.1016/j.epsr.2016.05.012

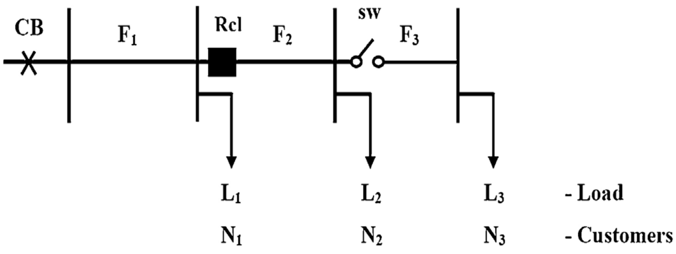

Fig. 1. Radial distribution system with 3 feeders and 3 load points with one switch and one recloser.

placement of switches in radial distribution system for minimizing the number of customers not supplied (CNS). The developed algorithm requires only the number of customers per load point and network topology. However, this work does not use failure rates and repair rates of the system components.

In all the above studies, a static loading condition has been considered. However, the switches and reclosers, once installed in the distribution system, are expected to be in operation over a considerable period of time, during which, the loading condition of the system, failure rates and repair rates are likely to vary. Therefore, there is a need for considering the uncertainties in the loading conditions, failure rates and repair rates in optimal placement of the switches and reclosers in a distribution system.

Towards this goal, in this paper, these uncertainties have been incorporated in the problem of optimal placement of switches and reclosers in a distribution system.

The paper is organized as follows: The basic concept of reliability calculation in the presence of switches and reclosers is explained in Section 2. The proposed problem formulation is explained in Section 3. Procedure for incorporating the uncertainties using three point estimate method (3PEM) is presented in Section 4. Results obtained are presented in Section 5 and the final conclusions are drawn in Section 6.

2. Distribution system reliability calculation with switches and reclosers

The reliability of a distribution system is assessed by evaluating the adequacy of supply at the customer load point. In practice the basic indices used are [12,13]: (a) average failure rate (λ) f/yr, (b) average outage duration (r) h/failure and, (c) average annual outage time (U) h/yr.

The procedure for calculating the average load point reliability indices in the presence of reclosers and switches in a distribution system is explained next.

Consider the case of a distribution system protected by a circuit breaker (CB) at the feed point, a recloser in the ith segment and a switch in the jth segment. For a fault in the ith feeder and other downstream feeders, the recloser will open instead of the circuit breaker (CB) to interrupt the fault current. As a consequence, all the loads upstream to ith feeder segment will not experience any interruption. Hence, interruption rate (λ) for these loads is set equal to 0 and for all the loads downstream to ith faulted segment, the interruption rate is set equal to 'λ_i' (the failure rate of ith segment). For faults in the jth segment and other downstream segments, all feeders upstream to jth segment will have an interruption time equal to the isolation time corresponding to the faulted segment, while the loads downstream to jth switch will have an interruption time equal to the repair time of the faulted segment.

For example, in Fig. 1, for faults in segment F_2 and F_3, load L_1 will not experience any supply interruption as the fault will be cleared by opening of the recloser and 'λ' will be zero for L_1. For faults in F_2 and F_3, loads L_2 and L_3 will have an interruption rate equal to the interruption rate of the faulted feeder. Further, for a fault in F_3, recloser will open to interrupt the fault and switch SW will be opened afterwards to isolate the faulted segment. Recloser will then be closed to resume supply to L_2. The interruption time of L_2 will now be equal to the isolation time '$r_{iso,3}$'. Supply to L_3 will be resumed only after the repairs are completed, i.e. after 'r_3' hours.

Let $X_{R,i}$ and $X_{S,i}$ be the binary variables representing recloser and switch respectively in line i. Also, let

$$\begin{aligned} X_{R,i}/X_{S,i} &= 0, \quad \text{if a recloser/switch is connected in line } i \\ &= 1, \quad \text{if a recloser/switch is not connected in line } i \end{aligned}$$

For the system shown in Fig. 1, for calculation of the equivalent 'λ' and 'r', first bus-injection to branch-current (BIBC) matrix is formed following the procedure given in [14]. The **[BIBC]** matrix contains values of 0 and 1 only.

If $bibc(i,j)=1$, it implies that jth load is downstream of ith feeder, where, $bibc(i, j)$ denotes the (i, j)th element of the **[BIBC]** matrix. Therefore, failure of ith feeder will result in outage of jth load and the supply can be resumed only after the feeder is repaired. Hence, the failure rate ($\lambda_{i,j}$) and repair time ($r_{i,j}$) of jth load due to failure of ith feeder can be written as,

$$\begin{aligned} &\lambda i,j = \lambda_i \\ &r_{i,j} = r_i \end{aligned} \tag{1}$$

If $bibc(i, j)=0$, it implies that jth load is upstream of ith feeder. Therefore, placement of reclosers/switches will help in isolating the faulted ith feeder, thereby, improving the availability of supply at jth load. Hence, the failure rate ($\lambda_{i,j}$) and repair time ($r_{i,j}$) of jth load due to failure of ith feeder can be written as,

$$\begin{aligned} &\lambda i,j = \lambda_i \prod_{k \epsilon F(i,j)} X_{R,k} \\ &r_{i,j} = r_i \prod_{k \epsilon F(i,j)} X_{S,k} + r_{iso,i}\left(1 - \prod_{k \epsilon F(i,j)} X_{S,k}\right) \end{aligned} \tag{2}$$

where,

$$F(i,j) = P_{ath}(1,i) \cap P_{ath}(j,i) \tag{3}$$

Further, $P_{ath}(1, i)$ is the path from root node to ith feeder including ith feeder and $P_{ath}(j, i)$ is the path from jth node to ith feeder including ith feeder. $F(i, j)$ is the feeder sections common to paths $P_{ath}(1, i)$ and $P_{ath}(j, i)$.

Following the above procedure, the calculated values of equivalent 'λ' and 'r' for the network shown in Fig. 1 are given in Table 1. In this system, feeder segment F_2 has a recloser and feeder segment F_3 has a switch. Hence,

$$\begin{aligned} &X_{R,1} = X_{R,3} = 1, \quad X_{R,2} = 0 \\ &X_{S,1} = X_{S,2} = 1, \quad X_{S,3} = 0 \end{aligned}$$

The **[BIBC]** matrix for this network is given below,

$$BIBC = \begin{array}{c} \\ Feeder1 \\ Feeder2 \\ Feeder3 \end{array} \begin{array}{c} \begin{array}{ccc} Load1 & Load2 & Load3 \end{array} \\ \begin{pmatrix} 1 & 1 & 1 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{pmatrix} \end{array} \tag{4}$$

Using the elements of **[BIBC]** matrix, Eq. (2) and the values of $X_{R,i}$ and $X_{S,i}$, the values of 'λ' and 'r' for the system are given in Table 2.

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