Available online at www.sciencedirect.com
ScienceDirect
Electric Power Systems Research 78 (2008) 372–381
ELECTRIC POWER SYSTEMS RESEARCH
www.elsevier.com/locate/epsr

Optimised placement of control and protective devices in electric distribution systems through reactive tabu search algorithm

Luis G. Wesz da Silva [a], Rodrigo A. Fernandes Pereira [a], Juan Rivier Abbad [b,c], José R. Sanches Mantovani [a,*]

[a] *São Paulo State University-UNESP, Department of Electrical Engineering, Avenida Brasil, 56, Zip Code 15385-000 Ilha Solteira, SP, Brazil*
[b] *Universidad Pontificia Comillas, ICAI, Madrid, Spain*
[c] *UNSW, Sydney, Australia*

Received 27 November 2006; received in revised form 6 March 2007; accepted 10 March 2007
Available online 30 April 2007

Abstract

Optimised placement of control and protective devices in distribution networks allows for a better operation and improvement of the reliability indices of the system. Control devices (used to reconfigure the feeders) are placed in distribution networks to obtain an optimal operation strategy to facilitate power supply restoration in the case of a contingency. Protective devices (used to isolate faults) are placed in distribution systems to improve the reliability and continuity of the power supply, significantly reducing the impacts that a fault can have in terms of customer outages, and the time needed for fault location and system restoration. This paper presents a novel technique to optimally place both control and protective devices in the same optimisation process on radial distribution feeders. The problem is modelled through mixed integer non-linear programming (MINLP) with real and binary variables. The reactive tabu search algorithm (RTS) is proposed to solve this problem. Results and optimised strategies for placing control and protective devices considering a practical feeder are presented.

Keywords: Network protection systems; Restoration; Reliability; Reactive tabu search

1. Introduction

Efficient and safe planning of distribution systems includes, among other investments, the placement of control and protective devices in strategic places of the network to improve power supply quality and reliability indices. Control devices include any device that an operator can use to open or close a circuit (either manually or remotely controlled), in order to control power supply interruptions when a permanent fault occurs as well as for the execution of expansion works and preventive maintenance interventions in network components. In this paper, reclosers and isolators (manual and automatic sectionalizing switches) are considered to be control devices. Protective devices include any device that operates automatically to isolate any permanent and/or temporary fault in a feeder. In this paper, fuses and reclosers are considered to be protective devices. In all of these cases, during the planning stage it ought to be foreseen that the network should have a set of switches for the reconfiguration to reduce the area to be disconnected as much as possible [1,2] and, consequently, the loads that will be disconnected when permanent faults occur. In general, the impact caused to customers, due to control and protective device placement in the system, is related to the interruption frequency and duration. Various papers, which deal separately with the optimised placement of control devices (switches) for network restoration [3–7] and protective devices [8–10], are found in literature.

Ref. [3] proposes a mathematical model for the optimal placement of control devices in radial distribution systems. In this model, outage, maintenance and investment costs are considered, and the objective is to optimise the relation between sectionalizing switch placement costs and the corresponding benefits related to the improvement of the reliability indices. The optimisation problem is solved using the simulated annealing technique. In the model proposed in [2] for the placement

* Corresponding author. Tel.: +55 18 3743 1150; fax: +55 18 3743 1163.
E-mail addresses: lgwesz@gmail.com (L.G.W. da Silva), ddigo@yahoo.com (R.A. Fernandes Pereira), juan.rivier@upcomillas.es (J.R. Abbad), mant@dee.feis.unesp.br (J.R. Sanches Mantovani).

0378-7796/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2007.03.005

of automatic sectionalizing switches in radial or weakly meshed distribution networks, reliability of supply is the main concern. In [4], a model for the optimal placement of control devices considering the cost of non-supplied energy and the investment cost of sectionalizing switch placement is presented. Repairing times and failure rates of the network and the sectionalizing switches are taken into account. The problem is solved using genetic algorithms. In [6] the switch placement problem is formulated as a combinatorial optimisation problem with a non-linear and non-differentiable objective function. So as to solve the problem, an optimisation algorithm based on the philosophy of ant colonies is used.

In [8], the problem of protection device placement is formulated as a binary (0/1) integer non-linear programming problem that is solved using genetic algorithms. In [9,10], a binary linear programming model is developed for the placement of protection devices, fault locators and sensors in the network, in order to improve the reliability indices of the system. Both technical and economic constraints related to the coordination and selectivity among protection devices and the number of devices to be placed is considered. For its solution, classic multiobjective programming techniques along with fuzzy logic, among others, are proposed. Ref. [12] presents a mixed integer non-linear programming (MINLP) model, with real and binary variables, for the control and protective device placement problem. The model proposed in [12] is solved in two steps: (1) protective devices are placed considering specific constraints for each feeder; (2) maintaining protective devices, placed during the first step, in their position, control devices are optimally placed. Reclosers are considered to be both protective and control devices.

This paper presents a novel technique to carry out optimised placement of control and protective devices in the same optimisation process, simultaneously. The problem is modelled through MINLP with real and binary variables. The reactive tabu search algorithm (RTS) is proposed to solve this problem. In order to illustrate the application of this technique, a practical, 13.8 kV, 134 nodes, overhead, three-wire feeder with a delta-grounded wye connection substation transformer, is used.

2. Mathematical model

Optimising control and protective devices placement and/or replacement for distribution network restoration means the searching for the best points to place different types of devices to minimize the sum of the cost of investment in the network and reduce the interruptions costs. The mathematical model should consider the search for optimal solutions that is both technically and economically viable. For example, fuses will clear faults very cheaply in the short term, but since the number of faults may be large and most of them temporary, protecting the system against temporary faults using reclosers may be cheaper in the long term [11]. The number and types of protective devices to be installed in a particular feeder will depend on the importance of the system, magnitude and type of load, circuit configuration and exposure to risks of different nature, which can lead the system towards permanent or temporary fault conditions.

The mathematical model for control and protective devices placement and replacement for system restoration proposed in this work, has been designed using the concept of interruption costs and the historical database of permanent and temporary fault indices in the system [3,4,6,8–10,12]. It is formulated as a combinatorial optimisation problem with a non-linear objective function, non-differentiable, including real and integer variables and a set of linear and non-linear constraints that is detailed following.

2.1. Objective function

The proposed objective function is the sum of the fixed cost due to the placement and replacement of switches and protective devices, and the cost of interruptions. In the mathematical model, the type of customer (residential, commercial and industrial), the connected load (L), the permanent (λ) and temporary (γ) fault rates, the costs associated with individual customer interruptions (long- and short-time interruptions), and the feeder's length is considered. The average cost of interruptions (both temporary and permanent) is used to compute the total cost of interruptions [6,9,10,12]. These costs can be assessed from surveys or simply be based on any pre-established standards imposed by the regulatory agencies with its associated penalization. These standards usually measure the number and duration of the interruptions in the system through, for example, the system average interruption frequency index (SAIFI) and the system average interruption duration index (SAIDI) of distribution systems.

The objective function for each feeder i of the distribution system is composed by the following terms:

$$f = \mathrm{FC}_i + \sum_{j=1}^{n\,\mathrm{sec}_i} (\mathrm{CIP}_j + \mathrm{CIT}_j) \tag{1}$$

Fixed costs (FC_i) are related to the investment for the purchase and installation of control and/or protective devices. In the case of replacement, involved fixed costs are basically due to the repositioning of control and/or protective devices. These costs are written as:

$$\mathrm{FC}_i = \sum_{j \in Q} \mathrm{FCP}_{jk} X_{jk} + \sum_{j \in \mathrm{CH}} \mathrm{FCC}_j Y_j \tag{2}$$

The interruption costs for each feeder i of a given distribution network is given by annual cost of interruption due to the occurrence of a permanent fault (CIP_j) and interruption costs due to the occurrence of temporary faults (CIT_j) in the section j of feeder i. The cost of each interruption is calculated taking into account the location of all control and protective devices on the radial distribution feeder.

Fig. 1 illustrates a generic distribution system presenting seven feeders as well as the protective and control devices placed on the feeders. The feeder is divided into sections according to the location of the installed devices. That is, every installed device establishes two sections: the upstream section will see the device at its receiving node (at the end of the section) and the downstream section will see the device at its sending node (at the beginning of the section). A fault in any section will