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Multiobjective planning of distribution networks incorporating switches and protective devices using a memetic optimization

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ABSTRACT

A multi-objective planning approach for the reliability of electric distribution networks using a memetic optimization is presented. In this reliability optimization, the type of the equipment (switches or reclosers) and their location are optimized. The multiple objectives considered to find the optimal values for these planning variables are the minimization of the total equipment cost and at the same time the minimization of two distribution network reliability indexes. The reliability indexes are the system average interruption frequency index (SAIFI) and system average interruption duration index (SAIDI). To solve this problem a memetic evolutionary algorithm is proposed, which combines the Non-Dominated Sorting Genetic Algorithm II (NSGA-II) with a local search algorithm. The obtained Pareto-optimal front contains solutions of different trade-offs with respect to the three objectives. A real distribution network is used to test the proposed algorithm. The obtained results show that this approach allows the utility to obtain the optimal type and location of the equipments to achieve the best reliability with the lower cost.

1. Introduction

Power quality has become a critical concern for utility customers. One of the most important factors that allow the attenuation of this problem is the improvement of the electrical power systems reliability. Reliability standards in power systems are traditionally established as a series of technical requirements to be fulfilled during planning and operation [1]. Due to the importance of reliability on the electrical power system, several studies and methods have been presented. In [2] it is considered the design of an accelerated life test methodology that may be suitable for demonstrating whether a platform design has achieved its reliability target, and which provides a reliability baseline for products derived from it. An approach for the analysis of power systems vulnerability based on a hybrid model that combines elements of the classical deterministic network interdiction problem with the use of a multi-objective optimization evolutionary algorithm was proposed by [3]. In this work it was recognized that, when analysing power system vulnerability, it is possible to have multiple competing objectives and multiple prospective solutions that may change based on the preference of the decision-maker. A coupling between risk-based inspection methodology and multiobjective genetic algorithm for defining efficient inspection programs in terms of inspection costs and risk level was proposed by [4]. Reliability plays also a fundamental role in the area of the protection of power systems. In fact, to prevent wide-area disturbances, and enhance power system reliability, various forms of system protection scheme have been designed and implemented by utilities [5]. Under this context, [6] proposed an energy reliability program which differentiates between the energy reliability performances of different DC protection schemes. One of the areas of the electrical distribution networks is related with underground systems. The increase of these systems together with the aging of networks, the lack of maintenance and interference from other (third party) nearby underground systems have caused many accidents in urban areas, thus endangering human life. Several studies related with risk analysis methodologies were presented in [7–9]. In [10] it is examined the competence of deterministic design methods in size optimisation of reliable standalone hybrid renewable energy systems. One of the power system areas in which the importance of the reliability is increasing is the electrical distribution networks. In fact, most of the supply interruptions to utility customers are related with failures in the distribution networks [11]. Improvement of reliability in a distribution system can be achieved thru the installation of sectionalizing switching devices [12,13]. These equipments may be used in two different ways to improve network reliability. One is to use them to isolate an area under a fault and thru network reconfiguration, downstream customers of the fault can be supplied [14]. The other

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way is simply to isolate the area under a fault, and restore service to the rest of the upstream customers. Both ways improve network reliability by reducing customer experienced outage time. Switching devices are normally located on main feeders or secondary distributors of radial networks, to isolate areas under a fault. However, these are expensive equipments, so installing them in a distribution system will increase investment in equipment. The analysis of critical infrastructures to identify critical elements is used in [15–17] to optimize equipment investment and system reliability and in [18] a reliability asset assessment is applied to distribution systems management activities.

Another way to maximize reliability and equipment investment is to optimize the placement of switching devices. The number of switching devices to be installed on the main feeders or secondary distributors depends on several factors such as, network configuration, type of load and exposure to risks of different nature [19–21]. The type of switching devices and their allocation is a discrete optimization problem with a wide solution space. This problem is extremely hard to solve using an analytical approach, because there isn't an analytical expression that associates the switching device type and location with the reliability index and overall equipment cost. Due to this, intelligent algorithms have been used to solve this problem. Thus, simulated annealing and ant colony algorithms have been used to find optimum location of switches [22,23]. An optimization technique that uses a reactive tabu search has been proposed in [24] to optimize the number and location of switches and protective devices minimizing the equipment investment and maintenance costs. Other algorithms such as genetic [25] or immune algorithms [26] have also been proposed in order to improve the reliability levels of the distribution power system through the placement of switching devices. In [27,28] is used a particle swarm optimization to find the number and location of switching devices. Some of these approaches present the optimization problem as a single objective where the goal is to minimize economic costs or reliability indexes. Other approaches use a multiobjective function where, for example, the goal is to minimize the economic costs and reliability indexes [29–32]. However, this multiobjective minimization is converted into a single objective minimization problem since it only uses a single function combining the several objectives functions. In this combination, weighs are used, associated to each objective. According to the value of the weighs it is given more importance to one objective relatively to the others. Compared with these approaches, when the goal is to minimize several distinct objectives, a true multiobjective optimization is more difficult to solve because it requires a trade-off between the several objectives. In these multiobjective optimization problems a Pareto-dominance principle is used. This principle allows the decision maker to decide between the preferable solution from those available in the Pareto front, based on a compromise between objectives. According to this principle, some approaches have been proposed. In [33] is presented a multiobjective planning of electrical distribution systems incorporating sectionalizing switches and tie-lines using particle swarm optimization. A multiobjective optimal placement of switches and protective devices in electric power distribution systems using ant colony optimization has been proposed in [34]. In [35] a multiobjective approach using a fuzzy criteria evaluation and grey relational analysis is used to allocate automation devices. The optimal number and location of sectionalizing switches is determined in [36] using a fuzzy logic approach considering technical, regulatory and economical aspects. In [37] is determined the open loop in distribution networks using a multiobjective genetic algorithm. In this study, it is proposed a multiobjective optimization using a memetic evolutionary algorithm for the optimal placement of switches and protective devices in a distribution network. The optimization algorithm determines the type, number and location of the switching devices considering the minimization of the following objectives: SAIFI, SAIDI and Equipment Cost (all at once). The proposed memetic evolutionary algorithm combines a Non-dominated Sorting Genetic Algorithm-II (NSGA-II) and a local search algorithm. This algorithm allows the finding of a set of solutions that represent the Pareto front. This approach is applied to a real distribution network.

This article is organized as follows. In Section 2 is defined the calculation of the reliability indexes. In Section 3 the multiobjective optimization problem is formulated considering the concepts. In Section 4 is presented the proposed planning approach using the memetic evolutionary algorithm. Section 5 provides numerical results and discusses the application of the proposed approach to a real distribution network. Finally, the conclusion of the work is presented in Section 6.

2. Reliability indexes

Considering that the function of an electrical system is to meet demand at an acceptable level of quality and continuity of supply, network reliability analysis is one of the most important tools in planning and operations. In particular, the distribution system is an important link between the generation and transmission system and customers. Several publications refer that more than 80% of all interruptions that affect customers occur in the distribution system.

Distribution networks are radial in nature, which makes them vulnerable to interruptions. With this kind of topology, even a single fault may affect many customers. The reduction of interruptions experienced by consumers is by the previous, an important issue in distribution systems.

A typical distribution radial network consists of main feeders and secondary distributors to supply energy to customers. Relatively to generation and transmission systems, reinforcements in the distribution systems are relatively inexpensive. With a relatively small investment, important gains in network reliability can be obtained. Reliability evaluation is therefore an important tool to maximize the investment in switching devices in terms of network reliability gains.

The objective with a reliability evaluation is to obtain the system reliability performance after any equipment and topology change, for example by calculating different types of reliability indexes. There are several indexes that can be used to evaluate the reliability of a distribution network [38]. For long interruption indexes, recommendations for Medium Voltage systems are to refer to Institute of Electrical and Electronics Engineers (IEEE) Standard 1366, which recommends indexes such as System Average Interruptions Duration Index (SAIFI), System Average Interruption Frequency Index (SAIDI), Momentary Average Interruption Frequency Index (MAIFI) and Customer Average Interruption Duration Index (CAIDI). Nevertheless, the best-known distribution system reliability measures are SAIDI and SAIFI. SAIDI represents the total amount of minutes, on average, that a customer could expect to be without electricity over a year, calculated as the sum of each customer interruption duration (in minutes), divided by the total number of connected customers averaged over the year. It is commonly measured in customer minutes or customer hours of interruption. SAIDI indicates the average duration of interruptions that a customer may experience over a predefined period of time. Mathematically, it is given by Eq. (1).

$$SAIDI = \frac{\sum(\gamma \times r_{iS} \times N_i + \lambda \times r_{iR} \times N_i)}{N_t} \text{ With} \begin{cases} \gamma = \begin{cases} 1 & if\ \ Switch \\ 0 & if\ \ Recloser \end{cases} \\ \lambda = \begin{cases} 0 & if\ \ Switch \\ 1 & if\ \ Recloser \end{cases} \end{cases} \tag{1}$$