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

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A B S T R A C T

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
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]
was used a particle swarm optimization to find the number and location
of switching devices. Some of these approaches present the optimiza-
tion problem as a single objective where the goal is to minimize
economic costs or reliability indexes. Other approaches use a multi-
objective function where, for example, the goal is to minimize the
economic costs and reliability indexes [29–32]. However, this multi-
objective minimization is converted into a single objective minimiza-
tion problem since it only uses a single function combining the several
objectives functions. In this combination, weights are used, associated
to each objective. According to the value of the weights 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 incorporat-
ing sectionalizing switches and tie-lines using particle swarm optimi-
zation. 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 multiobjec-
tive 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 inter-
ruptions experienced by consumers is by the previous, an impor-
tant issue in distribution systems.

A typical distribution radial network consists of main feeders
and secondary distributors to supply energy to customers. Rela-
tively to generation and transmission systems, reinforcements in
the distribution systems are relatively inexpensive. With a rela-
tively 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, recommenda-
tions 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 Cus-
tomer 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 inter-
ruptions that a customer may experience over a predefined period of
time. Mathematically, it is given by Eq. (1).

\[
SAIDI = \frac{\sum(y \times r_{gi} \times N_i + \lambda \times r_{rik} \times N_i)}{N_c}
\]

(1)
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