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A multiobjective placement of switching devices in distribution networks incorporating distributed energy resources

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ABSTRACT

With the growth of Distributed Energy Resources (DER) in electrical systems, an increase in the benefits with the reconfiguration of radial networks related to the use of renewable energy is expected. However, in some countries the reconfiguration of radial networks has some limitations like the impossibility of island operation. Also, many of them have contracts with Distributed Generation (DG) operators that force them to buy all the available generation of electricity. After a fault these limitations increase DG unavailability resulting in a waste of resources in the form of payments of available electricity generation not used. In this paper we propose a multiobjective optimal placement of switching devices considering DG unavailability, network reliability and equipment cost, with no island network operation. Two approaches are proposed in this multiobjective problem. In the first approach, besides the minimization of the equipment cost and the reliability indices, it is proposed an extra objective function that considers the minimization of the Distributed Generation Unavailability Index (DGUI). In the second approach two new composite indices comprising DG, interruption duration and interruption frequency are presented. Results obtained from a case study using a real utility distribution network are presented and discussed.

1. Introduction

In recent years there has been an increase in international awareness on climate change. This awareness has led people to question the impacts that electricity generation and use of energy has on the environment. In this context, local generation of electricity and local use of renewable energy resources are some of the most promising options to provide a more secure, clean and efficient energy supply [1,2]. Apart from environmental and energy efficiency motives, the introduction of DG and the optimal placement of restoration equipment is highly encouraged to improve distribution network reliability and DG availability. The normal approach when analyzing distribution networks with DG is to consider island operation. But many countries do not allow the exploration of radial systems in islands. On the other hand, some of them have established contracts with renewable energy producers that oblige them to purchase all of the available production (used or not used). In these countries, when a fault occurs and part of the electrical network is disconnected, DG are not used, thus resulting in an increase of DG unavailability and payments to DG producers without the use of the available production of electricity. Different approaches have been taken to improve network reliability and use of DG. These include network reconfiguration, protective and switching devices placement [3]. An overview of the state-of-the-art models and methods applied to the DG optimal allocation problem are presented in [4]. Many papers address this issue by studying the optimal placement of DG considering different approaches and different objectives. In [5], the placement and size of DG are optimized using a Genetic Algorithm (GA), considering a composite reliability index and using weights to represent the importance of the objectives. In [6] is presented a review on the current status of DG and FACTS controllers in power systems. A function of benefits (reliability, losses and voltage profile) vs. equipment cost is optimized in [7] using a GA to place DG. In [8], DG is allocated using a dynamic programing to improve loss and reliability. Other papers study the optimal placement of switching devices in distribution networks incorporating distributed generation. In [9], a particle swarm optimization is used to find the optimal placement of switches in a distribution network minimizing equipment, operation and maintenance cost. The optimum placement of reclosers is found in [10] using a multiple-population genetic algorithm considering a composite reliability index. In [11] recloser allocation is determined using a custom-tailored GA applied to a composite index to improve

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network reliability in the presence of DG. An IPSO Monte Carlo approach is used in [12] for the optimal placement of reclosers and auto sectionalizers to improve energy not supplied and equipment costs. A particle swarm optimization algorithm is used in [13,14] to find the optimal placement of switches in distributions networks to enhance system reliability. In [15] is used a fuzzy logic algorithm to obtain the optimal placement of switches in presence of DG considering a reliability index with economic indices. A hybrid simulated annealing is used in [16] for static expansion planning of distributed networks with the minimization of investment, cost of losses and customer interruptions. Ref. [17] uses an alliance algorithm to improve micro grid reliability. In [18], a risk analysis is used to optimize the allocation of protective devices in distribution networks. An alternative approach used by other works consists on studying network reliability improvement and DG placement with intentional island operation. In [19] it is discussed the possibility to improve reliability with island operation in distribution systems. Ref. [20] proposes a GA and Graph Theory for switch placement in distribution networks with DG, considering the maximum number of costumers to be supplied after a fault with island operation. Distribution network reliability is evaluated in [21] using particle swarm optimization, differential evolution and coordinated aggregation based particle swarm optimization. In [22], a new composite index is introduced to assess the impact on reliability of DG in distribution networks. Ref. [23] uses a GA to improve restoration processes in distribution networks with DG. In [24] an imperialist competitive algorithm is used for the optimal expansion of distribution networks. This work pretends to improve distribution network reliability and is analyzed from the point of view of the electrical distribution company. Thus, this research work proposes the improvement of the reliability indices according to the principles defined by the IEEE Standard 1366 [25]. These principles will be applied not only to consumers but also to the DGs. It also considers no island operation and proposes a multiobjective optimization of the optimal placement of switching devices in distribution networks incorporating DG. Two different approaches are used and compared, using a real utility distribution network.

2. Problem formulation

The optimal switching device placement is a problem with opposed objectives. Problems with conflicting objectives normally don't present a unique solution but rather a set of solutions. To find these solutions a multiobjective approach must be considered. In this work the evolutionary genetic algorithm NSGA-II (Fast Non-dominated Sorting Genetic Algorithm) was selected because of it's proven applicability to this type of problems. The location, type and number of switching devices are found using the evolutionary algorithm to find a trade-off between the conflicting objectives. The constraint of no island network operation is considered in this multiobjective problem. Two approaches are proposed for this multiobjective problem. In the first approach, besides the minimization of the equipment cost (EC) and the reliability indices (SAIDI and SAIFI) a new reliability objective function that considers the minimization of the Distributed Generation Unavailability Index (DGUI) is introduced, considered from the point of view of the electrical company. In the second approach, instead of the minimization of three objective functions, only two functions are considered. The reduction of the number of functions is obtained considering two new composite indices that integrate DG with network reliability.

2.1. Objective functions

The use of switching devices in distribution networks improves overall network reliability and DG availability by separating the part of the network with a fault from the rest of the network. The definitions of the reliability indices normally used by electric distribution companies are described in the IEEE Standard 1366. This standard, for long interruption indices, recommends amongst others, SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index). The mathematical definitions of SAIDI and SAIFI defined in the IEEE 1366 standard [25] are given by the following equations:

$$\mathrm{SAIDI} = \frac{\sum_i (t_i \times N_i)}{N_t} \tag{1}$$

$$\mathrm{SAIFI} = \frac{\sum_i (f_i \times N_i)}{N_t} \tag{2}$$

where f_t is the average frequency of outages in section i; t_i is the average outage time of section i; N_t are the clients affected by an outage in section i; N_t is the total number of clients in the network. These two indices are the most widely used by electric utilities managers and several works use SAIDI and SAIFI as reliability index to be minimized [26–30]. In this work, beside the minimization of network reliability indices (SAIDI and SAIFI), equipment cost and unavailability of DG will also be minimized. Two approaches to find the optimal number, type and locations of switching devices in the network are proposed. One directly minimizes the index of DG unavailability and the other approach that considers DG unavailability integrated in a composite index.

2.2. First approach

In this approach, three functions were minimized at the same time. Two of them consider network reliability (SAIDI and SAIFI one at a time) and Equipment Cost (EC). The third function considers the Distributed Generation Unavailability Index (DGUI), which represents the unavailability of all distributed generation connected to the network. It represents the time that DG are unavailable in result of a network fault. Considering that the highest power generators have a bigger impact on distribution utility's revenue, weights were included to differentiate the different power of each generator. This means that the solutions obtained privileges the connection of high power generators over low power generators, thus decreasing the unavailability of the first relatively to the second. Since the reliability indices SAIDI and SAIFI are the most used indices by utility CEO, this approach was subdivided into two parts, each of them considering the following objective functions: DGUI, EC and SAIDI in part A and DGUI, EC and SAIFI in part B. The mathematical formulation of each of these objective functions is forwardly described, considering the following three equations. A radial distribution network can be modeled as a tree with i buses and i sections. Each bus is connected to a section of the network and/or a client. Each of the interruption devices can be installed in the beginning of each section (bus). According to the problem, the decision variables are the interruption device type and it's location in the distribution network. Thus, the decision variables will be given by:

$$\lambda_i = \begin{cases} 1, & \text{if switch is allocated to the bus } i \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

$$\gamma_i = \begin{cases} 1, & \text{if recloser is allocated to the bus } i \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

$$\beta_i = \begin{cases} 1, & \text{if no equipment is allocated to the bus } i \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

Objective function SAIDI: In this objective function the purpose is to minimize the reliability index SAIDI as defined in (1). It can be described as the sum of the interruptions duration that a customer experiences over a year. It is calculated as the sum of the customer