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Multistage expansion planning for active distribution networks under demand and Distributed Generation uncertainties

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ABSTRACT

This paper presents a methodology for active distribution networks dynamic expansion planning based on Genetic Algorithms, where Distributed Generation integration is considered together with conventional alternatives for expansion, such as, rewiring, network reconfiguration, installation of new protection devices, etc. All aspects related to the expansion planning problem, such as multiple objective analysis, reliability constraints, modeling under uncertainties of demand and power supplied by Distributed Generation units and multistage planning, which are usually dealt with separately, are considered in an integrated model. Uncertainties are represented through the use of multiple scenario analysis. Multiple stages are incorporated by an algorithm based on the pseudo-dynamic programming theory. Results obtained with a test system and with an actual large scale system are presented and demonstrate the flexibility of applying the model for different purposes active network planning.

1. Introduction

The major problem of the dynamic expansion planning of distribution networks consists in determining the place, the capacity and the appropriate stage of reinforcement installation, based on the demand and the region geographical, political and economical data. Dynamic planning is conducted considering several stages and seeks to define the capacity of the reinforcements and where and when they should be installed to meet growing demand with minimal cost and acceptable quality standards. Conventional alternatives for expansion are rewiring, network reconfiguration by closing normally opened switches (NO) for load transfer, installation of new NO switches, capacity expansion or construction of new substations, installation of new feeders, among others. Currently, the installation of Distributed Generation (DG) units or the purchase of energy from DG enterprises can also be considered to meet the growing demand. Distribution utilities are usually hesitant to allow autonomous operation of DG because of their major impacts on system operation and protection. However, distribution systems are in the era of transition from passive networks with unidirectional flow supplied by the transmission grid to active distribution networks with the integration of DG [1]. Active distribution networks need flexible and intelligent planning methodologies in order to properly exploit the integration of DG and demand side management while still satisfying quality and reliability constraints.

Planning depends on two basic parameters: technical constraints (equipment capacity, voltage drop, radial structure of the network, reliability indices, etc.) and the optimization of economical targets such as minimization of investment and operating costs, minimization of energy imported from transmission, energy loss and reliability costs.

Important papers on passive distribution network planning are available. An algorithm based in the Branch Exchange technique is presented in [2], where the objective is to determine a radial structure for multistage planning that minimizes the system investment and operating costs, considering failures of equipment. Algorithms based on the pseudo-dynamic theory are presented in [3,4] aiming at obtaining the most favorable multistage expansion planning. An algorithm based on dynamic programming is presented in [5] for DG allocation for loss reduction and reliability improvement. Meta-heuristic optimization methods, particularly Genetic Algorithms (GA), have been applied in this area. Multistage distribution network expansion planning is analyzed in [6] through GA, while a method composed by two GA acting interlinked is presented in [7]. A non-dominated sorting GA is presented in [8] for optimally reconfiguring the network to minimize its operating costs. Fuzzy Dynamic Programming is applied in [9] for planning for a given period of tariff control.

This paper presents a methodology for dynamic expansion planning of active distribution network, based on Genetic Algorithms, where conventional alternatives for expansion such as

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rewiring and installation of new feeders, network reconfiguration by changing the status of switches, installation of new switches and protection devices, are considered together with installation or energy purchase from Distributed Generation. Multiple objectives optimization is applied concerning reliability, energy losses, transmission power import and investment costs. Uncertainties related to demand and power supplied by DG units are represented through multiple scenario analysis. A model that considers multiple stages of expansion has been developed based on the pseudo-dynamic programming theory aiming at determining the place and capacity of the reinforcements to be installed as well as the appropriate stage for installation. Results are presented for a test system and for an actual large scale system based on an implementation of the proposed methodology in MATLAB.

The novelty of this proposal is to have an integrated model that deals with almost all aspects of active distribution network expansion planning in one single model. It analyses DG integration together with conventional expansion alternatives, incorporating generation and load uncertainties, taking into consideration reliability, losses and costs multiple objectives in a multistage planning algorithm. The papers cited in the literature survey either evaluate separately the impact of DG installation, or deal with multiple objectives, or propose a method to incorporate uncertainty or present a multistage algorithm. The purpose of the model is to enable an integrated analysis of all these aspects or even evaluate only the desired ones. The integrated planning will be a requirement as DG employment changes from the ‘‘fit-and-forget strategy'' to a coordinated integration in modern active distribution networks.

2. Expansion planning based on Genetic Algorithms

The methodology proposed to solve the problem of expansion planning of active distribution networks uses Genetic Algorithms for Multi-objective Optimization considering uncertainties and multiple stages. The main advantages of GA when compared to classical optimization methods are the possibility of representing any kind of objective functions and constraints, independently of being continuous, discrete, linear or non-linear, and the ability to deal with complex problems with very large search space. Therefore, this technique is a natural candidate to solve this problem. On the other hand, GA demands high computational effort and does not guaranty to obtain the optimal global solution. These features, however, do not prevent the application of GA to planning problems, since the objective is to obtain a good alternative for expansion and not only the global optimum without major concerns about the computational efficiency.

The solution obtained by the methodology is a radial network that minimizes the adopted objective function. The objective function (*obf*) is composed by: (i) annualized energy loss costs; (ii) annualized expected value for non-distributed energy costs; (iii) annualized costs of investments in distribution network reinforcement and (iv) annualized costs of energy imported from transmission, as shown in the following equation:

$$obf = C_{losses} + ECOST + C_{inv} + C_{trans} \tag{1}$$

where C_{losses} is the annualized energy loss costs, *ECOST* the expected value of non-distributed energy costs, C_{inv} the annualized costs of system investments, and C_{trans} is the annualized costs of energy imported from transmission system.

The constraints of active and reactive power balance, bus voltage limits, power flow limits, network radial structure and expansion planning alternatives limits are considered in the optimization process.

Therefore, the expansion planning problem formulation may be represented as (2):

$$\begin{aligned}
&\text{Min } obf \\
&\text{subject to :} \\
&Pg_i - Pl_i - \sum_{j\in\Omega_i} p_{ij} = 0 \\
&Qg_i - Ql_i - \sum_{j\in\Omega_i} q_{ij} = 0 \\
&V_i^{\min} \leqslant V_i \leqslant V_i^{\max} \\
&p_{ij}^{\min} \leqslant p_{ij} \leqslant p_{ij}^{\max} \\
&PL_i \leqslant PL_i^{\max} \\
&NL_{ener} = NB - 1 \\
&N_{recon} \leqslant N_{recon}^{\max} \\
&N_{nsw} \leqslant N_{nsw}^{\max} \\
&N_{DG} \leqslant N_{DG}^{\max} \\
&N_{rew} \leqslant N_{rew}^{\max} \\
&N_{NCP} \leqslant N_{NCP}^{\max}
\end{aligned} \tag{2}$$

where Pg_i, Qg_i is the active and reactive generation at bus *i*, respectively; Pl_i, Ql_i the active and reactive load at bus *i*, respectively; p_{ij}, q_{ij} the active and reactive power flow at element *i–j*, respectively; Ω_i the set of elements connected to bus *i*; V_i the voltage at bus *i*; $V_i^{\min}, V_i^{\max}$ the minimum and maximum voltages at bus *i*, respectively; $p_{ij}^{\min}, p_{ij}^{\max}$ the minimum and maximum power flows at element *i–j*, respectively; PL_i the DG penetration level at bus *i*; $PL_i^{\max}$ the maximum DG penetration level at bus *i*; NL_{ener} the number of energized lines; *NB* the number os buses; N_{recon} the number of network reconfigurations (switches operations); N_{nsw} the number of new switches; N_{DG} the number of new DG units; N_{rew} the number of lines rewiring; N_{NCP} the number or new connected load points; $N_{recon}^{\max}$ the maximum number of network reconfigurations; $N_{nsw}^{\max}$ the maximum number of new switches; $N_{DG}^{\max}$ the maximum number of new DG units; $N_{recon}^{\max}$ the maximum number of lines rewiring; $N_{NCP}^{\max}$ is the maximum number or new connected load points.

The Genetic Algorithm uses binary codification and the chromosome may be divided in four parts, as represented in Fig. 1.

The first part of the chromosome refers to the possibility of network topology changes through changes in the status of some switches already installed or through the installation of new switches. In this case, 3 bits are used resulting in 8 possibilities for each alternative as shown in Table 1.

The radial structure of the network is one of the most difficult requirements to be ensured in distribution expansion planning models since it is not simple to represent this constraint by analytical equations. In the network reconfiguration problem, a switching operation involves the status change of two different switches in order to maintain the radial structure. For example, closing a NO switch causes the formation of a network loop and therefore another Normally Closed (NC) switch in the same loop must be opened to restore the radial structure. A necessary but not enough condition to ensure the radial structure may be represented by the sixth constraint equation in (2).

In this paper, an algorithm for optimal network reconfiguration developed based in [10] is used to obtain the new configuration of the network. Aiming to have a reduced size of the chromosome, only the switch that must be opened in each formed loop is represented. Each chromosome represents a particular configuration or network topology.

The analysis of radial structure is conducted either for NO switches already installed in the network or for candidate

(1) Topology changes	(2) Distributed Generation	(3) Rewiring	(4) New load points

Fig. 1. Chromosome structure.