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# Distribution network expansion planning and DG placement in the presence of uncertainties

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ABSTRACT

Distribution network expansion planning (DNEP) is one of the most important tools to deal with the demand growth in a system. DNEP is usually carried out through reinforcement or installation of new components. In this paper, a new and combined methodology is used to consider several practical aspects in DNEP such as uncertainty, distributed generation (DG), load growth, electricity market and multi stage dynamic expansion are included in the planning. So that DNEP is addressed in the presence of distributed generation (DG), considering load and price uncertainties under electricity market environment. The proposed planning aims at minimizing investment and operational costs simultaneously. Since DNEP in coordination with DG planning leads to reduce planning cost; therefore, the coordinated DNEP and DG planning are presented in this paper. The proposed planning is implemented by the particle swarm optimization (PSO) technique. Besides, the uncertainties are modeled as the probability distribution function (PDF) and Monte-Carlo simulation (MCS) is used to insert the uncertainties into the programming. The proposed planning is carried out based on the 9-bus as well as Kianpars–Ahvaz test systems (Kianpars–Ahvaz is a practical network in Ahvaz province, Iran). The simulation results demonstrate the ability and effectiveness of the proposed planning to deal with uncertainties under electricity market environment.



## Introduction

In recent decades, due to increasing the electric power systems efficiency and encouraging the investors, some fundamental changes have been occurred in the management and ownership of power systems; and in order to provide a perfect competitive electricity market, different sections of a power system such as generation, transmission, and distribution have been decentralized and restructured. In these restructured power systems, all participants try to increase their profit, and in this regard, they use different planning and components, etc. One of the most effective components in the restructured power systems is the distributed generation (DG). DGs can solve the problems of network expansion, reduce losses, increase reliability, and improve voltage profile, etc. Thus, power system operators would like to install the DG in their network. Distributed generation technologies are usually flexible from different views such as operation, size, and expandability; furthermore, their application in a power system leads to flexibility in electricity price and the system performance [1].

Regarding the DGs, the first problem is to model the DGs in the conventional power flow formulation, this issue has been addressed by Ref. [2]. Where, a helpful list of DG models and also an unbalanced three-phase power flow algorithm for radial distribution networks considering DG is presented by Ref. [2]. Besides, DGs have been investigated from different views such as impact of DGs on energy market [3], effects of DGs on stability, losses and voltage [4], reconfiguration of distribution networks incorporating DGs [5], DGs and islanding issues [6] effects of DGs on system reliability [7].

DGs have also been widely investigated in associated with distribution network expansion planning. The distribution network expansion planning is defined as a methodology for representing the place and type of the new lines and the size and place of the new transformers [8,9]. An overview of the methods developed for the distribution network expansion planning is presented in [10,11], where different methods have been reviewed and compared. Papers [12] provide a static model for the distribution network expansion planning in the presence of DGs; where the

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place and type of the lines are represented and the protective devices and relay are also incorporated. A multi-level distribution network expansion planning, considering the DG units, is presented in [13]. The distribution network expansion planning considering DGs for the peak cutting is presented in [14], where the planning aims at minimizing the total cost of the new lines, DGs, and losses. The effect of the DG uncertainty on the distribution network expansion planning is reported by Ref. [15]. A multi-stage expansion and unit commitment (UC) planning for distribution networks using artificial bee colony (ABC) is presented in [16]. An expansion planning of electric distribution systems is presented and solved by suing dynamic programming genetic algorithm in [17]. The proposed algorithm presented by Ref. [17] is endowed with problem-specific crossover and mutation operators, dealing with the problem through a heuristic search in the space of dynamic programming variables.

In this paper, a new method for the distribution network expansion planning, considering DGs in the presence of load and cost uncertainties is presented. The objective function of the planning is to minimize the total cost of energy and losses. In this regard, at first the conventional planning is carried out without considering DGs. The annual load profile is considered at three levels of low, medium, and heavy; and the associated energy cost is considered for each load level. Then, in order to demonstrate the effectiveness of DGs on the planning, the proposed planning is carried out in the presence of the DG units. In order to provide a flexible and robust planning to support the future loads subject to technical constraints, the load and cost uncertainties are modeled as PDF. Then, the Monte-Carlo simulation (MCS) is used to insert the uncertainty into the planning. The proposed constrained optimization problem is solved by using the particle swarm optimization (PSO) algorithm. Two test systems of 9-bus test network and Kianpars–Ahvaz networks are considered as the case studies, while the latter is a practical test system. The simulation results demonstrate that the proposed methodology can provide a flexible and robust planning under uncertainties. It should be mentioned that in electric power systems, there are many types of uncertainties; such as load and prices forecasting, wind and photovoltaic DG output variations. Although, the proposed methodology is a comprehensive method and can consider all uncertainties in the planning; but, including various types of uncertainties in the planning leads to a large scale mathematical problem which cannot be easily solved. Therefore, in order to reduce the time of simulation and scale of mathematical formulation, only two types of uncertainties are considered in the planning as load and price uncertainties.

## Problem formulation

The distribution network expansion planning is a constrained, nonlinear, mixed integer optimization programming and can be formulated as follows:

$$\text{Min } \nu = IC + OC \tag{1}$$

Subject to

$$V_{\min} \le V \le V_{\max} \tag{2}$$

$$0 \le S_i^{ss} \le S_{i-cap}^{ss} \tag{3}$$

$$S_j^{FD} \le S_{j-cap}^{FD} \tag{4}$$

$$S_k^{DG} \le S_{k-cap}^{DG} \tag{5}$$

$$\text{Radial structure} = 1 \tag{6}$$

where Eq. (1) shows the objective function of planning in term of dollars per year. The proposed objective function comprises two terms as $IC$ and $OC$. The first term, $IC$, represents the annual cost of the new installed or upgraded components and defined as follows:

$$IC = C_{RF}\left(\sum_{i\in s} IC_i^{ss} + \sum_{j\in F} IC_j^{FD} + \sum_{k\in G} IC_i^{DG} \times S_{k-cap}^{DG}\right) \tag{7}$$

where $C_{RF}$ shows the reduction factor which is used to convert all costs per year, $IC_i^{SS}$ represents the fixed cost of the $i_{th}$ distribution substation per "\$", $IC_j^{FD}$ demonstrates the investment cost of the $j_{th}$ feeder per "\$", $IC_j^{DG}$ shows the investment cost of $j_{th}$ DG per "\$/MVA", and $S_{k-cap}^{DG}$ is the total capacity of the $k_{th}$ DG per "MVA". The second term OC shows the annual operation cost of the system that depends on the power purchased from the network and the produced power of DGs. This term is expressed as follows:

$$OC = \sum_{t\in T} T_t\left(\sum_{k\in G} OC_k^{DG} \times P_{k-t}^{DG} + \sum_{i\in s} EC_{i-t}^{ss} \times P_{i-t}^{ss}\right) \tag{8}$$

where $T_t$ shows the time duration of the load level per "hours", $OC_k^{DG}$ is the operation cost of the $k_{th}$ DG per "\$/MW h", $P_{k-t}^{DG}$ represents the produced power of $k_{th}$ DG at load level $t$ per "MW", $EC_{i-t}^{ss}$ shows the nodal price of electricity market at $i_{th}$ substation during load level $t$ per "\$/MW h" , and $P_{i-t}^{ss}$ demonstrates the dispatched real power from the $i_{th}$ substation at load level $t$ per "MW".

The constraints of the planning are also denoted in (2)–(6), where, (2) shows the voltage limits, (3) represents the boundaries of the apparent power, and the maximum capacity of the feeders is denoted by (4) and (5) showing the DGs capacity. Constraint (6) is incorporated to keep the radial structure of network following expansion. In this regard, the radial condition should be satisfied for each expansion plan; otherwise, the proposed plan is ignored. It worth nothing that in this paper, it is assumed that ownership of DGs belongs to the utility, not to independent producers. In other words, the network operator aims at minimizing the investment cost of new lines and cost of DGs at the same time and both the DGs and network belongs to the network operator.

## Backward-forward power flow

The power flow in the distribution network comprises two phases as forward swept and backward swept. These two steps are briefly discussed in the following:

**Backward swept:** In this step, the transmitted power through the lines and also the ending bus are indicated, then, the transmitted power through the lines and the voltage of the buses are calculated as (9) and (10), respectively. It should be noted that the losses in the first iteration is not considered.

$$Sbranch_n^k = Snode_i^k + Sload_n + Loss_n^k \tag{9}$$

$$Snode_M^k = \sum_{n\in M} Sbranch_n^k \tag{10}$$

where $Sbranch_n^k$ shows the transferred power through the $n_{th}$ branch at $k_{th}$ iteration, $Snode_i^k$ represents the power injected to the $i_{th}$ bus at $k_{th}$ iteration, $Sload_n$ demonstrates the load demand on the $n_{th}$ branch, and $Loss_n^k$ shows the losses of the $n_{th}$ branch at $k_{th}$ iteration.

**Forward sweep:** In this step, the current in the branches and the first bus are presented, and then the branches currents are calculated as follows:

$$I_n^k = \left(\frac{Sbranch_i^k}{V_i^k}\right)^* \tag{11}$$