



DG integrated multistage distribution system expansion planning

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ABSTRACT

In this paper, a framework is presented to solve the problem of multistage distribution system expansion planning in which installation and/or reinforcement of substations, feeders and distributed generation units are taken into consideration as possible solutions for system capacity expansion. The proposed formulation considers investment, operation, and outage costs of the system. The expansion methodology is based on pseudo-dynamic procedure. A combined genetic algorithm (GA) and optimal power flow (OPF) is developed as an optimization tool to solve the problem. The performance of the proposed approach is assessed and illustrated by numerical studies on a typical distribution system.

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1. Introduction

Expansion planning of the power distribution systems is one of major activities of distribution utilities to deal with electric power demand growth. Distribution system expansion planning consists of defining facilities to be installed and/or reinforced so that the system serves the forecasted demand at the lowest cost while satisfying operational constraints. Additionally, the system must provide acceptable customer outage profile to ensure that customer reliability requirements are satisfied.

Distribution expansion planning is a highly complex problem, where solution often involves the use of sophisticated mathematical modeling and intensive numerical computation. This problem involves a large number of local optimal solutions and when system size become large, the number of solutions grows exponentially.

Traditionally, distribution expansion planning is solved in two ways:

- *Static approach*, which considers only one planning horizon and determines the location, type, and capacity of new equipment that should be expanded and/or added to the system. In other words, full expansion requirements are determined in one planning period [1–5].

- *Multistage approach*, that defines not only optimal location, type and capacity of investment, but also the most appropriate times to carry out such investments, so that the continuing growth of the demand is always assimilated by the system in an optimal way. Multistage approach refers to expansion of the system in successive plans over several stages, representing the natural course of progression in development [6–12].

The multistage approach, due to the interdependency between stages, is far more challenging to formulate and solve but the solution offers a more useful result. In this paper, we analyze the multistage distribution expansion planning (MSDEP) problem.

Today, power system economic and operation environment has changed as new capacity options are expanded. Distributed Generation (DG) is one of these new options. The introduction of DG in power system changes the operating features and has significant technical and economic advantages. Thus, optimal placement and sizing of DG sources attract active research interests and several works have been done in this area [13–15].

Due to the low investment risk and flexibility, DG can be implemented as a possible solution in distribution system expansion planning [16] to provide more diversity of expansion solutions for distribution utilities. Adding DG sources to the planning options is resulting in challenges in the distribution expansion planning process since the traditional planning approach is now no longer appropriate in this new era. Consequently, expansion planning modeling should now consider not only the substations and feeders but also DG sources in expansion planning alternatives. Therefore, new strategies and models for distribution system expansion planning need to be developed to accommodate this challenge.

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Nomenclature

Indices

e	failure events
i	substations
j	feeder sections
k	distributed generation sources
d	load points
t	load levels
nf	number of potential and existing feeder section
ng	number of candidate sites of DG installation
ns	number of candidate and existing substations

Variables

v	value of objective function (\$/year)
ic	investment cost of the system (\$/year)
oc	operation cost of the system (\$/year)
rc	reliability cost of the system (\$/year)
C_{RF}	capital recovery factor
EC_{i-t}^{SS}	electricity market price at the i th substation during load level t (\$/MW h)
IC^{DG}	investment cost of DG sources (\$/MVA)
IC_j^{FD}	investment cost of the j th feeder section (\$)
IC_i^{SS}	fixed cost of the i th substation (\$)
OC_k^{DG}	operation cost of the k th DG source (\$/MVA h)
P_{d-t}^{LD}	real power demand of the d th load point at load level t (MW)
P_{i-t}^{SS}	dispatched real power from the i th substation at load level t (MW)
P_{k-t}^{DG}	generated power by the k th DG at load level t (MW)
S_{k-cap}^{DG}	total capacity of the k th DG source (MVA)

S_{k-t}^{DG}	generated power of the k th DG source (MVA)
S_{RS}^{DG}	reserve DG capacity (MVA)
S_{j-cap}^{FD}	maximum capacity of the i th feeder section (MVA)
S_{j-t}^{FD}	transmitted power in the j th feeder section (MVA) at load level t
S_{i-cap}^{SS}	capacity of the i th substation (MVA)
S_{i-t}^{SS}	dispatched apparent power from the i th substation at load level t (MVA)
T_t	time duration of load level t (h)
$\lambda_{d,e}$	average failure rate affected load point d in case of each failure event e
$f_d(r_{d,e})$	the per unit cost of outage, based on the outage time $r_{d,e}$ at the load point d
$r_{d,e}$	average restoration time affected load point d in case of each failure event e
V_{max}, V_{min}	maximum and minimum allowed operation voltage (V)
V_{d-t}	calculated voltage magnitude at the d th load point during load level t (V)
f_t	fitness function
dr	discount rate
n	life of the project (year)

Sets

S	set of existing and new substations
F	set of existing and upgraded feeder sections
G	set of all selected DG sources
T	set of all load levels
D	set of all demand nodes
E	set of all failure events

Despite the great variety of methods for traditional distribution system planning, there are few studies available in the literature for the problem considering DG sources. The possibility to consider DG as a feasible alternative to traditional distribution system planning is discussed in [17]. In [18], the authors present a network capacity single stage expansion algorithm based on successive elimination capable of deferring network expansion by optimally siting DG sources at new or existing substations. In [19] a distribution system planning method considering DG for peak cutting is proposed which aims to minimize the sum of feeder investments, DG investments, energy loss cost and the additional cost of DG sources. Effects of DG on substations expansion and reliability costs are not considered in this work. In [20], the authors develop a model for static distribution system planning, considering DG sources. Reliability benefits of DG sources and effect of load variation in the system are not considered in this work. In [21], a multistage model for distribution system planning considering DG option is presented. However, impact of DG sources on reliability improvement and also varying nature of load are not considered in the planning model. In some other papers, importance of DG consideration in distribution system planning has been discussed [22–24].

In this paper, a new procedure for MSDEP is proposed in which the DG installation is considered as an option for system expansion planning in addition to upgrade and/or installation of substations and feeder sections. The developed model is based on minimization of overall cost in which reliability is included as customer outage cost (COC). Then, genetic algorithm (GA) combined with optimal power flow (OPF) is implemented to solve the optimization problem in which the optimal installation/upgrade of

substations and feeder sections as well as DG installation requirements is determined. The pseudo-dynamic procedure [8] is used for multistage expansion methodology. Reliability and load variation over the year as well as optimal operation strategy of DG sources over the year is considered in the proposed model. This MSDEP model also determines the optimal size and location of the reserve feeder sections (feeder sections that are not usually operative except for power transfer between circuits during failures in the distribution system in a radial operation state).

The remainder of this paper is structured as follows: Section 2 presents mathematical formulation of the problem. Next, the hybrid GA–OPF methodology for the solution is provided in Section 3. General steps of the proposed multistage expansion planning algorithm are presented in Section 4. Section 5 presents the results obtained with the application of proposed method to a case study based on a typical distribution system. Finally, conclusions are given in Section 6.

2. Mathematical formulation

The objective of MSDEP is to supply the loads over the planning stages while the fixed costs corresponding to the investment in substations, feeder sections and DG sources as well as variable costs associated with operation and reliability of the system are minimized. The decision variables of the MSDEP are:

- Expansion capacity of existing substations.
- Location and capacity of new substations to be installed.
- Upgrade of existing feeder sections.

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