Renewable Energy 66 (2014) 354–363

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Optimal distributed energy resources planning in a competitive electricity market: Multiobjective optimization and probabilistic design

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ARTICLE INFO

Article history:
Received 7 March 2012
Accepted 24 December 2013
Available online 18 January 2014

Keywords:
Distributed energy resources
Cost
Emission
Uncertainty
Multiobjective optimization
MINLP

ABSTRACT

This paper presents a probabilistic multiobjective framework for optimal distributed energy resources (DERs) planning in the distribution electricity networks. The proposed model is from the distribution company (DISCO) viewpoint. The projected formulation is based on nonlinear programming (NLP) computation. The proposed design attempts to achieve a trade-off between minimizing the monetary cost and minimizing the emission of pollutants in presence of the electrical load as well as electricity market prices uncertainties. The monetary cost objective function consists of distributed generation (DG) investment and operation cost, payment toward loss compensation as well as payment for purchased power from the network. A hybrid fuzzy C-mean/Monte-Carlo simulation (FCM/MCS) model is used for scenario based modeling of the electricity prices and a combined roulette-wheel/Monte-Carlo simulation (RW/MCS) model is used for generation of the load scenarios. The proposed planning model considers six different types of DERs including wind turbine, photovoltaic, fuel cell, micro turbine, gas turbine and diesel engine. In order to demonstrate the performance of the proposed methodology, it is applied to a primary distribution network and using a fuzzified decision making approach, the best compromised solution among the Pareto optimal solutions is found.

1. Introduction

Over the last years, utility restructuring and deregulation, technology development, public awareness about environmental aspects, and an expanding electricity markets are providing the motivation for distributed energy resources called distributed generations (DGs) to become an important electric energy option [1,2]. DG sources can secure the future power system with reliable and flexible energy sources [3]. DG strategically utilizes relatively small generating units at or near demand sites to meet a specific objective. The main objectives of DGs placement in distribution networks are peak operating costs reduction, power losses reduction, reliability and stability improvement, grid reinforcement, and system upgrades elimination [4,5].

Up to now, a wide variety of DG technologies have been used in distribution networks. The most popular types of DG are wind turbine, photovoltaic, fuel cell, micro turbine, gas turbine, gas engine, and diesel engine [6,7]. Availability of such flexible DERs at the distribution network level has a significant impact on the DISCO's operation and planning issues. In this regards, different frameworks have been proposed in recent years for DISCO's planning problem with considering DG units.

In recent years, several formulations based on different objective functions have been presented and solved using mathematical, evolutionary and heuristic approaches. The mathematical programming-based methods include linear programming and OPF-based approaches [8,9]. In these analytic techniques only the DG capacities are optimized while their locations in the network considered to be fixed.

Evolutionary-based methods such as genetic algorithms (GA) [10] and tabu search [11] have also been proposed to find the optimal (or local optimal) place and sizes of DGs. In Ref. [1], a GA-based approach for optimal placement of DG for loss minimization in the network was proposed. In Ref. [11], tabu search was applied for optimal DG allocation with an objective of losses minimization. In Ref. [5], a multiobjective DG planning model based on a non-dominant sorting genetic algorithm (NSGA-II) is presented in which the objective functions are the minimization of technical and economic risks and operation and planning costs.

Another approach is the heuristic models. In Refs. [12,13], two heuristic models were proposed for distributed systems planning

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http://dx.doi.org/10.1016/j.renene.2013.12.042

Nomenclature

C_k^{INV}	investment cost of kth DER technology
C_k^{OP}	operating cost of kth DER technology
$\cos\varphi$	the power factor of the system
d	the discount rate
$D_{s,i}$	demand at ith load bus in scenario s
E_m^G	emission factor of type m associated with electricity taken from the grid
$E_{k,m}^{DER}$	emission factor of type m in kth DER technology
f_1, f_2	monetary and environmental objective functions of DISCO, respectively
f_i^{max}, f_i^{min}	maximum and minimum values of the objective function i, respectively
g_i	equidistant grid point number of each objective function
kVA_B	base kVA of the system
i, j	index of buses
k	index of DER technologies
m	index of gaseous emissions
n	index of substations
n_p	number of randomly generated price samples
n_c	number of members at cluster c
n_r	number of clusters (reduced price samples)
NB	total number of buses
NLB	total number of load buses
P_M	the probability of each reduced price scenario
P_{ij}^{MAX}	thermal capacity of feeder connecting bus i to bus j
P_k^{CAP}	capacity limit of kth DER technology
$P_{s,ij}$	power flow in feeder connecting bus i to bus j in scenario s
$P_{s,ij}^{Loss}$	total loss power in feeder connecting bus i to bus j in scenario s
$P_{s,i,k}^{OP}$	DER operating generation of kth DER technology at bus i and in scenario s
$P_{s,n}^{PP}$	purchased power from substation n in scenario s
P_n^{SS}	distribution substation power
P_n^{SS-MAX}	distribution substation capacity limit
s	index of scenario
s_p	slack values
t	index of time
$V_{s,i}$	voltage of bus i in scenario s
Z_{ij}	impedance of the feeder connecting bus i to bus j
ρ_s	electricity market price in scenario s
π_s	probability of each scenario
Φ	payoff table
μ_i^k	membership function of ith objective function in the kth Pareto optimal solution
μ^k	the whole membership function of the kth Pareto optimal solution

List of abbreviations

AEC	augmented ε-constraint
DER	distributed energy resource
DG	distributed generation
DISCO	distribution company
FCM/MCS	fuzzy C-mean/Monte-Carlo simulation
GA	genetic algorithms
NLP	nonlinear programming
NSGA-II	non-dominant sorting genetic algorithm
MINLP	mixed integer non-linear programming
RW/MCS	roulette-wheel/Monte-Carlo simulation

with an objective of minimizing investment costs, operating costs and payments for compensation of losses. In a recent study, an ordinal optimization method for specifying the locations and capacities of DG such that a trade-off between loss minimization and DG capacity maximization is achieved [14]. Moreover, a mixed integer non-linear programming (MINLP)-based heuristic framework was proposed in Ref. [15] for determining optimal location and number of distributed generators.

Public policy, reflecting concerns over global climate change, is providing incentives for capacity additions that offer high efficiency and use of renewable [16]. Electricity generation sector is one of the most important sources of emissions. Reductions in these emissions are possible at relatively low cost when compared with other sectors; and radical reductions in emissions in this sector are essential if overall emission targets are to be achieved. Meeting the long term targets for emission reduction requires that emission free electricity generations are used by the target planning year [17].

With regard to public consciousness about environmental aspects and corresponding limitation, in this paper pollutant emission of fossil fueled DERs and that of purchased power from the grid is considered as an extra objective function of the model. This work will help DISCOs to do an environmental and techno-economic tradeoff analysis for deciding on the most preferred DER planning alternative. By applying the proposed model, in the long term capacity adjustments in the overall generation system DISCO will most likely contributes to emission reduction programs such as decarbonization.

In this paper, a new multiobjective mathematical programming framework is proposed in which two competing objective functions of monetary cost and pollutant emission are minimized in an uncertain environment subject to the constraints on DG operation capacity, substation capacity, power conservation, and distribution feeder.

To the best of the author knowledge, the new contributions of this paper with respect to previous publications in the area can be summarized as follows:

1) A new multiobjective probabilistic framework for DER planning of DISCOs participating in a competitive electricity market.
2) An effective scenario-based approach to model electricity price and load uncertainties.
3) Considering six different types of DERs including wind turbine, photovoltaic, fuel cell, micro turbine, gas turbine, and diesel engine, simultaneously.
4) Application of the modified augmented ε-constraint equipped with a fuzzy decision making approach to decide for the best compromise solution among the obtained Pareto optimal solutions.

The rest of this paper is organized as follows. The scenario-based modeling of price and load uncertainties is presented in Section 2. Formulation of the proposed multiobjective optimization and probabilistic design on distributed energy sources planning model is presented in Section 3. The mathematical formulation of the proposed multiobjective optimization strategy is provided in Section 4. Simulation results on the primary distribution network is reported and discussed in Section 5. This paper is concluded in Section 6.