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Distribution network expansion considering distributed generation and storage units using modified PSO algorithm

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ABSTRACT

Multistage distribution network expansion because of load growth is a complex problem in distribution planning. The problem includes minimizing cost of objective function subject to technical constraints. The objective function consists of investment, operation and reliability costs. In this paper, HV/MV substations, main and reserve MV feeders, dispatchable DG sources and storage units are considered as possible solutions for multistage distribution expansion planning. A three-load level is used for variable load and some strategies are proposed for DG and storage units operation. A modified PSO algorithm is applied to solve the complex optimization problem. Numerical results of the case studies show the ability of the modification. Moreover, the proposed strategies improve the distribution network from both economical and reliability points of view compared with the other methods.

1. Introduction

Optimal expansion of medium-voltage power network because of load growth is a common issue in electrical distribution network planning. The expansion planning approach determines the location, type and capacity of new equipments that should be expanded and/or added to the system. The problem consists of minimizing cost of the objective function subject to technical constraints. Additionally, the optimal system must provide acceptable customer outage profile to ensure that customer reliability requirements are satisfied. The objective function usually includes facilities installation and operation cost and the reliability cost.

Distribution network expansion planning is a complex problem. However, multistage procedure of planning because of dynamic load growth makes the problem more complicated. Multistage planning approach should define not only optimal location, type and capacity of investment, but also the most appropriate times to carry out such investments. Moreover, the intricacy of the problem is increased critically as the system size becomes large.

In recent years, a lot of mathematical models and algorithms have been developed for solving this problem. A comprehensive review of classical models and methods can be found in [1]. However, Dynamic Programming (DP), Branch Exchange (BE), Simulated Annealing (SA), Tabu Search (TS), Genetic Algorithm (GA), Ant Colony System (ACS) and Particle Swarm Optimization (PSO) are the most common modern algorithms which are used recently to solve the distribution network planning problem [2–8], and some hybrid approaches and improvements are proposed, too [9–15].

In conventional distribution expansion planning, HV/MV substations and main and reserve MV feeders installation/upgrade are considered as possible solutions. Today, new capacity options such as Distributed Generation (DG) and storage units are expanded. Due to more flexibility, DG and storage units can be implemented as possible solutions in distribution network planning. Recently several papers have considered either DG or storage units utilization in distribution network planning [16–28].

Importance of DG consideration in distribution network planning is discussed in [16–18]. In [19] analytical approaches are used for optimal placement of DG sources in radial and networked power systems with variable loads to minimize only energy loss. However, analytical approaches are not useful for more complex planning problems. In [20,21], distribution network planning considering DG sources is developed, however, load variation impact and reliability enhancement are not considered in these works. DG peak cutting benefits for distribution network planning is shown in [22] where sum of investment cost and energy loss cost is minimized. In this reference, GA is used for optimal distribution network expansion planning in a single stage. A similar study is performed in [23], meanwhile a linear

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Nomenclature

A_{DG} set of all DG sources
A_{EV} set of all failure events
A_{FD} set of all feeder sections
A_{LD} set of all load points
A_S set of all stages
A_{SS} set of all HV/MV substations
A_{ST} set of all storage units
A_T set of all load levels
c_1, c_2 positive constants as learning factors
C_{FD} fix cost of feeder section installation ($/km)
C_{DG}^{INS} cost function of DG source installation ($)
C_{SS}^{INS} cost function of installing/upgrading HV/MV substation ($)
C_{ST}^{INS} cost function of storage unit installation ($)
C_{ST}^{OM} cost function of operation and maintenance of storage unit ($)
C_{ST}^{REP} cost function of storage replacement ($)
CE_j^{SS} electricity market price at the jth HV/MV substation ($/MW)
CF_s^{INS} installation cost of the system at sth stage ($)
$CF_{s,t}^{OPR}$ operation cost of the system during tth year of the sth stage ($)
$CF_{s,t}^{RLB}$ reliability (outage) cost of the system during tth year of the sth stage ($)
CO cost function of costumer outage ($)
$E_{ST,i}^{CAP}$ capacity of the ith storage unit (MW h)
h_i type of the ith load point
$Infr$ inflation rate
$Intr$ interest rate
L_i length of the ith feeder section (km)
N number of all stages
N_g number of all groups in PSO algorithm
N_{pg} number of particles in each group
N_s^{LD} number of all load points in sth stage
N_s^{MFD} number of all main feeder sections in sth stage
OC_i^{DG} operation cost of the ith DG source including maintenance cost ($/MW)
OF objective function ($)
OF_s intermediate objective function of the sth stage ($)
$P_{i,j}^{DG}$ power generation of the ith DG at the jth load level (MW)
$P_{i,j,s,t}^{DG}$ power generation of the ith DG at the jth load level of the tth year of the sth stage (MW)
$P_{DG,i,l}^{FCAP}$ useful free capacity of the lth DG source for ith load point restoration (MW)
$P_{ST,i,l}^{FCAP}$ useful free capacity of the lth storage unit for ith load point restoration (MW)
$P_{i,s,t}^{LD}(u+k)$ power demand of the ith load point at the $(u+k)$th hour of the tth year of the sth stage (MW)
$P_{m,i}^{RES}$ restored power of the ith load point by facility m (MW)
$P_{DG,i}^{RES}$ restored power of the ith load point by all the DG sources (MW)
$P_{ST,i}^{RES}$ restored power of the ith load point by all the storage units (MW)
$P_{i,j,s,t}^{SS}$ dispatched real power from the ith HV/MV substation at the jth load level in tth year of the sth stage including network losses (MW)
$P_{i,j,s,t}^{ST}$ power generation of the ith storage unit at the jth load level of the tth year of the sth stage (MW)
P_f probability of failure event at uth hour
q real variable that determines the relative importance of the exploitation
r_j outage time of failure event j (h)
rd random function generating random numbers uniformly distributed within the range $[0,1]$
R_{LS} local search rate
$S_{DG,i}^{CAP}$ capacity of the ith DG source (MVA)
$S_{SS,i,s}^{CAP}$ capacity of the ith HV/MV substation at sth stage (MVA)
$S_{ST,i}^{CAP}$ capacity of the ith storage unit (MVA)
$S_{i,j,s,t}^{DG}$ generating power of the ith DG source at jth load level in tth year of the sth stage (MVA)
$S_{i,j,s,t}^{FD}$ power flow of the ith feeder section at jth load level in tth year of the sth stage (MVA)
$P_{j,s,t}^{LOSS}$ total power loss of the distribution network at jth load level in tth year of the sth stage (MW)
$S_{i,j,s,t}^{SS}$ dispatched appearance power from ith HV/MV substation at jth load level in tth year of the sth stage (MVA)
$S_{i,j,s,t}^{ST}$ charge/discharge power of the ith storage unit at jth load level in tth year of the sth stage (MVA)
T duration of the every stage (years)
T_j duration of jth load level (h)
t_{swt} switching time (h)
U standard step function
$V_{i,j,s,t}$ calculated voltage magnitude of ith load point at jth load level in tth year of the sth stage (p.u.)
$V_{\max}$ maximum allowed operation voltage (p.u.)
$V_{\min}$ minimum allowed operation voltage (p.u.)
w inertia weight of PSO algorithm
$x_{i,s}^{DG}$ binary decision variable associated to installation of the ith DG source at sth stage
$x_{i,s}^{MFD}$ binary decision variable associated to installation of the ith main feeder section at sth stage
$x_{i,s}^{RFD}$ binary decision variable associated to installation of the ith reserve feeder section at sth stage
$x_{i,s}^{RST}$ binary decision variable associated to replacement of the ith storage unit at sth stage
$x_{i,s}^{SS}$ binary decision variable associated to installing/upgrading of the ith HV/MV substation at sth stage
$x_{i,s}^{ST}$ binary decision variable associated to installation of the ith storage unit at sth stage
$x_{i,k}^{u,GB}$ kth component of the global best position of the ith group of particles associated to facility u
$x_{i,k}^{u,LB}$ kth component of the local best position of the ith group of particles associated to facility u
$x_{out}(i,j)$ binary variable associated to the ith load point outage due to jth failure event
λ_j average failure rate of jth event

programming is applied in GA to optimize the power of DG sources. However, this linear programming is not applicable to storage units. Moreover, reliability cost is not considered in [22,23]. Some DG integration advantages for distribution network planning are presented in [24], where hybrid optimal power flow (OPF) and GA are used for multistage distribution expansion planning. This multistage planning is suitable for the expansion of HV/MV substations, main and reserve feeders and DG units. The results show that integrating of DG sources in distribution expansion planning can improve voltage deviation, loss cost and reliability of the system. The proposed hybrid OPF/GA algorithm in [24] is appropriate for DG integrated distribution