Renewable and Sustainable Energy Reviews 66 (2016) 415–434

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Assessment of optimization algorithms capability in distribution network planning: Review, comparison and modification techniques

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ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form
4 March 2016
Accepted 13 August 2016

Keywords:
Distribution network planning
Distributed generation
Storage
Optimization algorithms

ABSTRACT

Optimal expansion of medium-voltage power networks because of load growth is a combinatorial problem which is important from technical and economic points of view. The planning solutions consist of installation and/or reinforcement of high voltage/medium voltage (HV/MV) substations, feeder sections, distributed generation (DG) and storage units to expand the capacity of the network. The cost objective function of the system should be minimized subject to the technical constraints. Due to the complicacy and the complexity of the problem, it should be solved by modern optimization algorithms. In this paper, the most famous optimization algorithms for solving the distribution network planning problem are reviewed and compared, and some points are proposed to improve the performance of the algorithms. In order to compare the algorithms in practice, and verify the proposed improvement points, the numerical studies on three test distribution networks are presented. The results show that every algorithm has its own advantages and disadvantages in specific conditions. However, in general manner, the hybrid Tabu search/genetic algorithm (TS/GA) and the improved particle swarm optimization (PSO) algorithm proposed in this paper are the best choices for optimal distribution network planning.

Contents

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http://dx.doi.org/10.1016/j.rser.2016.08.027
1364-0321/

Nomenclature

1) Problem parameters

A_{DG} set of all selected DG sources
A_{EV} set of all failure events
A_{FD} set of all selected feeder sections
A_{LD} set of all load nodes
A_{SFD} set of all feeder sections directly connected to new candidate HV/MV substations
A_{SS} set of all selected HV/MV substations
A_{ST} set of all selected storage units
A_T set of all load levels
$C_{DG,d}^{INS}$ cost of installing the d-th DG source ($)
$C_{ST,k}^{INS}$ installing cost of the k-th storage unit ($)
$C_{ST,k}^{OM}$ fixed operation and maintenance cost of the k-th storage unit ($)
$C_{ST,k}^{REP}$ replacement cost of the k-th storage unit ($)
$C_{FD,i}^{INS}$ fixed cost of installation feeder i ($)
CO cost function of customer outage ($)
$C_{SS,s}^{INS}$ cost function of installing/upgrading the s-th HV/MV substation ($)
$CE_{s,t}^{SS}$ electricity market price at the s-th HV/MV substation during t-th load level ($/MW h)
CF^{INS} installation cost of the system ($)
CF^{OPR} operation cost of the system ($)
CF^{RLB} reliability cost of the system ($)
$E_{ST,k}^{CAP}$ capacity of the k-th storage unit (MW h)
$E_{k,t}^{ST}$ variable energy stored in k-th storage unit during t-th load level (MW h)
$E_{\min,k}^{ST}$ minimum allowed state-of-charge (SOC) of the k-th storage unit (MW h)
$E_{\max}^{ST}$ maximum allowed SOC of the k-th storage unit (MW h)
F objective function ($)
h_l type of the l-th load node
$Infr$ inflation rate
$Intr$ interest rate
N_T life of the project (yr)
$OC_{d,t}^{DG}$ operation cost of the d-th DG source including maintenance cost at t-th load level ($)
$P_{d,t}^{DG}$ power generation of the d-th DG unit at t-th load level (MW)
$P_{l,y}^{LD}(t)$ demanded power of the l-th load node at t-th hour of day in y-th year (MW)
$P_{l,t}^{LD}$ demanded power of the l-th load node in t-th load level (MW)
P_t^{LOSS} total power loss of the distribution network in t-th load level (MW)
$P_{DG,l}^{RES}$ restored power of the l-th load point by selected DG units (MW)
$P_{ST,l}^{RES}$ restored power of the l-th load point by selected storage units (MW)
$P_{s,t}^{SS}$ dispatched real power from the s-th HV/MV substation in t-th load level including network losses (MW)
$P_{k,t}^{ST}$ power of the k-th storage unit at t-th load level (MW)
$P_f(t)$ probability of failure event at t-th hour
r_e repair/replacement time of the equipment failed due to the e-th failure event (h)
$S_{DG,d}^{CAP}$ capacity of the d-th DG source (MVA)
$S_{ST,k}^{CAP}$ power rating of the k-th storage unit (MVA)
$S_{d,t}^{DG}$ operation power of d-th DG unit in t-th load level (MVA)
$S_{k,t}^{ST}$ operation power of k-th storage unit during t-th load level (MVA)
$S_{FD,i,y}^{a}$ power flow of the i-th feeder of size a during y-th year (MVA)
$S_{FD,i}^{CAP,a}$ capacity of the i-th feeder section of size a (MVA)
$S_{s,t}^{SS}$ dispatched apparent power from the s-th HV/MV substation during t-th load level (MVA)
T_t time duration of the t-th load level (h/yr)
$V_{l,t}$ calculated voltage magnitude in l-th load point at t-th load level (p.u.)
$V_{\min}$ minimum allowed operation voltage (p.u.)
$V_{\max}$ maximum allowed operation voltage (p.u.)
$x_o(l, e)$ binary variable associated to the l-th load point outage due to e-th failure event
R standard ramp function
$\lambda_{l,e}$ average failure rate affected the l-th load node in case of the e-th failure event

2) Algorithms parameters

μ number of selected parents in ES algorithm
θ number of generated offsprings in ES algorithm
$iter$ iteration counter
c_1, c_2 positive constants as learning factors
m_{DG} mutation rate for DG units
m_{ST} mutation rate for storage units
m_{FD} mutation rate for MV feeder sections
m_{SS} mutation rate for HV/MV substations
q real variable that determines the relative importance of the exploitation over the exploration in ACS
q^{DG} controller parameter for intensification the DG unit solutions
q^{FD} controller parameter for intensification the MV feeder solutions
q_0^{FD} controller parameter for MV feeder solutions to remove candidate HV/MV substations in IPSO
q^{SS} controller parameter for intensification the HV/MV substation solutions
v_{ij}^k the j-th component of the i-th velocity vector in k-th iteration of PSO
w inertia weight in PSO
x_i^{DG} binary decision variable associated to the installation of DG in i-th node
x_{ij}^k the j-th component of the i-th particle's position in k-th iteration of PSO
$x_{gbest,j}^k$ the j-th component of the global best position vector in k-th iteration of PSO
$x_{pbest,ij}^k$ the j-th component of previous best position vector of the i-th particle in k-th iteration of PSO
x_i^{ST} binary decision variable associated to the installation of storage unit at i-th node
α maximum number of iterations in which the HV/MV substations are removed