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Renewable power generation employed in an integrated dynamic distribution network expansion planning

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ABSTRACT

The recent developments in green energy technologies and the importance of using clean energies have made the renewable resources more attractive for distribution network operators, specifically due to their inexhaustible and non-polluting features. In this way, the present study initiates an integrated dynamic distribution network expansion planning (DDNEP) in which most of the planning alternatives along with renewable and non-renewable distributed generation (DG) are taken into account. The proposed framework considers the important cost terms, including both the investment and operational ones. The uncertainties regarding the intermittent nature of renewable DGs, load demand, and energy price have been well-regarded in calculating the cost components. With the aim of a precise calculation of operation and interruption costs, the load duration curve (LDC) has been established for modeling of the network loads. Moreover, both the possibility of operating the DG units in islanding mode, and, the load transferring through the reserve feeders have been interrogated in the problem in order to improve the network reliability. In the present research, to provide an accurate evaluation of reliability indices, and to cover all of the uncertainty states, the required conditions for the successful and safe operation of island have been suitably studied in the problem. In numerical evaluations, a combination of improved genetic algorithm (IGA) and optimal power flow (OPF) is employed to solve the integrated problem in the 54-bus test system. The obtained results are discussed in details.

1. Introduction

Distribution network expansion planning (DNEP) is one of the main tasks of distribution companies to meet the rapid growth in the load demand [1]. Traditionally, the DNEP is fulfilled either through the reinfrcement of existing lines and substations, or by installation of new ones that leads to minimum expansion cost, subjected to the technical and operational constraints [2–6]. There are two main approaches for solving the DNEP: (a) static and (b) multi-stage planning [7–14]. The static planning simply considers a single planning horizon and decides the type, location, and capacity of network equipment which require to be reinforced and/or installed to meet the load growth in the horizon year. In this way, all of the requirements for the network expansion are determined in one period of the planning horizon. In comparison with the static one, the multi-stage planning not only determines the characteristics of the network equipment, but also, decides the time of reinforcement/installation of the network required equipment. In this case, the planning horizon is divided into several time stages, each with a predicted load demand. The multi-stage planning can be fulfilled using one of the following methods:

- Successive method
  In the successive method, a static planning is conducted for each time stage to meet the peak load demand of that stage regarding to the network's layout of the previous stage [9]. Since the optimal solution of each stage depends on the result of the previous stages, the successive method commonly leads to local minima [7].
- Pseudo-dynamic method
  In the pseudo-dynamic method, the DNEP is divided into two phases [8]. In the first phase, by the use of the static planning method, a system is designed to optimally supply the load demand in the horizon year. After that, the non-selected equipment are removed from the set of candidate ones. In the second phase, the load growth is considered at each time stage using the successive method. It has been demonstrated that the pseudo-dynamic method acquires better results compared to other non-dynamic planning methods [10].

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Nomenclature

Indices

dg	index for DG units
tr	index for the transformers of HV/MV substations
k	index for MV feeders
es	index for existing HV/MV substations
cs	index for candidate HV/MV substations
ef	index for existing MV feeders
cf	index for candidate MV feeders
s	index for uncertainty states
LL	index for load levels
i,j	index for buses
t	index for years

Constants

n_{dg}	number of DG units
n_{tr}	number of HV/MV transformers
n_{es}	number of existing HV/MV substations
n_{cs}	number of candidate HV/MV substations
n_{ef}	number of existing MVfeeders
n_{cf}	number of candidate MV feeders
ns	number of uncertainty states
n_{LL}	number of load levels during a year
λ_k	failure rate of feeder k (fail/km/year)
λ_{dg}	failure rate of DG unit dg (fail/year)
λ_{tr}	failure rate of transformer tr (fail/year)
r_{k}	repair time of feeder k (h)
r_{dg}	repair time of DG dg (h)
r_{tr}	repair time of transformer tr (h)
T	horizon year of planning
T_{LL}	time duration of load level LL (h)
Infr	inflation rate (%)
Intr	INTEREST rate (%)
$V_{\mathrm{safe}}^{\mathrm{min}}$	minimum safe value of bus voltage (p.u.)
$V_{\mathrm{crit}}^{\mathrm{min}}$	minimum critical value of bus voltage (p.u.)
$V_{\mathrm{safe}}^{\mathrm{max}}$	Maximum safe value of bus voltage (p.u.)
$V_{\mathrm{crit}}^{\mathrm{max}}$	maximum critical value of bus voltage (p.u.)
L_{ij}	length of feeder between buses i and j (km)
$\mathrm{LC}_{\mathrm{LL}}$	loss cost in load level LL (\$/kWh)
$\mathrm{RC}_{\mathrm{LL}}$	reliability cost of unsupplied energy in load level LL (\$/kWh)
$\mathrm{oc}_{\mathrm{LL.s}}$	operation cost of DG in load level LL and sate s (\$/kWh)
emc	cost of emission (\$/ton)
dc	cost of dissatisfaction of constraints (\$)
$S^L_{i,t,LL,s}$	apparent load demand of bus i in year t, load level LL, and state s (kVA)
$S^L_{\mathrm{peak},i,t}$	apparent load demand of bus i in year t, in peak condition (kVA)
$\mathrm{LLF}_{\mathrm{i,t,LL,s}}$	load level factor of bus i in year t, load level LL, and state s
$\mathrm{EP}_{\mathrm{i,LL}}$	price of energy purchased from the transmission network through ith HV/MV substation in load level LL (\$/kWh)
$\mathrm{EP}_{\mathrm{peak.i}}$	price of energy purchased from the transmission network through ith HV/MV substation in peak condition of year (\$/kWh)
$\mathrm{PLF}_{\mathrm{i,LL,s}}$	price level factor of energy purchased from the transmission network through ith HV/MV substation in load level LL, and state s
$P^L_{\mathrm{peak},i,t}$	active load demand of bus i in year t, in peak condition (kW)

Functions

$IC_i\left(S_i^{\mathrm{inst}}\right)$	installation cost of ith HV/MV substation with capacity of S (\$)
$\mathrm{sec}_i\left(S_i^{\mathrm{exp}}\right)$	expansion cost of ith existing HV/MV substation with capacity of S (\$)
$FC_{ij}(k)$	installation cost of feeder with the type of k between buses i,j (\$/km)
$MFC_{ij}(k)$	installation cost of new main feeder with the type of k between buses i,j (\$/km)
$RFC_{ij}(k)$	installation cost of new reserve feeder with the type of k between buses i,j (\$/km)
$DGIC_i\left(S_i^{DG}\right)$	installation cost of DG unit with the capacity of S^{DG} in bus i (\$)

Variables

$\mu^V_{i,t,LL,S}$	voltage constraint satisfaction rate for bus i, in year t, load level LL, and state s
μ^V_i	voltage constraint satisfaction rate for bus i
μ^V	voltage constraint satisfaction rate for the whole network
μ^I	current constraint satisfaction rate for the whole network
μ^S	satisfaction rate of substation capacity constraint for the whole network
$\delta_{i,t,LL,s}$	voltage angle of bus i, in year t, load level LL, and state s (rad)
$Y_{ij,t}$	magnitude of admittance between buses i and j in year t (p.u.)
$\theta_{ij,t}$	angle of admittance between buses i and j in year t (rad)
$P^{\mathrm{net}}_{i,t,LL,s}$	net active power of bus i in year t, load level LL, and state s (kW)
$P^L_{i,t,LL,s}$	active load demand of bus i in year t, load level LL, and state s (kW)
$P^{DG}_{i,t,LL,s}$	active power generated by the DG of bus i in year t, load level LL, and state s (kW)
$P^{\mathrm{Trans}}_{i,t,LL,s}$	power imported from the transmission grid to distribution system through ith HV/MV substation in year t, load level LL, and state s (kW)
$P^{DG}_{i,t}$	active power of DG installed on bus i in year t (kW)
$Q^{\mathrm{net}}_{i,t,LL,s}$	net reactive power of bus i in year t, load level LL, and state s (kVAr)
$Q^L_{i,t,LL,s}$	reactive load demand of bus i in year t, load level LL, and state s (kVAr)
$Q^{DG}_{i,t,LL,s}$	reactive power generated by the DG installed on bus i, in year t, load level LL, and state s (kVAr)
$S^{DG}_{i,t,LL,s}$	apparent power generation of DG installed on bus i, in year t, load level LL, and state s (kVA)
$S^{DG}_{i,t,\mathrm{max}}$	capacity of DG installed on bus i in year t (kVA)
$V_{i,t,LL,s}$	voltage magnitude of bus i, in year t, load level LL, and state s (p.u.)
$Loss_{i,t,LL,s}$	power loss of feeder i in year t, load level LL, and state s (kW)
$LNS_{f,t,LL,s}$	load not supplied in year t, load level LL, and state s due to outage of feeder f (kW)
$LNS_{dg,t,LL,s}$	load not supplied in year t, load level LL, and state s due to outage of DG unit dg (kW)
$LNS_{tr,t,LL,s}$	load not supplied in year t, load level LL, and state s due to outage of transformer tr (kW)
$P^{\mathrm{Grid}}_{t,LL,s}$	the power received from the transmission grid in year t, load level LL, and state s