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Two-layer optimization methodology for wind distributed generation planning considering plug-in electric vehicles uncertainty: A flexible active-reactive power approach

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ABSTRACT

With increasing the penetration of wind power, the voltage regulation becomes a more important problem in active distribution networks. In addition, as an uncertain load Plug-in Electric Vehicles (PEVs) will introduce a new concern in voltage adjustment of future distribution networks. Hence, this paper presents a flexible active-reactive power based Wind Distributed Generation (WDG) planning procedure to address the mentioned challenges. The uncertainties related to WDGs, load demand as well as PEVs load have been handled using the Point Estimate Method (PEM). The distribution network under study is equipped to on-load tap-changer and, as a conventional voltage control component, the Capacitor Banks (CBs) will be planned simultaneously with WDGs. The planning procedure has been considered as a two-loop optimization problem that is solved using Particle Swarm Optimization (PSO) and Tabu Search (TS) algorithms. The tap position and power factor of WDGs are taken into account as stochastic variables with practical limitations. The proposed methodology is applied to a typical distribution network and several scenarios are considered and analyzed. Simulation results show that the standard deviation of power factor depends on PEVs penetration that highlights the capability curve of WDGs. The optimal penetration of wind power increases nonlinearly versus increasing of PEVs connected to the distribution network, however the fixed CBs are required to increase the optimal penetration of WDGs. The proposed Modified PSO (MPSO) is compared with the conventional PSO in numerical studies that show MPSO is more efficient than the conventional algorithm for this analysis.

1. Introduction

Due to the environmental and economic benefits, the renewable-based Distributed Generation (DG) sources have become more popular in today's distribution network. Loss reduction, flattering of peak, increasing reliability, modifying voltage profile are the strong motivation for increasing the penetration of DGs in distribution networks [1,2]. Among all renewable energy generation technologies, Wind-based Distributed Generation (WDG) units have emerged very rapidly in recent years. Reduction of investment costs, reliability improvement, and efficiency enhancement of WDGs have made them able to compete with the conventional power generation [3,4]. However, to release the maximum benefit from WDG there is a need for optimal planning, i.e. sizing and siting, as well as optimal operation [5,6]. The output power of WDGs is affected by natural intermittency and variably of the wind resource, so the related uncertainty should be considered in optimal planning and operation procedures [7,8].

In the literature some methods have been proposed to model the uncertainties in WDGs planning. Optimal combination of different renewable resources is proposed by Atwa et al. [9]. The uncertainty of load demand and renewable generation are often modeled with Probability Distribution Functions (PDF). In [10], Soroudi proposes a hybrid possibility–probabilistic method for technical assessment of DG impact on distribution network performance. In this work, the uncertainty related to load demand, DG operation and investments are taken into account, while the objective function considers active power losses and technical risk including the possibility of under/over voltage in load nodes. In [11], Soroudi et al. propose a possibilistic method to handle the uncertainties of load demands and energy prices considering different objective functions like cost and technical and economic risks. A stochastic dynamic model for integration of DGs in

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Nomenclature

Parameters and variables

C_{DG}^{INS}	installation cost related to the capacity of WDG ($)
C_{CAP}^{INS}	installation cost related to the capacity of capacitor banks ($)
C_c^{CAP}	capacity of the *c*-th capacitor bank (kVAR)
$C_{DG,j}^{OM}$	operation and maintenance cost of WDG units in *j*-th season ($)
$C_{s,j}^{SS}(t)$	operation cost of the *s*-th HV/MV substation at time *t* of *j*-th season ($)
$C_{p,j}^{pr}(t)$	active power price at time *t* of *j*-th season ($)
$C_{q,j}^{pr}(t)$	reactive power price at time *t* of *j*-th season ($)
c_1, c_2	constant controller parameters of PSO
CR_{ij}	the normalized index for *i*-th particle in *j*-th node
E_k^{DG}	capacity of the *k*-th WDG unit (kVA)
$\mathrm{E}(\cdot)$	the expected value
F	cost objective function ($)
$h(.)$	nonlinear function of deterministic load flow
IC	total investment cost ($)
$Infr$	inflation rate
$Intr$	interest rate
I_n^{scwd}	maximum allowed rotor current (p.u.)
M	a fixed large number
n_{DG}	number of all WDG units
n_{CB}	number of all capacitor banks
n_{SS}	number of all HV/MV substations
n_{EQ}	number of all the equipment
n_N	number of all nodes in distribution network
n_{LD}	number of all load nodes
OC	total operation cost ($)
OC_j	total operation cost in *j*-th season ($)
PF	penalty factor ($)
$P_{p,j}^{SS}(t)$	absorbed/injected active power in *s*-th HV/MV substation at time *t* of *j*-th season (kW)
$P_{l,t}^{PEV}$	PEVs load demand in *l*-th load node at time *t* (kW)
$p_{j,t}^u$	probability of capacity constraint violation in device *u* at time *t* of *j*-th season
$p_{j,t}^n$	probability of voltage constraint violation in *n*-th node at time *t* of *j*-th season
$P_{n,st}^{wd}$	active power injection of Doubly Fed Induction Generator (DFIG) (p.u.)
q	a constant controller parameter in MPSO to increase intensification
$Q_{s,j}^{SS}(t)$	absorbed/injected reactive power in *s*-th HV/MV substation at time *t* of *j*-th season (kVAR)
Q_c^{CAP}	injected reactive power of *c*-th capacitor bank to the grid (kVAR)
$Q_{n,st}^{wd21}$	maximum allowed reactive power absorption (p.u.)
$Q_{n,st}^{wdlu}$	maximum allowed reactive power injection (p.u.)
rand	a random number within (0,1)
R_n^m	equivalent main resistance of a DFIG (p.u.)
R_n^s	stator resistance of a DFIG (p.u.)
S_t^u	power of equipment *u* at time *t* (kVA)
$S_{\max}^u$	allowed maximum power of equipment *u* (kVA)
$S_{s,t}^{SS}$	power of *s*-th HV/MV substation at time *t* (kVA)
$S_{k,t}^{DG}$	generated power of *k*-th DG unit at time *t* (kVA)
$S_{l,t}^{LD}$	demand of the *l*-th load node at time *t* (kVA)
S_t^{LOSS}	total power loss in distribution network at time *t* (kVA)
$S_{n,st}$	slip associated with steady state operation of DFIG
T	period of the project (years)
T_j	duration of the *j*-th season in one year (days)
U	standard step function
$V_{j,t}$	voltage magnitude in *j*-th node at time *t* (p.u.)
$V_{\min}$	allowed minimum voltage magnitude (p.u.)
$V_{\max}$	allowed maximum voltage magnitude (p.u.)
$V_{n,st}$	voltage magnitude at node *n* over a system state *st* (p.u.)
v_{ij}^k	the *j*-th component of velocity of the *i*-th particle in *k*-th iteration of PSO
$v_{\min}$	minimum allowed velocity
$\overline{V}_{ij}$	average voltage level in *j*-th node considering the *i*-th solution
x_j^{CB}	total capacity of the installed CBs in *j*-th node (kVAR)
x_j^{DG}	total capacity of the installed WDG units in *j*-th node (kVA)
X_n^s	stator reactance of a DFIG (p.u.)
X_n^m	equivalent main reactance of a DFIG (p.u.)
x_{ij}^k	the *j*-th component of position of the *i*-th particle in *k*-th iteration of PSO
$x_{pb,ij}^k$	the *j*-th component of the previous best position of the *i*-th particle in *k*-th iteration of PSO
$x_{gb,j}^k$	the *j*-th component of position of the global best particle in *k*-th iteration of PSO
w	inertia weight of PSO
Z_n^m	equivalent main impedance of a DFIG (p.u.)
Z_n^s	stator impedance of a DFIG (p.u.)
$\gamma_{n,st}$	power factor angle
φ_c	critical power factor angle for free reactive power in electricity market (°)
$\varphi_{s,j}^{SS}(t)$	power factor angle in *s*-th HV/MV substation at time *t* of *j*-th season (°)
σ_{ij}^H	normalized hourly variance of voltage magnitude in *j*-th node considering the *i*-th solution
σ_{ij}^D	normalized daily variance of voltage magnitude in *j*-th node considering the *i*-th solution
ε	small constant controller parameter in MPSO

Abbreviations

CBs	Capacitor Banks
DFIG	Double Fed Induction Generator
DG	Distributed Generation
HV/MV	High Voltage/Medium Voltage
MCS	Monte Carlo Simulation
MINLP	Mixed Integer Nonlinear Programing
MPSO	modified particle swarm optimization
NHTS	National Household Travel Survey
O&M	operation and maintenance
PAROPF	Probabilistic Active/Reactive Optimal Power Flow
PDF	Probability Distributed Function
PEM	Point Estimate Method
PEVs	Plug-in Electric Vehicles
PLF	Probabilistic Load Flow
PSO	Particle Swarm Optimization
TS	Tabu search
WDGs	Wind Distributed Generations

distribution networks is presented in [12]. The proposed multi-objective model optimizes three objectives including technical constraint dissatisfaction, costs and environmental emissions. A scenario-based uncertainty modeling is applied to load demands, electricity price and wind power generators.

In addition to the uncertainty modeling, if the WDGs are planned without considering optimal operation, the WDGs ability on improving branch power flow and node voltage may be reduced. This concern is highlighted with high penetration of WDGs. Therefore, they should be planned under active operation