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Multi-objective probabilistic reactive power and voltage control with wind site correlations

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ABSTRACT

This paper proposes a multi-objective probabilistic reactive power and voltage control in distribution networks using wind turbines, hydro turbines, fuel cells, static compensators and load tap changing transforms. The objective functions are total electrical energy costs, the electrical energy losses, total emissions produced, and voltage deviations during the next day. Since the wind sources and load demand have intermittent characteristics, a probabilistic load flow based on $2m + 1$ point estimated method is used to investigate the objective functions. The correlation in wind speed is considered as the distances between WTs are not large in distribution systems. Furthermore, a multi-objective modified bee swarm optimization is proposed to solve the optimization problem by defining a set of non-dominated points as the solutions. A fuzzy based clustering is used to control the size of the repository and a niching method is utilized to choose the best solution during the optimization process. Performance of the proposed algorithm is tested on a 69-bus distribution feeder. The results confirm the necessity of modeling the reactive power and voltage control problem in a stochastic framework. Also, the effects of wind site correlations on different objective functions are discussed completely.

1. Introduction

Reactive power and voltage control is one of the most important problems in power system from management or planning point of view [1]. It is usually addressed by minimizing the predefined objective functions while regulating the voltage over feeders and controlling reactive power (or power factor) at substations using transformer LTC (Load Tap Changers) and fixed and switched capacitor banks [2]. Besides, competition in open access market and public environmental concerns encourages the use of RESs (renewable energy sources) [3]. Integration of RESs in distribution systems posed many issues for the SOs due to their intermittent nature, reverse of power flow, small X/R ratio of distribution lines, and radial structure of networks [4,5]. These issues have increased with high proliferation of RESs.

Many researchers have investigated the RPVC (reactive power and voltage control) problem in the distribution networks. Baron et al. suggested a supervisory RPVC scheme based on the measurements, which were available at the substation [6]. Roytelman et al. proposed a centralized Volt/Var algorithm for the distribution system management [7]. Niknam et al. suggested a cost-based compensation methodology for the daily RPVC in the presence of DG (Distributed Generation) units [8]. A combined heuristic and algorithmic approach for reactive power optimization with different load level in distribution systems was presented in Ref. [9]. Viawan and Karlsson investigated the impact of DG units on the voltage and reactive power control scheme. They also proposed a proper coordination method among DG units and other traditional voltage and reactive power control apparatus [10].

In above researches [6–10], the uncertainties imposed on distribution system are not considered. The uncertain variables in distribution networks are loads at consumer's terminal and wind speed for WTs. Liang et al. suggested a fuzzy optimization approach to solve the Volt/Var control problem in distribution systems [11]. In their proposed method, the errors in the forecast load demand and wind speed modeled by means of fuzzy sets. They used a max–min operator to solve the multi-objective problem. Hong and Luo proposed a method to regulate the voltage profile of the operation planning in the distribution networks [2]. They used a cumulant method to calculate the bus voltage fluctuation by using genetic algorithm. Also, several other articles have been investigated the uncertainty related to the DG units in distribution networks. El-Khattam et al. proposed a new algorithm in order to evaluate the distribution network performance with DG units considering the

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Nomenclature

Symbols

$c_{\text{bmax(min)}}$	maximum (minimum) values of the cognitive weight factors.
$c_{\text{gmax(min)}}$	minimum (maximum) values of the social weight factors.
$C^t_{\text{u(o)}}$	over (under) estimated cost coefficients
$\text{DOT}^{\text{cap,max}}_{i_{\text{cap}}}$	maximum allowable number of switching of the ith capacitor.
$\text{DOT}^{\text{trn}}_{i_{\text{trn}}}$	number of switching of the ith transformer taps.
$\text{DOT}^{\text{trn,max}}_{i_{\text{trn}}}$	maximum allowable number of changing of the ith transformer tap.
$E(C^t)$	expected value for the electric energy supply costs by RES and distribution companies ($).
$E(L^t)$	expected value for the network losses (kWh).
$E(E^t)$	expected value for the total emission of RES and grids (kg).
$E(V^t_{\text{d}})$	expected value for the voltage deviation from nominal (p.u).
$E^t_{i_{\text{RES}}}$	emission rate of RES i (kg/kWh).
$E^t_{i_{\text{grid}}}$	emission coefficient of energy supplied at the ith grid (kg/kWh).
$\tilde{j}$	probabilistic Jacobian matrix
h^t	duration of time interval t (h).
$I^t_{i_{\text{br}}}$	current of branch i (A).
$\text{Iter}(\text{iter}_{\text{max}})$	current (maximum) iteration.
m	number of input random variables.
M^{iter}	vector of mean for all control variables.
max(min)_var	upper and lower limits of each control variable.
n	number of the decision variables.
$N_{\text{efb(ob,sb)}}$	number of experienced forager (onlooker, scout) bees.
N_{obj}	number of objective functions
N_{rep}	number of non-dominated solutions in repository
N_{RES}	number of RES ($N_{\text{WT}} + N_{\text{FC}} + N_{\text{HY}}$).
N_{ORV}	number of output random variables.
$N\mu$	normalized membership value
$P(P')$	vector of input correlated(uncorrelated)variables.
P_{RES}	vector of RES active power output.
P_{FC}	vector of FC active power output.
$P_{i\text{FC}}$	vector of active power output for FC i.
$P^t_{i_{\text{FC}}}$	active power output for FC i.
P_{HY}	vector of HY active power output.
$P_{i\text{HY}}$	vector of active power output for HY i.
$P^t_{i_{\text{HY}}}$	active power output for HY i.
$\left\|P^{\text{br}}_{ij}\right\|^t$	active power flow of line from bus i to bus j (kW).
$P^t_{i_{\text{grid}}}$	active power withdrawal from the ith grid (kW).
$P^t_{i_{\text{RES}}}$	active power output of RES i (kW).
$P^t_{\text{min(max)},\, i_{\text{RES}}}$	minimum (maximum) power output of the ith RES.
$P^{\text{br,max}}_{ij}$	active power limit of line between bus i and j (kW).
$\text{Pf}^{\text{min (max)}}_{i_{\text{grid}}}$	minimum (maximum) power factor of the ith grid.
$\text{Pf}^t_{i_{\text{grid}}}$	power factor of grid i.
$\text{Pf}^{\text{min(max)}}_{i_{\text{RES}}}$	minimum (maximum) power factor of the ith RES.
$\text{Pf}^t_{i_{\text{RES}}}$	power factor of RES i.
p_l	input random variable l ($l = 1, 2, \ldots, m$).
$\text{Price}^t_{i_{\text{grid}}}$	electrical energy price supplied by grid i ($/kWh).
$\text{Price}^t_{i_{\text{RES}}}$	electric energy price supplied by RES i ($/kWh).
rand, r, r_{b}, r_{g}	random number between 0 and 1.
$R_{i_{\text{br}}}$	resistance of branch i (Ω).
R_factor	constant value between 0 and 1.
s	constant value in the range [0, 10].
T	number of time intervals.
$\text{Tap}_{i_{\text{trn}}}$	tap positions vector of transformer i.
$\text{Tap}^{\text{min(max)}}_{i_{\text{trn}}}$	minimum (maximum) tap position of the ith transformer.
$\text{Tap}^t_{i_{\text{trn}}}$	tap position of transformer i.
Tap_{trn}	transformer tap position matrix.
TF	random number equals 1 or 2.
U_{cap}	capacitor statuses (on/off) matrix.
U_{icap}	status vector of capacitor i.
$U^t_{i_{\text{cap}}}$	status (on/off) of capacitor i.
$V_{i,\text{min(max)}}$	minimum (maximum) voltage magnitude of the ith bus (V).
V^N_i	nominal voltage of bus i (V).
V^t_i	voltage magnitude of bus i (V).
X	vector of control variables.
$y_{\text{min(max)}}$	minimum (maximum) values of the sinusoidal function.
Z	vector of output variables.
z_i	output random variable i.
$\xi_{l,k}$	standard location.
$\mu_{p_l}(\sigma_{p_l})$	mean (standard deviation) of the input variable p_l
$\lambda_{p_l,3}$	third standard central moments of p_l (skewness)
X	vector of control variables.
$y_{\text{min(max)}}$	minimum (maximum) values of the sinusoidal function.
$\lambda_{p_l,4}$	fourth standard central moments of p_l (kurtosis)

Subscripts

br	branch.
cap	capacitor.
FC	fuel-cell.
grid	grid.
HY	hydro turbine.
RES	renewable energy source.
trn	transformer.
WT	wind turbine.
ξ,β,χ	experienced forager, onlooker, and scout bees.
Ψ	mutated vector.

Subscripts

t	tth time interval (corresponding to tth load level).

Abbreviation

BSO	bee swarm optimization
EA	evolutionary algorithm
EFB	experienced forager bee
FC	fuel cell
HY	hydro turbine
MBSO	modified bee swarm optimization
MPRPVC	muliobjective probabilistic RPVC
MRPVC	muliobjective RPVC
OB	onlooker bee
PDF	probability distribution function
PEM	point estimated method
PLF	probabilistic load flow