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An interval optimization based day-ahead scheduling scheme for renewable energy management in smart distribution systems

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ABSTRACT

The integration of renewable energy generation into distribution systems has a significant influence on network power losses, nodal voltage profile and security level due to the variability and uncertainty of renewable energy generation. This paper proposes a novel interval optimization based day-ahead scheduling model considering renewable energy generation uncertainties for distribution management systems. In this approach, the forecasting errors of wind speed, solar radiation intensity and loads are formulated as interval numbers so as to avoid any need for accurate probability distribution. In this model, the total nodal voltage deviation and network power losses are optimized for the economic operation of distribution systems with improved power quality. Consequently, the order relation of interval numbers is used to transform the proposed interval optimal scheduling model into a deterministic optimization problem which can then be solved using the harmony search algorithm. Simulation results on 33-node and 119-node systems with renewable energy generation showed that considerable improvements on system nodal voltage profile and power losses can be achieved with multiple interval sources of uncertain renewable energy generation and loads.

1. Introduction

Day Ahead Scheduling (DAS) scheme is an essential function required for the optimum energy management of distribution systems to improve various alternative energy utilizations [1]. With the exhaustion of fossil fuel and the increasing environmental crisis, renewable energy generation (REG), such as wind and photovoltaic generation, have been extensively developed due to its sustainable, eco-friendly properties and relatively high efficiency. The proper integration of wind and photovoltaic power into distribution systems is beneficial to the reduction of network power losses and enhance power quality. Kai et al. [2] have proposed a distribution system expansion planning strategy, highlighting the reduction in total cost with the consideration of DG. In [3], optimum placements of DGs were investigated to prove that DG can be placed to improve the reliability. Nevertheless, renewable energy based Distributed Generators (DGs) always accompany with uncertainty due to their natural fluctuations [4]. Therefore, the uncertainty modeling is the most consequential challenge for system operators and managers for distribution management systems (DMS) with REG.

Generally, DAS is a 24-h scheduling program to achieve the secure and economic operation of distribution systems. Currently, numerous investigations have already been done in taking uncertainty in distribution network DAS into consideration. A scheduling model for power systems with significant REGs based on scenario generation/reduction method was proposed in [5]. In [6], the uncertainty related to hourly load, wind power, and solar irradiance forecasts were modeled in a scenario-based stochastic framework for daily Volt/Var control. In [7], a stochastic framework, which consists of two hierarchical stages, was presented for a distribution company to optimize their short-term operational decisions so that the expected operating cost is minimized at a restricted risk level. The accuracy of scenario method mainly depends on the number of scenarios, but it is not easy to determine the optimal scenarios. Demailly et al. adopted the Monte Carlo simulation method in [8] to consider the uncertainties in DGs output. Nevertheless, it is well known that Monte Carlo simulation method suffers from low computation efficiency. An alternative to avoid dealing with uncertainty is the fuzzy method. Liang et al. [9] proposed a fuzzy optimization based day-ahead scheduling method that considers wind speed and prediction errors of load. Also, a hybrid possibilistic–probabilistic approach was presented in [10] to assess the impact of DGs on distribution network performance, and a fuzzy method is proposed for describing the DG investment and operation schedule. In the fuzzy optimization based approach,

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Nomenclature

Symbols

a, c	interval variable
I	interval
L	lower bounds of the range
R	upper bounds of the range
ω	radius of interval number
ρ	midpoint of interval number
λ	constant number
x	decision variable
n	total number of x
q	dimensional number of x
y_m	m-th inequality constraint equation
h_z	z-th equality constraint equation
v_m^I	m-th inequality constraints
c_z^I	allowed range of$z$-th equality constraints
M	total number of inequality constraint equations
l	total number of equality constraint equations
$\leqslant_{\rho w}$	order relation
η	weighting factor
U	voltage (V)
P	active power (kW)
Q	reactive power (kVar)
T	number of time sections
P_G	active power output of distributed generation (kW)
Q_G	reactive power output of distributed generation (kVar)
α, β	coefficients
N	number of nodes
S	apparent power
ΔU^I	interval value of voltage magnitude deviation
P_{loss}^I	interval value of network power losses
n_b	number of branches
$f_{ts,t}^I$	optimal values of hourly interval objective function
F^I	final interval objective function
g_k	network structure after reconfiguration
G_{RNS}	set of all feasible radial network structure
N_k	number of state changes per day of the k-th switch
Q_{ck}	k-th reactive power compensation device output
N_{k0}	maximum number of switchings
k_{ci}	tap position
n_k	number of daily switching
n_{max}	maximum allowable number of switchings per day
HM	harmony memory
SD	solution dimensions
HMS	harmony memory size
$HMCR$	harmony memory considering rate
PAR	pitch adjusting rate
bw	distance bandwidth
NI	termination criterion
SL	solution
C	node set
θ	angle
r	resistance of branch
X	reactance of the branch
G	conductance
B	susceptance
ε	convergence threshold
s	basic-loop state
SS_i	open sectionalizing switch in the i-th basic-loop
NG	number of the corresponding DG
J_{pen}	penalty term

Subscripts

t	time section
H	number of reactive power compensation device
b	branch
NG	number of DG
max	maximum
min	minimum
$Gmax$	maximum of DG power output
$Gmin$	minimum of DG power output
d	dimension

Acronyms

REG	renewable energy generation
DGs	Distributed Generators
DMS	distribution management systems
DAS	Day Ahead Scheduling
VPP	virtual power plant
PEM	point estimate method
NINP	nonlinear interval number programming

the fuzzy membership function, instead of probability distribution, is required. Mistry et al. considered overestimation and underestimation cost due to the uncertainty of wind power in the DAS of smart distribution grid [11]. In [12], Peik-herfech et al. proposed a comprehensive framework to optimally manage a cluster of distributed energy resources in the distribution network through the virtual power plant (VPP) concept; a probabilistic price based unit commitment using point estimate method (PEM) was proposed for VPP optimal bidding. The methods mentioned above require probabilistic or possibilistic information of REGs. However, due to the effects of climate change, wind and photovoltaic power exhibit great uncertainty in some cases and it is difficult to accurately obtain probabilistic and fuzzy parameters.

Interval optimization is one of the effective methods in handling uncertain problems. In interval optimization, only the interval of uncertain parameters is needed, rather than probabilistic or fuzzy parameters [13]. Currently, the interval optimization method has received wide application in power systems. An interval power flow calculation method was presented in [14], and its advantages were shown by comparison with other stochastic power flow methods. The investigations in [15] presented an interval optimization method to solve uncertain problems of power market quantification models under deregulation conditions, avoiding the drawback of the traditional method which is too conservative. In [16], comparison with scenario based stochastic optimization approach shows that interval optimization has the advantages of high computing speed and simple calculation when considering wind generation uncertainty in power system unit commitment. However, the application of interval optimization in distribution systems is limited and needs to be further investigated.

In this paper, an interval optimization based approach is proposed for day-ahead distribution systems operation in which forecasting errors in wind speed, photovoltaic and load are formulated as interval numbers. Therefore, no probabilistic and fuzzy parameters are required, and the transformed problem can be solved by a hybrid harmony search and interval power flow method.

2. Interval optimization model

While wind speed and solar radiation intensity have strong uncertainty, load also has a strong uncertainty in some cases. With