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A novel stochastic framework based on fuzzy cloud theory for modeling uncertainty in the micro-grids

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ABSTRACT

This article proposes a novel stochastic framework based on cloud theory to handle the uncertainty effects in the optimal operation of microgrids. In respect of the Monte Carlo simulation (MCS) method, cloud theory can contain more uncertainty of the problem using the cloud drops. The main concept is to include the fuzziness and randomness of qualitative parameters and then change them to the quantitative form. Due to the high difficulty and nonlinearity of the problem, a new optimization algorithm based on krill herd (KH) is devised to search the problem space globally. Also a new modification method based on Levy flight is proposed to increase the local search ability of the algorithm. In order to see the high performance and ability of the proposed method, a typical grid connected microgrid with several dispatchable and non-dispatchable units are considered as the case study.

Introduction

The increasing popularity of renewable energy sources has resulted in high research to find its potential advantage and disadvantages. Regarding the advantages, decreasing power losses, enhancing the voltage profile of the buses, increasing the electricity services and higher reliability can be named [1–3]. Along with these benefits, there are some disadvantages such as increasing the intricacy of power grid, changing the efficiency of the available strategies and additional costs for supporting the infrastructure requirements and protection issues can be named [4–6]. Nonetheless, the current expansion in the wide usage of renewable energy sources (RESs) reveals their high success to replace the traditional fossil-fuel based sources as clean and practical alternative energy source [7,8]. In this regard, microgrid is a new concept to address some challenges of using RESs in the new systems. By definition, microgrid is an aggregation of distributed generations (DGs), electrical loads and generation interconnected among them and with the distribution network [9]. The idea of microgrid has attracted the attention of many researchers in recent years.

In [10], a smart microgrid is constructed in the laboratory for showing the efficiency of their intelligent technique for optimally operating the microgrid in the scheduling time which is one week. In [11], a mixed-integer linear programming solution is suggested to decide the optimal power dispatch of DGs in a microgrid incorporating RESs. In [12], a multi-agent system is designed to control a photovoltaics (PV) based microgrid. The capability of power exchange between the microgrid and the main grid through the minimization of the total power generation strategy is assessed in [13]. With the intention of reducing the total system lifecycle cost, a three phase process including design, sizing and operation of the microgrid is devised in [14]. In [15], a linear programming approach is suggested to minimize the cost of a PV-based microgrid. So as to see the consequence of storages in the microgrid, authors in [16] managed a linear programming approach to operate a microgrid with different load levels. In [17], a real-coded genetic algorithm based on a three-phase solution of forecasting, storage and operation was proposed. In [18], an intelligent method was devised to check the unit commitment problem in a microgrid incorporating wind turbine (WT) and storages. While each of these works has proposed valuable results, their major deficiency is ignoring the uncertainties effects of some sources such as RESs and market price and load. In order to consider the uncertainty effects, several works have been implemented to operate the microgrid in the presence of uncertainty. These methods are mainly categorized in [19,20] (1) Monte Carlo Simulation (MCS), (2) analytical methods and (3) approximate methods. MCS is the most famous and well-liked method in this group. The second group goes to the analytical methods that utilize some simplifications in the organization of the uncertain problem to model the

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Nomenclature

X	state variables vector
$B_{Gi}(t)$	the bid of *i*th DG at time *t*
$B_{Sj}(t)$	the *j*th storage device bid at time *t*
$S_{Sj}(t)$	start-up/shut down cost of *j*th storage device at time *t*
$S_{Gi}(t)$	start-up/shut down cost of *i*th DG at time *t*
$P_{Grid}(t)$	active power bought (sold) from (to) the utility at time *t*
$B_{Grid}(t)$	utility bid at time *t*
$u_i(t)$	state of the *i*th unit denoting ON/OFF statuses
n	number of the state variables
N_g	number of generating units
N_s	number of storage devices
P_g	vector including the power generation of all power units
U_g	vector including ONN/OFF statuses of all power units
T	number of time intervals
$P_{G,i}(t)$	active power production of *i*th power unit
$P_{G,i,\min}(t)$	minimum active power production of *i*th power unit at *t*
$P_{G,i,\max}(t)$	maximum active power production of *i*th power unit at *t*
$P_{s,j,\min}(t)$	minimum active power production of *j*th storage device at *t*
$P_{s,j,\max}(t)$	maximum active power production of *j*th storage device
$P_{Grid,\min}(t)$	minimum active power production of the grid at *t*
$P_{Grid,\max}(t)$	maximum active power production of the grid at *t*
$P_{L,i}(t)$	the amount of *l*th load value at time *t*
N_L	total number of load levels
$W_{ess}(t)$	amount of stored energy inside the battery at time *t*
$W_{ess,\max}/W_{ess,\min}$	maximum/minimum stored energy inside the battery
$P_{charge}/P_{discharge}$	permitted rate of charge/discharge during a finite time period (Δt)
$\eta_{charge}/\eta_{discharge}$	battery efficiency during charge/discharge period
$P_{charge,\max}/P_{discharge,\max}$	maximum permitted rate of charge/discharge during a finite each time period (Δt)
$C_L(x)$	membership cloud of L
Ex	expectation parameter
En	entropy parameter
He	hyper entropy parameter
N	number of cloud drops
X^b	best krill in the population
$V_{r,i}^k$	velocity of the krill *i* in the iteration *k*
$V_{ind,i}^k/V_{frg,i}^k/V_{dif,i}^k$	induced/foraging/diffusion velocity of *i*th krill at the *k*th movement
ρ	empirical constant factors
N_v	number of control variables
$\omega_{ind/frg/dif}$	inertia of induction/foraging/diffusion motion
ε	small positive number
rand	mathematical operator for random value in the range [0,1]
f_w	fitness function of the worst krill in population
N_p	number of population
Iter	iteration number
Mn_K	column-wise mean value of the krill population
φ_1	random value in the range [0,1]
β	constant value

uncertainty effects with less computational weight than MCS. In the third group, approximate methods subsist that Taylor series expansion method [21]; discretization method [22]; common uncertain source method [23,24]; first-order second-moment method (FOSMM) [25] and point estimate method (PEM) are amongst the the majority renowned methods of this set. The last two groups (analytical methods and approximate methods) are basic versions of MCS. However, the MCS method can itself be improved by considering the uncertainty of the standard deviation of the uncertain parameters. Therefore, this article proposes a novel method based on cloud theory to model the uncertainties of the microgrid problem more, efficiently.

This article suggests a new stochastic method based on cloud theory to reflect the uncertainties of concept in the MCS. The proposed method can model more information in terms of the uncertain problem. Cloud model (CM) employs some cloud drops to find more information in the targets. In order to see the performance of the proposed method, a typical microgrid with some DGs including WT, PV, fuel cell (FC), micro turbine (MT) and a Nickel-Metal-Hydride Battery (NiMH-Battery) as the storage appliance is considered as the case study. Also, a new optimization algorithm called modified krill herd (MKH) is suggested to solve the problem optimally. KH algorithm is a novel metaheuristics optimization algorithm that copies the search performance of krill during the foraging process [26]. In addition, a satisfactory modification method is devised to authorize its aptitude for steady and quicker convergence. The rest of this paper is organized as follows: Section 'Problem formulation' explains the objective function and constraints. Section 'Cloud theory in the stochastic framework' describes the stochastic framework based on CM. Section 'Optimization algorithm' explains the proposed MKH algorithm. The simulation results are shown in Section 'Results and discussion'. Finally, the main conclusions and concepts are provided in Section 'Conclusion'.

Problem formulation

Cost function

The cost function incorporates the cost of power supply by the main grid, by DGs (FC, WT, PV and MT), by the storages and the shut-down or start-up of the DGs. The main strategy is that the microgrid central control will dispatch the power among the power units according to the economical preferences. The storage device is charged at light-load hours and discharged at peak-load hours. This strategy can reduce the cost of the system:

$$Min\ \ f(X) = \sum_{t=1}^{T} Cost^t = \sum_{t=1}^{T}\Bigg\{\sum_{i=1}^{N_g}[u_i(t)p_{Gi}(t)B_{Gi}(t) + S_{Gi}\times \max(0,u_i(t) - u_i(t-1))] + D_{Gi}\times\max(0,u_i(t-1)-u_i(t)) + \sum_{j=1}^{N_s}[u_j(t)p_{sj}(t)B_{sj}(t)] + p_{Grid}(t)B_{Grid}(t)\Bigg\} \tag{1}$$