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Stochastic energy management of renewable micro-grids in the correlated environment using unscented transformation

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ABSTRACT

This paper addresses the optimal stochastic scheduling of the distributed generation units in a micro-grid. In this way, it introduces a new sufficient stochastic framework to model the correlated uncertainties in the micro-grid that includes different types of RESs such as photovoltaics, wind turbines, micro-turbine, fuel cell as well as battery as the storage device. The proposed stochastic method makes use of unscented transforms to model correlated uncertain parameters. The ability of the unscented transform method to model correlated uncertain variables is particularly appealing in the context of power systems, wherein noticeable inherent correlation exists. Due to the highly complex nature of the problem, a new optimization method based on the harmony search algorithm along with an intelligent modification method is devised to solve the proposed optimization problem, efficiently. The proposed optimization algorithm is equipped with powerful search mechanisms that make it suitable for solving both discrete and continuous problems. In comparison with the original harmony search algorithm, the proposed modified optimization algorithm has few setting parameters. The new modified harmony search algorithm provides proper balance between the local and global searches. The feasibility and satisfactory performance of performance of the proposed method are examined on two typical grid-connected MGs.

1. Introduction

The high penetration of DG (distributed generation), especially from RES (renewable energy sources) has been subject to a lot of research that has addressed specific advantages and disadvantages of incorporating DGs (including RES) in power systems. Some of the main benefits that are achieved from using DGs are power loss reduction, emissions reduction, improvements to system reliability and electric power quality enhancement. These valuable and significant improvements in the grid can be attained if the appearance of RESs is managed and controlled optimally. On the other hand, if DGs are not utilized correctly, it could cause serious problems to grid operations that include feeder congestion, transformer saturation, high resistive losses and voltage drops in the lines. From the point of view of power system operations, some of these issues stemming from the use of DGs in utility grids are also investigated in the context of MG (micro-grid) energy management. A MG can include different types of DGs or RESs such as WT (wind turbine), PVs (photovoltaics), FCs (fuel cell) and MTs (micro turbine) and thus would play a significant role in the future energy market.

By definition, a MG is a collection of DGs, RESs and electrical loads with an interconnection to the main grid [1–4]. Nevertheless, a MG can operate either in the connected or in islanding mode depending on the decisions made in the MCC (MG central control). In the view of the main grid, a MG is a controllable unit that may be considered as a single load or as a single power source [5]. Energy management in MGs with various DGs, RESs and distributed storage devices has primarily been treated as an optimization problem involving “unit-commitment decisions”. According to the significance of the problem several works have been implemented on the unit-commitment of MG in recent years. In Refs. [6], an intelligent energy management system is introduced for optimal scheduling of a CHP (combined heat and power)-MG. In that paper, the MG should be able to see the power mismatch in both thermal and electrical load and supply. In Refs. [7], the interaction between the MG and the main grid is studied through the minimization of the total cost of power supply. Recent technological advancements in

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Nomenclature

$(A)_k$ — kth row or column of matrix A
B_{Gi}^t & B_{sj}^t — cost of the ith RES and jth storage device at hour t
B_{Grid}^t — price of utility at hour t
bw — arbitrary distance bandwidth
bw_{max} & bw_{min} — maximum and minimum values of the bandwidth
d — dimension of the problem (length of each control vector X)
f — cost objective function
HM — harmony memory matrix
$HMCR$ — a constant called Harmony Memory Considering Rate parameter in the range of [0,1]
$Iter$ — Iteration number in HS
$Iter^{max}$ — maximum number of iterations in HS
M_{HM} — mean value of the HM
m — number of uncertain parameters
N_T — number of scheduling time intervals in the study (in this paper 24)
N_s — number of storage devices
N_g — number of power units
N_{sw} — number of solutions in HM
N_{Load} — number of load levels
n — total number of energy generation sources in MG
n_{rand} — random integer lower than the size of HM
P_{Grid}^t — active power bought/sold from/to the utility at time t
P_{Gi}^t & P_{sj}^t — active power output of the ith generator and jth storage device at time t
$P_{Load,k}^t$ — load value in kth level of tth hour
$P_m^{Inj,t}/Q_m^{Inj,t}$ — active and reactive power injection in bus m at time t
$P_{Gi,\min}^t$ & $P_{Gi,\max}^t$ — minimum and maximum active power production of ith RES at hour t
$P_{Sj,min}^t$ & $P_{Sj,max}^t$ — minimum and maximum active power production of jth storage device at hour t
$P_{grid,min}^t$ & $P_{grid,max}^t$ — minimum and maximum active power production of the utility at hour t
P_{charge} ($P_{discharge}$) — permitted rate of charge (discharge) through a definite period of time Δt
$P_{charge,max}$ ($P_{discharge,max}$) — maximum rate of charge (discharge) during definite period of time Δt
$P_i^{Line,t}$ — amount of active power flow in line i at time t
$P_{i,\max}^{Line}$ — allowed maximum power flow at line i
P_{zz}/P_{yy} — covariance matrix of input/output variables
PAR — constant value in the range of [0,1]
Res^t — scheduled spinning reserve at time t
$rand$ — random value operator
S_{Gi}^{on} & S_{Gi}^{off} — start-up/shut-down costs for the ith RES unit
S_{sj}^{on} & S_{sj}^{off} — start-up/shut-down costs for the jth storage device
T_F — random integer equal to 1 or 2
u_i^t — status of the ith unit at hour t
U_g — ON/OFF status of RESs
V^{min}/V^{max} — minimum and maximum values of voltage
V/δ — voltage magnitude/phase
$W_{ess,min}$ ($W_{ess,max}$) — lower (upper) bounds on the battery energy storage
W_{ess}^t — battery energy storage at time t
W^0 — weight of the mean value μ
X — control variable (or solution vector in HM)
X_{best} — best solution in the algorithm
$x_{i,j}$ — j^{th} element of the ith control vector X_i
Y/θ — magnitude/phase of line admittance
y — output vector
Z — input vector of random variables
$\rho_1, \ldots, \rho_8$ — random number in the range of [0,1]
η_{charge} ($\eta_{discharge}$) — charge (discharge) efficiency of the battery
μ — mean value of random variables

power electronics and storage devices have enabled the use of storage devices such as batteries, fly wheels or energy capacitors to reach more flexible and efficient unit-commitment. In this way, the effect of optimal control of battery status on the MG cost is assessed in Ref. [8]. In Refs. [9], the authors present a useful technique for optimizing the total electrical/thermal fuel cost when satisfying a prescribed reserve in the supply. The role of batteries in supplying the power mismatch in the MG equipped with a WT is assessed in Ref. [10]. In this reference, the analysis is done as a unit commitment problem with 24 h. In Refs. [11], a three-phase approach based on matrix real-coded genetic algorithm is devised. The proposed method works using three sequential steps of 1) forecasting, 2) storing and 3) managing the power modules in the MG. In Refs. [12], the authors investigate the operation optimization of MGs with renewable sources, diesel generators, and battery storage. The problem is formulated as a multi-objective optimization problem minimizing the generation cost and battery life cost using NSGA-II algorithm. While each of the aforementioned research articles have provided valuable insights into the MG scheduling problem, the main drawback with all these lies in their use of a deterministic framework. In fact, the uncertainties produced by the appearance of RESs are ignored. Neglecting the uncertainty inherent in power production from WT and PV leads to unreliable output. The significance of the problem becomes more severe in a competitive open power market. In Refs. [13], the authors assess the key features of MGs and provide a comprehensive literature survey on the significance and necessity of stochastic modeling and optimization tools in a MG. That research is done according to different time frames including the planning, operation and control of MGs. In Refs. [14], a two-stage stochastic programming frame is developed, where first-stage decisions are the generation schedules and adjustable load set points, and the second-stage decisions include energy transactions with the main grid as well as load adjustments made in real time. While these works have considered the uncertainty of the MG in the analysis, they have neglected the uncertainty correlation between the WTs.

Based on the above discussions, this paper aims to investigate the optimal unit-commitment in renewable MGs in the presence of uncertainty. In this regard, a sufficient stochastic framework based on UT (unscented transformation) is proposed to model uncertainties in the forecasts of WT and PV power output, day-ahead electricity prices and hourly load consumption. In addition to the above uncertainties, the proposed UT based framework will model the correlated uncertainty associated with the interaction between WTs. Owing to the complexity of the problem being investigated, we propose a new optimization algorithm based on HS (harmony search) algorithm called modified HS (MHS). The proposed algorithm will use three sufficient modification methods to improve the total search ability of the algorithm. The proposed problem is examined on a typical grid-connected MG incorporating different types of RESs such as PV and WT as well as FC, MT and battery as the storage device. The rest of this paper is organized as follows: