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Scenario-based stochastic operation management of MicroGrid including Wind, Photovoltaic, Micro-Turbine, Fuel Cell and Energy Storage Devices

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ABSTRACT

In this paper, an efficient stochastic framework is proposed to investigate the effect of uncertainty on the optimal operation management of MicroGrids (MGs). The proposed stochastic framework would concurrently consider the uncertainties of load forecast error, Wind Turbine (WT) generation, Photovoltaic (PV) generation and market price. The proposed stochastic method consists of two main phases. In the first phase, by the use of Probability Distribution Function (PDF) of each uncertain variable and roulette wheel mechanism, several scenarios are generated. Now by the use of scenario reduction process, the most probable and dissimilar scenarios are selected. By means of this strategy, the stochastic problem is converted to a number of deterministic problems with different probabilities. In this regard, the Weibull and normal PDFs are utilized to model the stochastic random variables. In the second phase, a new optimization strategy based on Adaptive Modified Firefly Algorithm (AMFA) is employed to solve each of the deterministic problems generated in the first phase. The stochastic optimization problem is investigated while meeting different equality and equality constraints. In order to see the efficiency and satisfying performance of the proposed method, a typical grid-connected MG including WT/PV/Micro-Turbine/Fuel Cell and Energy Storage Devices is studied as the test system.

1. Introduction

In recent years, major developments in the technology of Distributed Generators (DGs) such as Renewable Energy Sources (RESs) have made them the center of attention more than before [1]. In fact, the utilization of DG units like WTs, biomass, solar, and hydro has become widespread as the result of many benefits for better reliability, more satisfying power quality, loss reduction, cost decrease and smaller environmental pollutions [2,3]. On the other hand, the integration of DGs in the new power networks can result in inevitable challenges both in operation and management sides. This issue can be addressed shortly as the MicroGrids (MGs) management which is defined as the utilization of DGs, electrical loads, power generation as well as the interrelated effects among DGs and with the distribution network [4–6]. Moreover, as the result of recent progresses in the field of power electronics, more useful and cost-benefit energy storage applications have become available. The utilization of these types of energy sources in the power system can help to supply electrical loads at the peak hours more reliably while storing the surplus electrical energy at the low-load (low-price) hours [7,8]. In the meantime, the utilization of energy storage devices along with the DG units in the MG can increase the complexity of the network even more than before [9]. Therefore, it is clear that several researches are required to inspect all different aspects of the problem.

In [10], Sortomme and El-Sharkawi proposed a new method based on optimal power flow and Particle Swarm Optimization (PSO) algorithm to study two MGs including wind farms. In their work it is demonstrated that selling the stored energy at high load level along with executing load shaving can result in a proper cost-saving. In [11], Chakraborty et al. proposed a linear programming algorithm such that the MG operational cost would be reduced and the charge/discharge of the battery is optimized. In [12], Chen et al. suggested a new method based on the matrix real-coded genetic algorithm to find a three-phase smart strategy (including forecasting, storage and management modules) for optimizing the MG operation. A new approach based on linear programming is suggested by Chedid and Raiman to optimize the total power production cost in a solar-wind MG when considering the environmental variables [13]. In [14], Tsikalakis and Hatziargyriou assessed the optimal operation of MG by optimizing both the active power production of the units and power exchange with the upstream power networks. Logenthiran and Srinivasan [15]

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Nomenclature

t time interval index
n total number of optimization variables
NT total number of hours
N_g, N_s total number of generation and storage units, respectively
N_D total number of load levels
$f(X)$ cost objective function
u_i^t status of unit i at hour t
p_{Gi}^t, p_{sj}^t active power output of the ith generator and the jth storage device at time t, respectively
p_{Grid}^t active power bought/sold from/to the utility at time t
B_{Gi}^t, B_{sj}^t bid of the ith DG source and the jth storage device at hour t, respectively
B_{Grid}^t bid of utility at hour t
$S_{Gi}^{start}, S_{Gi}^{Shut}$ start-up/shut-down costs for the ith DG unit
$S_{sj}^{start}, S_{sj}^{shut}$ start-up/shut-down costs for the jth storage device
P_g the power production vector of DGs and storage devices
U_g the status vector of DGs
P_S the power production vector of DGs
P_S the power production vector of storage devices
T number of time intervals; here equals 24 h
p_{LD} amount of the Dth load level
$p_{G,\min}^t, p_{G,\max}^t$ minimum and maximum active power production of the ith dg at hour t, respectively
$p_{s,\min}^t, p_{s,\max}^t$ minimum and maximum active power production of the jth storage at hour t, respectively
$p_{grid,\min}^t, p_{grid,\max}^t$ minimum and maximum active power production of the utility at hour t, respectively
Res^t scheduled spinning reserve at time t
W_{ess}^t, W_{ess}^{t-1} battery energy storage at time t and $t-1$, respectively
$P_{Charge}(P_{discharge})$ permitted rate of charge (discharge) through a definite period of time Δt
$\eta_{charge}(\eta_{discharge})$ charge (discharge) efficiency of the battery
$W_{ess,\min}(W_{ess,\max})$ lower (upper) bounds on the battery energy storage, respectively
$P_{charge,\max}(P_{discharge,\max})$ maximum rate of charge (discharge) during definite period of time Δt
v wind speed
c the scale parameter of Weiball function
K the shape parameter of Weiball function
υ_0 location parameter of Weiball function
υ_{ci} the cut-in speed of wind
υ_{co} the cut-out speed of wind
υ_r the wind speed
p_r the rated output power of WT
s the sth scenario
$N_{WT,t}$ number of WTs in ON status at the tth hour
$N_{PV,t}$ number of WTs in ON status at the tth hour
$N_{Load,t}$ number of WTs in ON status at the tth hour
$N_{price,t}$ number of WTs in ON status at the tth hour
N_u number of uncertain variables
$P_{WT,j,t}^s$ power production of the jth WT at hour t in the sth scenario
$P_{PV,j,t}^s$ power production of the jth PV at hour t in the sth scenario
$P_{Load,j,t}^s$ the value of the jth load point at hour t in the sth scenario
$\text{Price}_{N_{price,t}}^s$ market bid at hour t in the sth scenario
f_s value of the decision variable (here objective function) in the sth scenario
f expected value of the decision variable in the whole scenarios
$Prob_{i,s}$ probability of the ith variable in the sth scenario
X_i the ith control vector/firefly
$x_{i,L}$ the Lth element of the ith control vector/firefly
d the dimension of the control vector
γ absorption coefficient
r distance between any two fireflies
β_0 initial attractiveness at $r = 0$
α randomization parameter is in the range of (0,1).
X_{Best}^{Iter} the best individual in the iteration number $Iter$
X_{Worst}^{Iter} the best individual in the iteration number $Iter$
Δ random number in the range [0,1].
$\kappa_1, \kappa_2, \ldots, \kappa_5$ random numbers in the range [0,1].
ψ, ζ random numbers in the range [0,1].
$k_{\max}$ a constant value
N_{swarm} number of fireflies in the population

List of abbreviations
Adaptive Modified Firefly Algorithm AMFA
Distributed Generation DG
MicroGrid MG
Wind Turbine WT
Photovoltaic PV
MicroGrid Central Controller MGCC
Phosphoric Acid Fuel Cell PAFC
Nickel–Metal-Hydride Battery NiMH-Battery
Probability Distribution Function PDF
Status of Operation SOP

proposed a three-phase approach to find the optimal solution for the cost objective function. In [16], Mohamed and Koivo investigated the MG energy management problem when considering the effect of storage facilities. However, as the result of neglecting time intervals in the problem, the charge/discharge aspect of the storage tools is not considered so that the total cost is increased. Nevertheless, the main deficiency with all the above mentioned works is the implementation of the analysis in a deterministic framework.

In fact, the presence of uncertainty in the nature of the MG can deprive the mentioned researches from the real optimal solution of the investigated problem. In a deterministic framework, the accuracy of the output solutions depends on the accuracy of the input variables when the possibility of some prediction error is just common in a power market. Moreover, in an open access power market, the degree of uncertainty of the load forecast error and market price can be even more perceptible [17,18]. By considering the unpredictable characteristics of WT and PV power generation [19] along with the uncertainty of load demand and market price, the necessity of a wide investigation with a stochastic structure becomes more evident. This situation requires the re-assessment of the above mentioned works to see the validity of the proposed methods in a stochastic environment. By the way, in order to reduce the amount of error associated with the uncertainty of the input variables, new methods or techniques are needed to be investigated [20].

Therefore, in this paper a stochastic framework based on scenario production technique is proposed such that the uncertainty associated with the load forecast error, WT/PV power generation and market price would be considered in the operation management of MGs, sufficiently. The proposed stochastic framework consists of two phases. In the first phase, for each of the input variables a specific PDF is considered. Then by the use of roulette wheel mechanism, different scenarios with different probabilities are