



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.

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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. Logenthran and Srinivasan [15]

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Nomenclature

t	time interval index	p_r	the rated output power of WT
n	total number of optimization variables	s	the sth scenario
NT	total number of hours	$N_{WT,t}$	number of WTs in ON status at the t th hour
N_g, N_s	total number of generation and storage units, respectively	$N_{PV,t}$	number of WTs in ON status at the t th hour
N_D	total number of load levels	$N_{Load,t}$	number of WTs in ON status at the t th hour
$f(X)$	cost objective function	$N_{price,t}$	number of WTs in ON status at the t th hour
u_i^t	status of unit i at hour t	N_u	number of uncertain variables
p_{Gi}^t, p_{sj}^t	active power output of the i th generator and the j th storage device at time t , respectively	$P_{WT,j,t}^s$	power production of the j th WT at hour t in the sth scenario
p_{Grid}^t	active power bought/sold from/to the utility at time t	$P_{PV,j,t}^s$	power production of the j th PV at hour t in the sth scenario
B_{Gi}^t, B_{sj}^t	bid of the i th DG source and the j th storage device at hour t , respectively	$P_{Load,j,t}^s$	the value of the j th load point at hour t in the sth scenario
B_{Grid}^t	bid of utility at hour t	$Price_{N_{price,t}}^s$	market bid at hour t in the sth scenario
$S_{Gi}^{start}, S_{Gi}^{shut}$	start-up/shut-down costs for the i th DG unit	f_s	value of the decision variable (here objective function) in the sth scenario
$S_{sj}^{start}, S_{sj}^{shut}$	start-up/shut-down costs for the j th storage device	f	expected value of the decision variable in the whole scenarios
P_g	the power production vector of DGs and storage devices	$Prob_{i,s}$	probability of the i th variable in the sth scenario
U_g	the status vector of DGs	X_i	the i th control vector/firefly
P_S	the power production vector of DGs	$x_{i,L}$	the L th element of the i th control vector/firefly
P_s	the power production vector of storage devices	d	the dimension of the control vector
T	number of time intervals; here equals 24 h	γ	absorption coefficient
p_{LD}	amount of the D th load level	r	distance between any two fireflies
$p_{G,\min}^t, p_{G,\max}^t$	minimum and maximum active power production of the i th dg at hour t , respectively	β_0	initial attractiveness at $r = 0$
$p_{s,\min}^t, p_{s,\max}^t$	minimum and maximum active power production of the j th storage at hour t , respectively	α	randomization parameter is in the range of (0, 1).
$p_{grid,\min}^t, p_{grid,\max}^t$	minimum and maximum active power production of the utility at hour t , respectively	X_{Best}^{iter}	the best individual in the iteration number $Iter$
Res^t	scheduled spinning reserve at time t	X_{Worst}^{iter}	the best individual in the iteration number $Iter$
W_{ess}^t, W_{ess}^{t-1}	battery energy storage at time t and $t - 1$, respectively	Δ	random number in the range [0, 1].
$P_{charge}(P_{discharge})$	permitted rate of charge (discharge) through a definite period of time Δt	$\kappa_1, \kappa_2, \dots, \kappa_5$	random numbers in the range [0, 1].
$\eta_{charge}(\eta_{discharge})$	charge (discharge) efficiency of the battery	ψ, ζ	random numbers in the range [0, 1].
$W_{ess,\min}(W_{ess,\max})$	lower (upper) bounds on the battery energy storage, respectively	k_{max}	a constant value
$P_{charge,\max}(P_{discharge,\max})$	maximum rate of charge (discharge) during definite period of time Δt	N_{swarm}	number of fireflies in the population
v	wind speed		
c	the scale parameter of Weibull function		
K	the shape parameter of Weibull function		
v_0	location parameter of Weibull function		
v_{ci}	the cut-in speed of wind		
v_{co}	the cut-out speed of wind		
v_r	the wind speed		

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

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