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Microgrid operation and management using probabilistic reconfiguration and unit commitment

Reza Jabbari-Sabet [a,*], Seyed-Masoud Moghaddas-Tafreshi [b], Seyed-Sattar Mirhoseini [c]

[a] Faculty of Electrical Engineering, K.N. Toosi University of Technology, Seyed Khandan, P.O. Box 16315-1355, Tehran, Iran
[b] University of Guilan, Faculty of Engineering, Power Engineering Group, Guilan, Iran
[c] Department of Electrical Engineering, Iran University of Science and Technology (IUST), Tehran, Iran

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ABSTRACT

A stochastic model for day-ahead Micro-Grid (MG) management is proposed in this paper. The presented model uses probabilistic reconfiguration and Unit Commitment (UC) simultaneously to achieve the optimal set points of the MG's units besides the MG optimal topology for day-ahead power market. The proposed operation method is employed to maximize MG's benefit considering load demand and wind power generation uncertainty. MG's day-ahead benefit is considered as the Objective Function (OF) and Particle Swarm Optimization (PSO) algorithm is used to solve the problem. For modeling uncertainties, some scenarios are generated according to Monte Carlo Simulation (MCS), and MG optimal operation is analyzed under these scenarios. The case study is a typical 10-bus MG, including Wind Turbine (WT), battery, Micro-Turbines (MTs), vital and non-vital loads. This MG is connected to the upstream network in one bus. Finally, the optimal set points of dispatchable units and best topology of MG are determined by scenario aggregation, and these amounts are proposed for the day-ahead operation. In fact, the proposed model is able to minimize the undesirable impact of uncertainties on MG's benefit by creating different scenarios.

Introduction

Distribution networks are reconfigured in order to power loss reduction, load balancing and service restoration in critical operational conditions [1]. Impact of MG on Distribution Network Reconfiguration (DNR) is discussed in [2–4]. To solve the optimal DNR problem for power loss minimization, the PSO algorithm using some scenarios generated by MCS is presented in [2]. Load Economic Dispatch (ED) and DNR, considering costs of generation and storage in MG, utility and network power loss as OF, are studied in [3,4]. The Distributed Generators (DGs) are considered by the stochastic nature according to forecasting weather data. However, load ED and DNR are not considered within the same time intervals.

MG reconfiguration is analyzed in [5–8]. A new algorithm is proposed to solve MG reconfiguration problem based on an ordered binary decision diagram in order to minimize power loss cost in [5]. A hybrid programming technique to solve MG reconfiguration problem to minimize power loss and service restoration is proposed in [6]. Considering the operational requirements, load maximizing and demand supply priority after fault, some methodologies that are based on genetic algorithm (GA) and graph theory, are used to reconfigure MG in [7]. Neglecting network power loss and line capacity, a scheme to recover much more loads with minimum switching operation is presented in [8]. However, stochastic nature of renewable energy resources and load demand in MGs are neglected in these studies.

MG UC and ED are discussed in [9–14]. A stochastic model for considering wind power uncertainty is investigated in [9]. Different scenarios are generated by MCS and are applied to solve UC problem. A probabilistic approach including point estimate method for handling uncertainties and a self-adaptive optimization algorithm for optimal energy management of MGs is proposed in [10]. The offered mutation technique makes the solution able to meet global optimum. A new algorithm based on an adaptive modified PSO algorithm to optimize multi-objective management of MG is presented in [11]. Three optimization algorithms are developed for optimal MG operation in [12]. A multi-objective optimization, using weight coefficient to coordinate the proportion of generation and environmental costs, is applied to the environmental and economic problem of MG in [13]. A new stochastic method using the probability distribution function of variables and the roulette wheel mechanism is proposed in [14]. Some scenarios

* Corresponding author. Tel./fax: +98 21 84062163.
E-mail address: reza.jabbari90@gmail.com (R. Jabbari-Sabet).

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Nomenclature

x_n	decision variable
OF	objective function
N_{mt}	number of microturbines
$\alpha_{mt}, b_{mt}, \gamma_{mt}, K_{om}, \alpha_{st,mt}, \beta_{st,mt}$	micro-turbine cost coefficients
t_{off}	micro-turbine off time
u_j	on/off state of micro-turbine j at interval t
i	the interest rate
n	unit life time
CF	unit capacity factor
β_{em}	micro-turbine emission coefficient
$T_{j-1}^{on}, T_{j-1}^{off}$	micro-turbine on/off time
MUT, MDT	minimum up/down time
$C_{WC,bat}$	battery wear cost
$C_{rep,bat}$	battery replacement cost
N_{bat}	number of batteries
$Q_{lifetime}$	lifetime throughput of battery
η_{bat}	battery roundtrip efficiency
SOC	battery state of charge
SOC_{in}	battery initial state of charge
$\rho_{buy\text{-}network}$	power cost bought from upstream network
N_{load_out}	number of not supplied loads
$\rho_{penalty}$	power cost paid to vital loads if is shed
$N_{load\_vital\_out}$	number of unsupplied vital loads
$N_{switching}$	number of switching
cv_x	variance coefficient of parameter x
σ_x	standard deviation of parameter x
μ_x	mean value of parameter x
N_s	number of scenarios
$w_1, w_r, w_{cut\text{-}out}$	cut-in, rated, and cut-out wind speed
Pbest, Gbest	best position of each particle until current iteration and best global particle

are generated by using of the proposed probabilistic method. Then similar scenarios are eliminated. A self-adaptive bee swarm optimization algorithm is proposed in [15]. Different uncertainty modeling methods are reviewed and the $2m + 1$ point estimate method is used for modeling uncertainties of load demands, market price, WT and photovoltaic systems. UC is investigated on a MG including several grid parallel PEM-fuel cell power plants in [16,17]. The objective is optimal sizing of storage devices and committed units' output power is scheduled with 15 min step over a day. A two stage algorithm is proposed to solve the complexity of the problem imposed by stochastic nature of electrical/thermal load, photovoltaic and WT output power and market price.

Some novel aspects in DNR studies are represented in [18–24]. Time varying data characteristic is considered in [18,20]. A method to determine annual reconfiguration scheme, considering switching cost and time-dependent variables such as load profiles, is proposed in [18]. The best topology for each hour is determined in [19], aimed at minimizing power loss and switching cost. Considering time-varying loads, a probabilistic approach for optimal DNR to reduce the total cost of operation, including power loss and switching cost, is presented in [20]. The proposed method can obtain an optimal balance between the number of switching and the power loss.

Reconfiguration with different kinds of uncertain data is presented in [21,22]. Different kinds of uncertainty are modeled in [21], in order to assess stochastic distribution feeder reconfiguration in the presence of fuel cell power plants. Interval analysis is used in [22], to deal with imprecision and uncertainties in reliability input, electrical parameters and load data to present a reliability oriented reconfiguration method in order to enhance distribution network performance. A methodology to convert a distribution network to an autonomous MG is presented in [23]. The methodology determines number, site and size of DGs and structural modifications in distribution network. Multi-scenario analysis handled with decision theory concepts is applied in [24], to determine intra-day distribution configuration. The determined configurations are then used to formulate a demand response scheme, aimed at demand reduction to further decreasing in distribution network losses.

However, none of the above-mentioned papers has considered the reconfiguration and UC simultaneously. As the review shows, probabilistic reconfiguration and UC for MG optimal management, is a novel operation scheme. Considering wind power and load demand uncertainties, simultaneous reconfiguration and UC for hourly scheduling is used to estimate MG's benefit in the uncertain environment. The paper includes five sections. In section 'Problem formulation', problem formulation is introduced. In section 'Proposed algorithm', proposed algorithm is described. Section 'Simula tion results' indicates simulation results and section 'Conclusion' is dedicated to conclusion.

Problem formulation

One of the most involving problems that MG owner faces is how to increase the benefit. There are two methods to achieve this goal: UC and reconfiguration. UC has been regarded very much. However, reconfiguration has been ignored for this purpose. Reconfiguration provides MG with more benefit by changing the topology. Topology changes can cause loss reduction or line allocation with more power transfer capacities. Uncertainties of wind power and load demand are taken into account in this paper. The MG under study includes WT, battery, MTs, vital and non-vital loads. The MG's structure is shown in Fig. 1 [25]. In the following subsections problem formulation is described.

Decision variables

The three MTs output power (P_{mt}), battery charge or discharge (P_{bat}), power exchange with upstream network (P_{grid}) and switches status ($n\_topology$) are considered as decision variables for each hour. So, there are six vectors of decision variables for each hour and 144 variables for day-ahead, which must be determined.

$$x_n = \begin{bmatrix} P_{mt1}(1) & P_{mt2}(1) & P_{mt3}(1) & P_{bat}(1) & P_{grid}(1) & n\_topology(1) \\ P_{mt1}(2) & P_{mt2}(2) & P_{mt3}(2) & P_{bat}(2) & P_{grid}(2) & n\_topology(2) \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ P_{mt1}(24) & P_{mt2}(24) & P_{mt3}(24) & P_{bat}(24) & P_{grid}(24) & n\_topology(24) \end{bmatrix} \quad (1)$$

Objective function

MG's benefit, which is defined as the difference between revenue and cost, is considered as OF and defined as follows [26]:

$$Max: \; OF = \sum_{t=1}^{24} (revenue(t) - cost(t)) \quad (2)$$