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Short-term resource scheduling of a renewable energy based micro grid

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A B S T R A C T

In recent years due to the decreasing fossil fuel reserves and the increasing social stress, complex power networks have no other choices except to seek for alternative energy sources to eliminate the environmental issues caused by the traditional power systems. Thus, the scheduling of energy sources in a complex Micro-Grid (MG) comprising Micro Turbine (MT), Photo Voltaic (PV), Fuel Cell (FC), battery units and Wind Turbine (WT) has been investigated in this paper. Furthermore, a multi-objective framework is presented to simultaneously handle the two objective functions including minimization of total operation cost and minimization of emission. In this regard, Normal Boundary intersection (NBI) technique is employed to solve the proposed multi-objective problem and generate the Pareto set. Besides, a fuzzy satisfying method is used for decision making process. Afterward, the results obtained from the presented method are compared to the ones derived from other methods. Finally, it is verified that the proposed solution method results in better solutions for operation cost, emission and the execution time.

1. Introduction

The electricity companies tend towards using the Distributed Energy Resources (DERs) close to the load, because of many economic/environmental and technical issues [1]. Many types of power sources can be categorized as DERs like diesel engines, battery units, Photo Voltaic (PV), Fuel cell (FC), Wind Turbine (WT) and Micro Turbine (MT) [1–4]. A concept recently introduced to power systems is Micro-Grid (MG) that includes a low-voltage distribution system with DERs, storage devices and controllable loads operating in grid-connected or stand-alone modes taken into account as a controlled entity [4].

So far, many research works have been dedicated to the control and operation of the MGs. Various solution methods are proposed in Refs. [1,4] for economic scheduling of MG. Over the recent years, the conventional economic dispatch has been replaced by economic/environmental dispatch [7–19], since it cannot satisfy the requirements for optimal operation of MGs after the Clean Air Act Amendments was passed in 1990 to take into account the emission concerns [5,6]. Ref. [7] proposes a Genetic Algorithm (GA)-based approach in order to solve the sizing optimization problem comprising multiple objectives as lifecycle cost minimization, maximization of Renewable Energy Sources (RESs) penetration as well as pollutant emission minimization. A comprehensive model is presented in Ref. [8] for MG operating in stand-alone mode while a multi-cross learning-based chaotic differential evolution algorithm is used to solve the economic/environmental optimization problem. Ref. [9] employs a stochastic bidding strategy for an MG participating in joint day-ahead energy and spinning reserve markets considering the uncertainty of load and renewable DERs' power output. Ref. [10] uses a performance metric taking into account the electricity price, emission and service quality that each one is given a weighting factor. It is noted that this performance metric is applied to MGs operating in stand-alone, grid-tied and networked modes. The optimal operation of WTs and other DERs operating in an interconnected MG is done in Ref. [11] through an expert energy management system. The main aim beyond using the presented approach was to determine the optimal set points of DERs and storage devices in order to concurrently minimize the total operation cost and the net emission. Ref. [12] utilizes an intelligent energy management system for optimal operation of an MG that is based on Combined Heat and Power (CHP) generation over a 24-h horizon to simultaneously minimize the total operation cost and the net emission. Artificial intelligence techniques along with linear-programming-based multi-objective framework are used in Ref. [13] to present a

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Nomenclature

Indices

b	battery index
f	fuel cell index
i	emission index
g	grid index
m	micro turbine index
p	photo voltaic index
t	time index
w	wind turbine index

Sets

BA	battery units
ET	Emission group consists of CO_2, SO_2 and NOx
FC	fuel cell units
MT	micro turbine units
PV	photo voltaic units
WT	wind turbine units
T	time study horizon

Constants and parameters

β	weighting factor in NBI method
$B(*,t)$	bid at hour t
$E_i(*,t)$	emission coefficient of ith emission type (CO_2, SO_2 and NOx) of unit at hour t
$P_{Max}(*,t)$	maximum power output at hour t
$P_{Min}(*,t)$	minimum power output at hour t
$PF_{Max}(*,t)$	maximum forecasted power output at hour t
$PF_{Min}(*,t)$	minimum forecasted power output at hour t
Load(t)	load at hour t
SUC_*	start-up cost
SDC_*	shut-down cost

Variables

Φ	payoff table
μ_i^r	value of the ith membership function in the rth Pareto optimal solution
μ^r	total membership function of the rth Pareto optimal solution
Ω	feasible region
D	Objective function of NBI method
f^U, f^N, f^{SN}	Utopia and nadir point and pseudo nadir point, respectively
F_1	first objective function (cost minimization)
F_2	second objective function (emission minimization)
F_i^r	value of the ith objective function in the rth Pareto optimal solution
$\hat{n}$	denote the unit normal to the CHIM simplex towards the origin
$P(*,t)$	power generation at hour t
$V(*,t)$	binary variable which is equal to one if unit is online at hour t
$\bar{x}_i^*$	vector of decision variables which optimizes the objective function f_i
w_i	weighting factor of the ith objective function in fuzzy decision making

generalized formulation for intelligent energy management of an MG. Ref. [14] determines the optimal operation of an MG which is on the basis of CHP generation. This MG includes energy storage system, three types of thermal units and demand response programs. A stochastic multi-objective framework is proposed in Ref. [15] using teaching-learning based optimization to obtain the Pareto optimal solutions. Ref. [16] implements the MG planning in a primary distribution system through a two-stage multi-objective model. In the first stage, the loss sensitivity factors are used to specify the optimal region for the MG while the second stage determines the optimal locations and the size of a number of DERs in MG employing Non-dominated Sorting Genetic algorithm II (NSGA-II). The optimal generation scheduling is done in Ref. [17] using a Fuzzy Self-Adaptive Particle Swarm Optimization (FSAPSO), while the objective functions are cost and emission minimization. Ref. [18] presents an expert multi-objective adaptive modified particle swarm optimization algorithm for economic/environmental operation of a typical MG including back-up MT, FC and battery hybrid power source.

So far, there are many research works devoted to the operation of MGs using Meta heuristic optimization algorithms to deal with multi-objective economic/environmental operation of MGs. Meta heuristic approaches are usually employed to solve multi-objective problems like economic/environmental operation of MGs, as they have a population-based search capability, simplicity and convergence speed [19]. It is worth noting that the papers previously cited have employed the weighted sum method to transform the original multi-objective problem into a single-objective optimization problem, then they use Meta heuristic approaches to solve them. The weighted sum method is widely used for economic/environmental management problems rather than other optimization methods [20]. In this regard, this paper proposes a multi-objective framework for the problem of short-term economic/environmental scheduling of an MG employing Normal Boundary Intersection (NBI) technique. However, there are two main controversial issues with the weighted sum method as follows:

1. In the case of non-convex Pareto set, the Pareto points on the concave sections of the trade-off surface will be failed to be obtained.
2. For an even spread of the weights, generally the optimal solutions in the criterion space are not evenly distributed [20].

In this regard, NBI technique is an efficient method for numerical computation of fairly distributed points on the Pareto optimal front in multi-objective optimization problems [20].

A comprehensive literature survey on the stochastic modeling and optimization tools for an MG can be found in Ref. [21].

This paper proposes a multi-objective framework for the problem of short-term economic/environmental scheduling of an MG using Normal Boundary Intersection (NBI) method. The main contributions of this paper can be summarized as follows:

1. Presenting a bi-objective framework for short-term scheduling of an MG considering cost and emission objective functions.
2. Employing NBI technique to solve the proposed multi-objective framework.
3. Using a fuzzy satisfying method for the decision making process.
4. Obtaining superior solutions using the presented method in comparison with recently employed methods.

The remainder of this paper is organized as follows: Section 2 presents the problem formulation. The description of NBI method is included in Section 3. Section 4 proposes the simulation results with detailed discussion. Finally, some relevant conclusions are drawn in Section 5.