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Environmental/economic scheduling of a micro-grid with renewable energy resources

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ABSTRACT

Nowadays, modern power grids are moving towards using alternative energy sources, as the fossil fuel reserves are exhausting and international societies worry about the environmental effects by conventional electric power generation systems. In this regard, this paper implements the scheduling of energy sources in a micro-grid including different power sources like photo voltaic, fuel cell, battery units, wind turbine and micro turbine. Besides, this paper proposes a multi-objective framework for the optimal scheduling of a micro-grid in order to concurrently minimize the total operation cost and minimize the emission caused by generating units. For this end, lexicographic optimization and hybrid augmented-weighted epsilon-constraint method have been employed to solve the multi-objective optimization problem and generate the Pareto optimal solutions. The decision making process has been performed using a fuzzy technique. Afterwards, the effectiveness and the efficiency of the proposed method are verified using two case studies. Besides, the results of the proposed method are compared to those obtained from other methods recently employed. Finally, it is indicated that incorporating the lexicographic optimization and hybrid augmented epsilon-constraint technique lead to superior solutions in the case of operation cost, emission and execution time.

1. Introduction

Distributed Generation (DG) is defined as generating units in small-scale, installed and operate next to the consumers. From different technologies of DG units, the renewable ones are widely used, as they are considered green, sustainable and free energy sources. On the other hand, excessive employment of DGs may cause severe challenges to the electric grid in the case of secure and efficient operation of the power system (Görbe et al., 2012; Lidula and Rajapakse, 2011; Jiayi et al., 2008). In this regard, Micro-Grid (MG) is a concept having the capability to provide the required infrastructures in order to integrate small-scale DGs into the large electric power system, while it satisfies the future needs of power grids (Cardenas et al., 2014; Rozali et al., 2014; Battaglini et al., 2009).

In recent years, a lot of researches have been done focusing on the operation of MGs. So far, many optimization techniques have been used to solve the problem of optimal operation scheduling considering different loading conditions and different objectives. One of the common problems encountered by some previous optimization algorithms is to determine the most economical units to dispatch. Many optimization techniques have been reported in literature to consider cost or profit to find the overall power dispatch of MGs. The optimal energy and spinning reserve bids have been modeled using bi-level bidding by Moghimi et al. (2013), while Dali et al. (2010) and Hawkes and Leach (2007) have proposed an economic framework to meet the electricity demand and operational constraints. Zhang et al. (2013) have taken into consideration the distributed economic dispatch for a MG with high penetration of Renewable Energy Sources (RESs) and demand-side management which operates in grid-connected state, while the objective function is minimization of the net cost of MG, comprising DG and distributed storage costs, utility of dispatchable loads and the worst-case transaction cost caused by the uncertainty of RESs. The optimal operation scheduling of renewable-powered MGs has been solved by Zhao et al. (2014a,b) to determine the Unit Commitment (UC) and the associated dispatch with the least cost while satisfying demand and requirements of system operation. It should be noted that the aforementioned papers have used single-objective framework disregarding the issues of greenhouse gas emission. Despite the performed research works in the area, more comprehensive MG operation models are still needed. It is

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Nomenclature

Indices

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

Units

BA	battery
FC	fuel cell
MT	micro turbine
PV	photo voltaic
WT	wind turbine

Constants

a_i,b_i,and c_i	cost coefficients of thermal generating unit *i* for case 1
d_i, e_i, and f_i	greenhouse gas emission coefficients of thermal generating unit *i* for case 1
$B_{\alpha\beta}$	loss coefficients for case 1
B(*,t)	bid at hour t
E_i(*,t)	emission coefficient of ith emission type (CO_2, SO_2 and NO_x) 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

F_1	the main objective function (Cost minimization)
F_2	the secondary objective function (Emission minimization)
F_i^r	the value of the *i*th objective function in the *r*th Pareto optimal solution
P(*,t)	power generation at hour t
V(*,t)	binary variable which is equal to one if unit is online at hour t
μ_i^r	the value of the *i*th membership function in the *r*th Pareto optimal solution
μ^r	the total membership function of the *r*th Pareto optimal solution

noted that traditional pure economic scheduling no longer meets the requirements of optimal operation of MGs after passage of the Clean Air Act Amendments in 1990 and it is required to consider the issues relating to greenhouse gas emission (Norouzi et al., 2014a; Ahmadi et al., 2012; Le et al., 1995).

Significant researches have been conducted on operation of MGs, while they have used Meta heuristic optimization methods to solve multi-objective environmental/economic operation of MGs. Due to the population-based search capability, simplicity, and convergence speed, Meta heuristic optimization methods are widely used for solving multi-objective optimization problems like environmental/economic operation of MGs (Moghaddam et al. (2011). Basak et al. (2012) have scrutinized a techno-economic factor for Distributed Energy Resources (DERs) on the basis of the impact of their generation on the network losses, while making an attempt to decrease the operation cost and emission generation. Moghaddam et al. (2012) have used a Fuzzy Self-Adaptive Particle Swarm Optimization (FSAPSO) algorithm for economic/emission dispatch of the generating units in a typical MG. The optimal operation scheduling of a typical MG with RESs along with a back-up MT/FC/battery hybrid power source has been done using an Adaptive Modified Particle Swarm Optimization (AMPSO) algorithm by Moghaddam et al. (2011), taking into account the cost and emission as two objective functions. Aghaei and Alizadeh (2013) have presented an optimal operation of a MG which is based on Combined Heat and Power (CHP), while the two objectives considered are cost and emission. This MG includes the energy storage system, three types of thermal power generating units and demand response programs. A multi-objective, intelligent energy management framework has been presented by Chaouachi et al. (2013) to minimize the operation cost and the emission of a MG considering its pre-operational variables as future availability of renewable energies and load demand. Zhao et al. (2014a,b) have used an approach based on Genetic Algorithm (GA) to deal with the sizing optimization problem for MGs operating in stand-alone mode with multiple objectives consisting of life-cycle cost minimization, maximization of RESs penetration and minimization of emission. A linear programming technique has been used by Quiggin et al. (2012) to model a MG system comprising RESs, energy storage and demand response programs while it is found that MGs with contemporary technologies are able to remarkably reduce the CO_2 emissions. An energy management model has been presented by Chen et al. (2013) to determine the optimal operating strategies associated with the maximum profit for a MG system in Taiwan. It is found that using an efficient power generation MG system would decrease the greenhouse gas emissions. The problem of economic/environmental dispatch of DG-based MGs has been solved using a chaotic quantum GA by Liao (2012). The problem of optimal size, design and operation of a hybrid, renewable energy based MG has been determined by Hafez and Bhattacharya (2012.), in order to minimize the life cycle cost taking into consideration the environmental concerns. The performance of a MG has been assessed by Zhang et al. (2014), using a performance metric with respect to the electricity price, emission and service quality, while a weighting factor is assigned to each one. With the weighting factors set by Zhang et al. (2014), performance metric was further applied to MGs operating in stand-alone, grid-tied and networked modes. Alagoz et al. (2012) have investigated the tree-like user-mode network architecture, which provides flexible, observable, and controllable network architecture for reliable and efficient energy delivery under uncertain conditions. A comprehensive model has been presented by Hemmati et al. (2014) for MG operating in stand-alone mode, while a multi-cross learning-based chaotic differential evolution algorithm has been used to solve the economic/environmental optimization problem. The optimal operation of WTs and other DERs operating in an interconnected MG has been presented by Motevasel and Seifi (2014) through an expert energy management system. The main aim beyond using the presented approach is to determine the optimal set points of DERs and storage devices in order to concurrently minimize the total operation cost and the net greenhouse gas emission. Motevasel et al. (2013) have utilized an intelligent energy management system for optimal