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Multi-objective energy management in a micro-grid

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ABSTRACT

In recent years, the management and operation of micro-grids are considered by many advanced societies with regard to the development of scattered energy resources. The main goals that are paid attention in micro-grid management are the operation cost and pollution rate, which the aggregation of such contradictory goals in an optimization problem can provide an appropriate response to the management of the micro-grid. In this paper, the MOPSO method has been used for management and optimal distribution of energy resources in proposed micro-grid. On the other hand, the problem was analyzed with the NSGA-II algorithm to demonstrate the efficiency of the proposed method.

1. Introduction

At present, considering the significant growth of distributed generation (DG), specifically renewable energy resources, there is a growing interest in the use of micro-grids. Micro-grids combine different DG resources, thereby providing a control system at the voltage distribution level to supply electricity or heat to a group of local loads (Xie et al., 2011; An et al., 2015; Gollou and Ghadimi, 2017). Renewable energy resources such as wind and the sun play important roles in micro-grids but they also exhibit random behavior, so it is necessary to perform appropriate planning to facilitate the suitable operation of these resources and their optimal management while considering different practical objectives. Various structures and methods have been proposed for energy management systems using different optimization algorithms for micro-grids with diverse resources. In particular, micro-grid operation has been optimized using a mixed integer nonlinear programming (MINLP) model with the aim of minimizing an objective function that considers investment, operation, repair and maintenance, and environmental costs (Xie et al., 2011). However, mathematical solution methods such as MINLP cannot optimize large-scale nonlinear problems, which must be addressed using heuristic techniques. Thus, particle swarm optimization (PSO) and genetic algorithms have been used to economically allocate power to generation units in a power grid (Moghaddam et al., 2012; Muthuswamy et al., 2015). A single-objective gravitational search algorithm was also employed for determining the optimal energy management strategy (Sharifi et al., 2017). In addition, a combination of modified honey bee mating optimization and chaotic local search was proposed (Wu and Hao, 2014). Furthermore, a company-based energy management strategy was developed to facilitate power exchange among micro-grids using demand response and energy storage (Akbary et al., 2017), where the main focus was on the theoretical load consumption patterns of consumers, the available energy in DG resources, and an electricity cost-saving system.

In this study, we propose the use of the multi-objective PSO (MOPSO) algorithm for the optimal management of generation units in micro-grids, where demand side management and the exchange of micro-grids with the national grid are analyzed to minimize the operating costs and pollution emissions.

The remainder of this paper is organized as follows. The problem is stated fully in Section 2. We introduce micro-grids in Section 3 and the principles of multi-objective optimization are presented in Section 4. The results of simulations and numerical analyses are discussed in Section 5. Finally, we give the main conclusions of this study in Section 6.

2. Problem statement

In this study, we present an accurate mathematical model for energy management over the short term in order to minimize the operating costs and pollution emissions for a micro-grid.

2.1. Defining the objective function

The objective function is considered to include operating costs and pollution emission costs, as follows.

Objective function cost: Minimizing the total operating costs for a micro-grid: See Eq. (1) given in Box I, where T is the total time period of the study (hours), N_g and N_s are the numbers of energy

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$$\text{Min}\, f_1(X) = \sum_{t=1}^{T} \left\{ \begin{array}{l} \sum_{i=1}^{N_g} [U_i(t)P_{Gi}(t)B_{Gi}(t) + S_{Gi}\,|U_i(t) - U_i(t+1)|] - \cdots \\ \sum_{j=1}^{N_s} \left[U_j(t)P_{sj}(t)B_{sj}(t) + S_{sj}\,\left|U_j(t) - U_j(t-1)\right|\right] - (P_{Grid}(t)B_{Grid}(t)) \end{array} \right\}, \quad (1)$$

Box I.

generation and storage units, respectively, $U_i(t)$ is the status of the ith unit at time t (either on or off), $P_{Gi}(t)$ and $P_{sj}(t)$ are the amounts of output power for the ith unit and jth storage at time t, $B_{Gi}(t)$ and $B_{sj}(t)$ represent the energy price offered for the ith unit and jth storage at time t, $S_{Gi}(t)$ and $S_{sj}(t)$ are the startup or shut-down costs for the ith unit and jth storage, and $P_{Grid}(t)$ and $B_{Grid}(t)$ indicate the amounts of power exchanged with the offered market at time t.

Objective function for pollution: Minimizing all the pollution attributable to the most common pollutants in a micro-grid:

$$\text{Min}\, f_2(X) = \sum_{t=1}^{T} Emission^t = \sum_{t=1}^{T} \left\{ \sum_{i=1}^{N_g} [U_i(t)P_{Gi}(t)E_{Gi}(t)] + \sum_{j=1}^{N_s} \left[U_j(t)P_{sj}(t)E_{sj}(t)\right] + (P_{Grid}(t)E_{Grid}(t)) \right\}, \quad (2)$$

where $E_{Gi}(t)$, $E_{Sj}(t)$, and $E_{Grid}(t)$ represent the amounts of pollution attributable to the ith generation unit, jth storage unit, and the market at time t in kg/MWh, respectively.

2.2. Constraints and limitations

• Load-generation balance:

$$\sum_{k=1}^{N_k} P_{LK}(t) = \sum_{i=1}^{N_g} [P_{Gi}(t)] + \sum_{j=1}^{N_s} \left[P_{sj}(t)\right] + (P_{Grid}(t)), \quad (3)$$

where P_{LK} is the amount of K at the load level and N_K is the total number of load levels present in the grid.

• Power limit of units

All the units, including DGs, storage units, and the market, have lower and upper limits for their generation power.

$$\begin{aligned} &P_{Gi,\min}(t) \le P_{Gi}(t) \le P_{Gi,\max}(t) \\ &P_{Sj,\min}(t) \le P_{Sj}(t) \le P_{Sj,\max}(t) \\ &P_{Grid,\min}(t) \le P_{Gridi}(t) \le P_{Grid,\max}(t) \end{aligned} \quad (4)$$

• Limitations on the charging and discharging rates of the storage unit

$$\begin{aligned} &SOC_{Sj}(t) = SOC_{Sj}(t-1) + P_{chg/Dchg}(t) \\ &0 \le \left|P_{chg/Dchg(t)}\right| \le P_{CDSj,\max}, \end{aligned} \quad (5)$$

where $SOC_{sj}(t)$ and $SOC_{sj}(t\text{-}1)$ are the charging amounts of a storage unit at the current and previous times, respectively, $P_{chg/Dchg}(t)$ is the charging (discharging) amount during the tth hour, and $P_{CDSi\max}$ is the maximum charging (discharging) rate.

3. Structure of the grid

A micro-grid is a combination of DGs, including micro-turbine, wind turbine, solar cell, fuel cell, battery, and diesel generator units, which are connected to each other as well as exchanging energy with the upstream grid. Thus, all the resources are capable of decision making and planning for energy generation, where these control measures are facilitated by local and central controllers in micro-grids.

A schematic overview of the system considered in the present study is shown in Fig. 1, where the micro-grid includes generation resources comprising micro-turbine, wind turbine, solar cell, fuel cell, and battery units. The micro-grid also has the capability of exchanging energy with the upstream grid.

4. Principles of multi-objective optimization and PSO algorithms

In the real world, many problems involve the simultaneous optimization of several objective functions, which are usually not proportionate and in conflict with each other. This optimization process yields a set of responses instead of an optimal response because no single response can be obtained to optimize all the functions by considering all of the objectives simultaneously. Therefore, the multi-objective optimization problem includes a number of objective functions, which must be optimized simultaneously, and a number of equality and inequality constraints must be satisfied. Thus, this problem can be formulated as follows:

$$\begin{aligned} &\text{Min}\, F(\overrightarrow{X}) = \left[f_1(\overrightarrow{X}), f_2(\overrightarrow{X}), \ldots, f_N(\overrightarrow{X})\right]^T \\ &\textit{Subject to}: \\ &\quad g_i(\overrightarrow{X}) < 0\; i = 1, 2, \ldots, N_{ueq} \\ &\quad h_i(\overrightarrow{X}) = 0\; i = 1, 2, \ldots, N_{eq}, \end{aligned} \quad (6)$$

where F is a vector containing the objective functions, X is a vector comprising the optimization variables of $f_i(X)$ representing the ith objective function, $g_i(X)$ and $h_i(X)$ are the equality and inequality constraints, respectively, and N indicates the number of objective functions in the problem. In this study, based on the PSO algorithm (Kennedy, 2010), the multi-objective functions are solved using the MOPSO algorithm. Further details of the MOPSO algorithm, can be found in previous studies (Xuebin, 2009; Ghadimi and Firouz, 2015).

The MOPSO algorithm can be readily applied to our problem according to the following steps.

First step: Gathering input information for the program.

First, information related to the structure of the sample micro-grid, the technical and functional specifications of the elements in the grid, wind and solar power predictions for the future 24-h period, the energy price offered by the market and DG units, as well as the daily load curve are treated as the primary data.

Second step: Initialization

In this step, a primary population is defined by considering the limitations on the problem according to Eq. (7):

$$X^0 = [X_1, X_2, \ldots, X_N]^T, \quad (7)$$

where X is a decision variable vector that includes the output power of units and the on/off status of units, which is described