Energy management of a multi-microgrid system

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1. INTRODUCTION

Existing optimization models (Ren et al. (2014); Kargarian et al. (2012); Nguyen and Le (2013)) only minimize the operational cost of a multi-micorgrid system and do not consider the pollutants (CO_2, NO_x, SO_x, etc.) emitted by the controllable generating units within the microgrids and thermal power plants of the main grid (Lora and Salomon (2005)). These pollutants have a negative impact on the environment as they cause droughts, acid rain, heat waves, hurricanes, increase in sea levels, increase in average global temperature, increase in infectious and allergic diseases, etc. (Franchini and Mannucci (2015)). The aim of this study is to address this problem by formulating a constrained multi-objective optimization model which simultaneously minimizes the operational cost and environmental impact of a multi-microgrid system.

2. PROPOSED OPTIMIZATION MODEL OF A MULTI-MICROGRID SYSTEM

2.1 Objective Functions

Operational cost. The equation used to calculate the operational cost of the a-th microgrid within a multi-microgrid system is given by

$$\begin{aligned} F_a = \sum_{t=1}^{T}[\sum_{i=1}^{C_a}[FC_{i,a}(P_{i,a,t}^{Con})] \\ + \sum_{i=1}^{C_a}[OM_{i,a}(P_{i,a,t}^{Con})] \\ + \sum_{j=1}^{U_a}[OM_{j,a}(P_{j,a,t}^{Uncon})] \\ + \sum_{k=1}^{E_a}[OM_{k,a}(|P_{k,a,t}^{ESS}|)] \\ + \sum_{n=1}^{M}[\gamma_{a,n,t}C_n(P_{n,a,t}^{MG}) \\ -\delta_{a,n,t}I_n(P_{n,a,t}^{MG})] \\ +\alpha_{a,t}C_{grid}(P_{grid,a,t}) \\ -\beta_{a,t}I_{grid}(P_{grid,a,t})], \end{aligned} \tag{1}$$

where T is the number of time periods; C_a is the number of controllable generating units (diesel generator, fuel cell, micro-turbine, etc.) within the a-th microgrid; U_a is the number of uncontrollable generating units (Photo-voltaic system, wind turbine, etc.) within the a-th microgrid; E_a is the number of energy storage systems (ESS) within the a-th microgrid; M is the number of microgrids within the multi-microgrid system; $FC_{i,a}$ is the fuel cost of the i-th controllable generating unit in the a-th microgrid as a function of $P_{i,a,t}^{Con}$; $OM_{i,a}$ is the operational and maintenance cost of the i-th controllable generating unit in the a-th microgrid as a function of $P_{i,a,t}^{Con}$; $OM_{j,a}$ is the operational and maintenance cost of the j-th uncontrollable generating unit in the a-th microgrid as a function of $P_{j,a,t}^{Uncon}$; $OM_{k,a}$ is the operational and maintenance cost of the k-th energy storage system in the a-th microgrid as a function of $P_{k,a,t}^{ESS}$; C_n is the cost of purchasing power from the n-th microgrid as a function of $P_{n,a,t}^{MG}$; I_n is the income received for selling power to the n-th microgrid as a function of $P_{n,a,t}^{MG}$; C_{grid} is the cost of purchasing power from the main grid as a function of $P_{grid,a,t}$; I_{grid} is the income received for selling power to the main grid as a function of $P_{grid,a,t}$; $P_{i,a,t}^{Con}$ is the output power of the i-th controllable generating unit in the a-th microgrid during time period t; $P_{j,a,t}^{Uncon}$ is the output power of the j-th uncontrollable generating unit in the a-th microgrid during time period t; $\alpha_{a,t}$ and $\beta_{a,t}$ are binary numbers which prevent the a-th microgrid from simultaneously purchasing and selling power from and to the main grid; $P_{grid,a,t}$ is the power flowing between the main grid and the a-th microgrid during time period t. If $P_{grid,a,t} \geqslant 0$ then the a-th microgrid is purchasing power from the main grid ($\alpha_{a,t} = 1$ and $\beta_{a,t} = 0$); however, if $P_{grid,a,t} \leqslant 0$ then the a-th microgrid is selling power to the main grid ($\alpha_{a,t} = 0$ and $\beta_{a,t} = 1$). $\gamma_{a,n,t}$ and $\delta_{a,n,t}$ are binary numbers which prevent the a-th microgrid from simultaneously purchasing and selling power from and to the n-th microgrid; $P_{n,a,t}^{MG}$ is the power flowing between the n-th microgrid and the a-th microgrid during time period t. If $P_{n,a,t}^{MG} \geqslant 0$ then the a-th microgrid is purchasing power from the n-th microgrid ($\gamma_{a,n,t} = 1$ and $\delta_{a,n,t} = 0$); however, if $P_{n,a,t}^{MG} \leqslant 0$ then the a-th microgrid is selling power to the n-th microgrid ($\gamma_{a,n,t} = 0$ and $\delta_{a,n,t} = 1$). $P_{k,a,t}^{ESS}$ is the power flowing from or to the k-th energy storage system in the a-th microgrid during time period t. If $P_{k,a,t}^{ESS} \geqslant 0$ then the k-th energy storage system is charging; however, if $P_{k,a,t}^{ESS} \leqslant 0$ then the k-th energy storage system is discharging.

Equation (1) is used to formulate the first objective function of the proposed optimization model. This objective function is used to minimize the operational cost of the entire multi-microgrid system as given by

$$minimize\ F_{Total} = \sum_{a=1}^{M}[F_a]. \tag{2}$$

Environmental impact. The equation used to calculate the mass of the emissions (CO_2, NO_x, SO_x, etc.) emitted into the environment as a result of the a-th microgrid within the multi-microgrid system is given by

$$E_a = \sum_{t=1}^{T}[\sum_{s=1}^{V}[\sum_{i=1}^{C_a}[E_{s,i,a}(P^{Con}_{i,a,t})] + \alpha_{a,t}E_{s,grid}(P_{grid,a,t})]], \quad (3)$$

where V is the number of different emissions emitted by the generating units; $E_{s,i,a}$ is the mass of the s-th emission emitted by the i-th controllable generating unit (diesel generator, fuel cell, micro-turbine, etc.) within the a-th microgrid as a function of $P^{Con}_{i,a,t}$; and $E_{s,grid}$ is the mass of the s-th emission emitted by the thermal power plants of the main grid as a function of $P_{grid,a,t}$.

Equation (3) is used to formulate the second objective function of the proposed optimization model. This objective function is used to minimize the environmental impact of the entire multi-microgrid system as given by

$$minimize\ E_{Total} = \sum_{a=1}^{M}[E_a]. \quad (4)$$

2.2 Decision Variables

(1) Output power of each controllable generating unit within each microgrid ($P^{Con}_{i,a,t}$).
(2) Power flowing to or from each energy storage system within each microgrid ($P^{ESS}_{k,a,t}$).
(3) Power flowing between each microgrid ($P^{MG}_{n,a,t}$).
(4) Power flowing between each microgrid and the main grid ($P_{grid,a,t}$).

2.3 Constraints

The constraint used to ensure that there is a balance between the supply and load demand of the a-th microgrid for each time period t is given by

$$\sum_{i=1}^{C_a}[P^{Con}_{i,a,t}] + \sum_{j=1}^{U_a}[P^{Uncon}_{j,a,t}] - \sum_{k=1}^{E_a}[P^{ESS}_{k,a,t}] + P_{grid,a,t} + \sum_{n=1}^{M}[P^{MG}_{n,a,t}] = LD_{a,t}, \quad (5)$$

where $LD_{a,t}$ is the load demand of the a-th microgrid during time period t.

The upper and lower boundary constraints of the decision variables are

$$P^{ConMin}_{i,a} \leqslant P^{Con}_{i,a,t} \leqslant P^{ConMax}_{i,a}, \quad (6)$$

$$P^{Min}_{grid,a} \leqslant P_{grid,a,t} \leqslant P^{Max}_{grid,a}, \quad (7)$$

$$P^{MGMin}_{n,a} \leqslant P^{MG}_{n,a,t} \leqslant P^{MGMax}_{n,a}, \quad (8)$$

$$P^{ESSMin}_{k,a} \leqslant P^{ESS}_{k,a,t} \leqslant P^{ESSMax}_{k,a}, \quad (9)$$

where $P^{ConMin}_{i,a}$ and $P^{ConMax}_{i,a}$ are the minimum and maximum output power of the i-th controllable generating unit within the a-th microgrid, respectively; $P^{Min}_{grid,a}$ and $P^{Max}_{a,grid}$ are the minimum and maximum power which can flow between the a-th microgrid and the main grid, respectively; $P^{MGMin}_{n,a}$ and $P^{MGMax}_{a,n}$ are the minimum and maximum power which can flow between the a-th microgrid and the n-th microgrid, respectively; $P^{ESSMin}_{k,a}$ and $P^{ESSMax}_{k,a}$ are the minimum and maximum power which can flow to the k-th energy storage system within the a-th microgrid, respectively.

The ramp rate constraints of the i-th controllable generating unit in the a-th microgrid are given by

$$P^{Con}_{i,a,t} - P^{Con}_{i,a,t-1} \leqslant R_{up,i,a}\Delta t \quad (10)$$

$$P^{Con}_{i,a,t-1} - P^{Con}_{i,a,t} \leqslant R_{down,i,a}\Delta t \quad (11)$$

where Δt is the time interval; $R_{up,i,a}$ and $R_{down,i,a}$ are the upper and lower power ramp rates of the i-th controllable generating unit in the a-th microgrid, respectively.

The constraint which ensures that the state of charge limits of each energy storage system are not exceeded is given by

$$SOC^{ESSMin}_{k,a} \leqslant SOC^{ESS}_{k,a,t} \leqslant SOC^{ESSMax}_{k,a}, \quad (12)$$

where $SOC^{ESS}_{k,a,t}$ is the state of charge of the k-th energy storage system within the a-th microgrid during time period t; $SOC^{ESSMin}_{k,a}$ and $SOC^{ESSMax}_{k,a}$ are the minimum and maximum state of charge of the k-th energy storage system within the a-th microgrid, respectively.

3. CONCLUSION

There are multiple advantages if the proposed optimization model is used instead of using the existing optimization models, namely the following.

(1) The proposed optimization model minimizes the amount of hazardous pollutants (CO_2, NO_x, SO_x, etc.) emitted into the environment.
(2) The proposed optimization model considers the operational and maintenance cost of the controllable and uncontrollable generating units.
(3) The proposed optimization model considers the financial income a microgrid receives if it sells power to another microgrid or to the main grid.

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