Multi-Objective Optimization of Smart City Considering Time-Varying Carbon Emission Factor

T. Ishibashi[1], M. Furukakoi[2], A. Uehara[1], H. Takahashi[3] and T. Senjyu[1]
[1]Department of Electrical Engineering, University of the Ryukyus,
[2] Department of Electrical Engineering, Sanyo-Onoda City University,
[3] Fuji electric Co., Ltd.
ishibashi_smdr@cs.u-ryukyu.ac.jp

Introduction

For a sustainable society, cities are transitioning to smart cities (SCs) [1], which require an energy management system (EMS) that integrates renewable energy sources (RES) and combined cooling and heating (CCHP) to reduce environmental impacts. To create a low-carbon and eco-friendly society, cities need to minimize not only costs but also carbon emissions. However, many studies calculate emission factors using fixed values [2], and it will be important to conduct studies that investigate time-varying carbon emission factor (CEF). This study investigates the multi-objective optimization of the smart city considering time varying CEF and compares it with the conventional case. The optimization problem is formulated in MILP and simulated using MATLAB.

Proposed method for CEF calculation

Decarbonization requires economy-friendly and environmentally conscious development. Most power systems rely on fossil fuels, emitting carbon from thermal power plants. Generally, carbon emissions are calculated using the CEF published by electricity suppliers. While many published CEFs are fixed values, CEF is primarily influenced by thermal plant power and should be adjusted according to their output. Therefore, this study proposes a time-varying CEF (TCEF) to more precisely capture the time-series fluctuations in carbon emissions and incorporate them into the optimization process. The calculation procedure is as follows, and the TCEF is shown in Figure 1.

Step.1 Calculate total emissions based on nominal CEF and total power generation (thermal, RES, etc.)
Step.2 Divide the total emissions calculated in Step (1) by the amount of thermal power generation.
Step.3 Multiply the CEF calculated in Step (2) by the thermal output to calculate the hourly carbon emissions.
Step.4 Divide the emissions obtained in Step (3) by the corresponding generation to calculate the Time-varying CEF.

To verify the effectiveness of TCEF, this paper performs a multi-objective optimization to minimize SC costs and carbon emissions. The problem is formulated using the ε-constraint method, as shown in the following equations:

$$\min C_{cost}(t)\ ;$$

$$subject\ to\colon\ EM(t) \leq \varepsilon_i \cdot EM_{\varepsilon_i}^{max}\ (i = 0.1, 0.2, \dots, p)$$

where C_{cost} represents the operational cost of the SC, $EM(t)$ represents the carbon emissions of the SC, and $EM_{\varepsilon_i}^{max}$ is the upper limit of $EM(t)$ for ε_i.

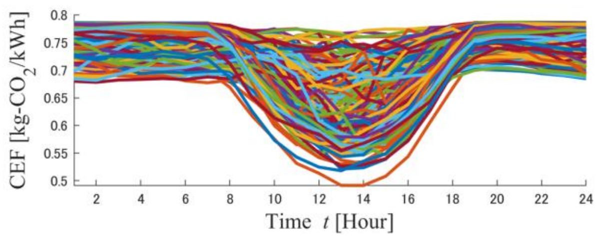

Figure 1 Time-varying CEF

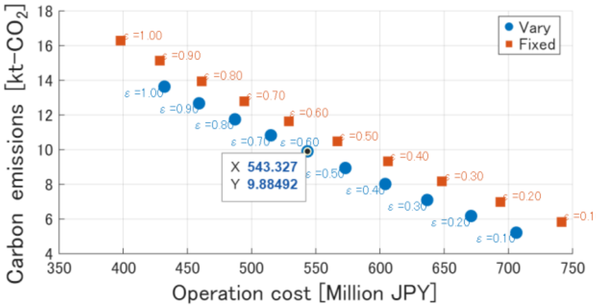

Figure 2 Pareto front

Results and Discussion

Figure 2 shows the Pareto front for multi-objective optimization. All optimal solutions using TCEF are located in the lower left corner relative to the fixed case. Therefore, the proposed method achieves low-carbon and low-cost by precisely capturing and optimizing hourly carbon emissions. According to the Pareto front in Figure 2, this paper determines the solution with $\varepsilon_i = 0.6$ as the optimal solution. Comparing the two cases, operating costs are reduced by 4.1% and carbon emissions by 5.6%.

References

[1] VAHID JAVIDROOZI , HANIFA SHAH, AND GERALD FELDMAN, IEEE Access, 10.1109/ACCESS.2019.2933045 (2019)
[2] Xiaoqing Zhong, Weifeng Zhong, Yi Liu, Chao Yang and Shengli Xie, Elsevier, Energy 123428 (2022)