**Applied Energy Symposium 2021: Low carbon cities and urban energy systems**
**September 4-8, 2021, Matsue, Japan**
**Paper ID: 79**

# A QUANTITATIVE APPROACH OF MICROGRIDS PERFORMANCE ASSESSMENT AT THE PLANNING STAGE

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**ABSTRACT**

A microgrid, as a typical low-carbon energy system, has gained great attentions in the last decade. Most studies focused on improving the system performance at the design and control stages while the evaluation of the system performance at the planning stage is usually ignored. Commonly, three key indicators (cost, renewable energy penetration, and reliability) are used to evaluate the system performance. The cost and/or the renewable energy penetration are set as the objectives while the reliability is set as a constraint in design/control optimization. However, due to lacking adequate investigations of system performance at the planning stage, fewer supports are provided in energy policy formulation. This study, therefore, proposed a quantitative approach to evaluate the system performance in terms of these three indicators at the planning stage. By using the proposed model, optimization algorithm, and regression analysis, these three indicators are quantified. A case study is proposed to test and verify this approach. Three different reliability requirements are adopted. In the end, a reasonable range (40%-60%) of renewable energy penetration is recommended. The system performance of the cost-saving (the largest one as 61.5%) is evaluated based on three ratios of reliability requirements and renewable penetration ratios.

**Keywords:** planning stage, microgrid optimization, renewable penetration, reliability

**NONMENCLATURE**

| *Abbreviations* | |
|---|---|
| REP | Renewable energy penetration |
| GA | Genetic algorithm |
| COP | Coefficient of performance |
| ELF | Equivalent loss factor |

| *Symbols* | |
|---|---|
| $Y_k$ | Lifecycle |
| $t$ | hour |
| $bpg$ | Backup power generation |
| $emi$ | Carbon emission |
| $ren$ | Renewable energy |
| $fac$ | Microgrid facility |
| $ref$ | Reference data |
| $Rad$ | Solar radiation |
| $\eta_{pv}$ | Overall efficiency of PV panels |
| $\eta_{bpg}$ | Backup power generation efficiency |

## 1. INTRODUCTION

The remarkable growth of renewable energy utilization has been experienced in the last decade with the developments of the technologies. The technologies from different studies have been proposed in terms of increasing the renewable energy penetration (REP) and/or optimization in system design and energy management. The microgrid, as one typical form of the renewable power generation system, has attacked attentions due to its advantages such as low carbon emission, stable power supply, and cost-saving [1].

Among the existing studies, decreasing the overall cost is the major objective. Besides, to address the world's energy crisis issue, increasing the REP is considered as another objective. However, high REP may cause the high overall cost. By proposing the microgrid optimization approaches in terms of design and management [2], a trade-off between the overall cost and REP is achieved. In addition, due to the uncontrollable features of renewable power generation, the large fluctuation of the power supply is another challenge. Thus, maintaining the energy balance

Selection and peer-review under responsibility of the scientific committee of CUE2021
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between the supply side and demand side is another vital objective in microgrid investigations.

Most studies focused on optimizing the microgrid at the design and/or control stages. They aim to increase the renewable power generation efficiency, where the locations, sites, and sizes of the renewable power generator are considered [3]. Besides, the power consumers at the demand side are also involved. Various schemes of the electricity prices are proposed and tested, which can decrease the possibilities of the system blackout due to energy imbalance [4, 5]. Some technologies (e.g. building flexibility [6], and demand response [7]) are further used to optimize the system, where many promising achievements in economic benefits and environmental friendliness are presented.

In summary, previous studies are mainly investigated the system performance at the design and control stage. Those design and management approaches are adopted at the design and control stages. At the planning stage, policies from the government are vital in the microgrid system determination while it usually lacks adequate technological supports. This study therefore proposed a novel quantitative approach at the planning stage, which not only quantified the relationship of the REP, economies, and reliability but also provided the guideline of the system optimization. The main contribution of this research is to provide a comprehensive assessment considering the different conditions before developing a real system, which is convenient for the decision-makers to decide scientific decisions in terms of policy formulations and systematic estimations.

## 2. PROCEDURE, KEY EVALUATION INDEXES INTRODUCTION, AND MODEL DEVELOPMENT

Compared with the system performance at the design and control stage, those studies mostly aim to provide a final decision of these three indicators. However, at the planning stage, the decision-maker prefers to get the trending of these three indicators and their relationship. Thus, the study introduced the approach and the microgrid model. The assessment results of the microgrid system performance is provided at the planning stage rather than a specific scheme and final results of the design variables' determination.

### *2.1 Procedure and the major steps*

The proposed quantitative approach is divided into four main steps as shown in Fig 1. In the first step, the input variables are determined, where the major facilities are considered. Then, these variables with their ranges and the weather data as well as the occupant profile are fed into the microgrid model that is developed according to the presumed load density and power generation at the ideal condition. The second step is to conduct the optimization calculations. The GA (Genetic algorithm) is adopted in the calculation process. Comparing to the optimization at the design/control stage, the planning optimization aims to search many different local optimization points in the different conditions rather than giving one final global optimization point. Thus, the reliability ratio and the range of the REP ratio are set as constraints of the optimization. According to setting different constraints of the REP ratio ranges and reliability ratios, the various local optimization points in the different conditions are calculated. Then, in the third step, these obtained optimization points are analyzed based on different REP ratio ranges and reliability ratios. The regression analysis is conducted. The microgrid performance can be evaluated. In the last step, the recommendation of the microgrid system determination can be presented.

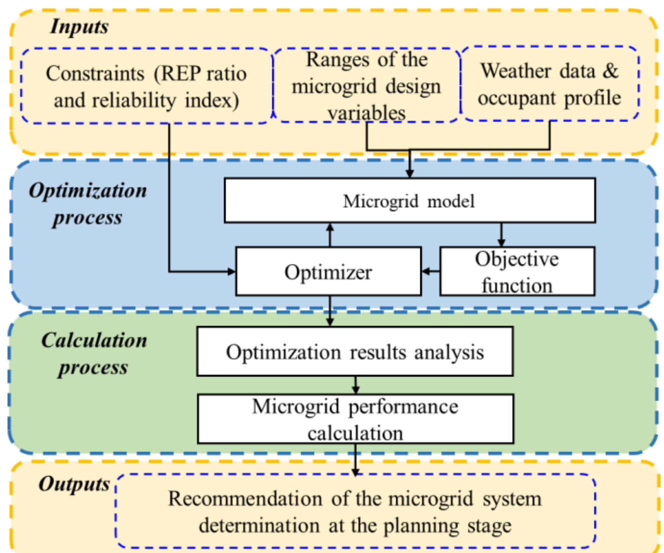


Fig. 1. Outline of reliability assessments quantification procedure and method

### *2.2 Key evaluation indexes introduction*

Fig. 2 shows the schematic representation of these three indicators' relationship. Commonly, the REP ratio and the reliability have significant impacts on the overall cost. High REP can effectively decrease carbon emissions. The penalty of the carbon emission and operation cost from the backup power generation are lower while the


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capital costs of the renewable power generators and battery storage are higher vice versa.

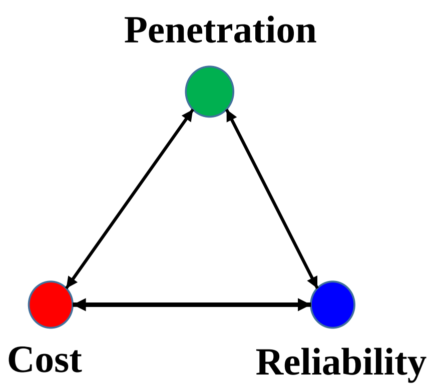


Fig. 2 Schematic representation of these three indicators' relationship

High reliability means the system can achieve a stable power supply. However, renewable power generation is not stable due to its uncontrollable features. To meet the demand timely with high reliability and achieve the High REP ratio simultaneously, setting the large capacity of the backup power generation is needed, which causes the high overall cost. To provide the reasonable planning of the system, providing a quantitative relationship of these three indicators is valuable and necessary.

2.2.1 Overall cost

The overall cost is a significant indicator to measure the system economies. It consists of the initial cost of the major facilities and operation cost of the backup power generation as well as the carbon emission penalty as shown in Eq. (1). The initial cost ($IC$) is calculated considering the capital cost ($C_{fac,k}$) of the major facilities and their lifetime ($Y_k$) as shown in Eq. (2). The operation cost is calculated by the backup power generation as shown in Eq. (3) while the amount of the carbon emission in this part is quantified and shown in Eq. (4).

$$C_{ove} = IC + OC + Penlty \quad (1)$$

$$IC = \sum (C_{fac,k} \times \frac{1}{Y_k}) \quad (2)$$

$$OC = (\sum_{t=1}^{8760} P_{bpg}^{t}) \times GP_{bpg} \quad (3)$$

$$Penlty = (\sum_{t=1}^{8760} E_{bpg}^{t}) \times T_{emi} \times cde_{bpg} \quad (4)$$

2.2.2 Renewable energy penetration (REP)

Renewable energy penetration (REP) is one significant indicator to measure the renewable energy ratio of power generation. High REP means that more renewable energy is involved in power generation, where the calculation of the REP ratio ($R_{ren}$) has presented in Eq. (5). $E_{ren}$ is the renewable energy consumption and $L_{served}$ is the total energy consumption. Commonly, the range of the REP can be from 0% to 100% in practice. Thus, the range from 0% to 100% is adopted in the study to test and analyze.

$$R_{ren} = \frac{E_{ren}}{L_{served}} \quad (5)$$

2.2.2 Reliability

Reliability is a significant indicator to describe the system performance in terms of the energy balance. Normally, the reliability index, i.e. the equivalent loss factor (ELF) is adopted to assess the system performance of the energy balance during the operating period [8, 9]. The equation has been shown as Eq. (6). Where, $h$ is the time step. The $D(h)$ is the energy consumed and $E(h)$ is the not supplied energy. Note that, according to [10], the ELF can be set as different ratios. In this study, three different ratios of the reliability requirements (90.00%, 99.00%, and 99.99%) are set and tested in the following studies.

$$ELF = \frac{1}{8760} \sum_{h=1}^{8760} \frac{E(h)}{D(h)} \quad (6)$$

*2.3 Model development of microgrid structure*

The microgrid model is developed by the clusters of mathematical equations is achieved in Matlab-Trnsys. At the supply side, two major renewable power generations (solar and wind sources) are adopted in this study as shown in Eq. (7) [11, 12]and Eq. (8) [13], respectively. Where, $A_{PV}$ is the PV area and *Rad* is solar radiation. PV panel temperature is $T_{PV}$ and $P_{PV}$ is the output power from the PV panels. $P_{wind}$ is the output power from the wind turbine and the wind speed is represented as $v_{wind}$.

$$P_{PV} = Rad \times A_{PV} \times (1 + K_{PV}(T_{PV} - T_{ref})) \times \eta_{pv} \quad (7a)$$

$$T_{PV} = T_{amb} + 0.0256 \times Rad \quad (7b)$$

$$P_{wind} = 0.12615 \times {v_{wind}}^2 - 0.4915 \times v_{wind} - 0.008 \quad (8a)$$

$$(3.65\text{m/s} \leq v_{wind} < 10.4 \text{ m/s})$$

$$P_{wind} = -0.078 \times {v_{wind}}^2 + 1.78144 \times v_{wind} - 0.016 \quad (8b)$$

$$(10.4\text{m/s} \leq v_{wind} \leq 18.0 \text{ m/s})$$

Backup power generation and battery are adopted to maintain reliability. In simplified, the backup power generation is calculated as Eq. (9), while the battery is used by setting charging and discharging limits at 20% and 80%, respectively. Where, $P_{bpg}$ is the output power from the backup power generation and $E_{bpg}$ is


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the amount of the backup source that is used in power generation. $\eta_{bpg}$ is the power generation efficiency.

$$P_{bpg} = E_{bpg} \times \eta_{bpg} \tag{9}$$

At the demand side, to obtain the dynamic electrical load, a simple assumption of the electrical load is adopted. The electrical load is grouped into the commercial electrical load (such as computers, lights, etc.) and cooling load. The load densities can be obtained according to different types of buildings in different regions. Then, the Trnsys model can be developed by using these presumed load densities.

## 3. RESULTS AND DISCUSSION

### *3.1 Overview of the case study*

The proposed case in this study is a hotel microgrid that is located on a remote island in Hong Kong as shown in Fig. 3, as a typical subtropical region. The typical meteorological data of Hong Kong is adopted while the coefficient of performance (COP) of the cooling system is assumed to be a constant value of four.

The hotel microgrid is presumed as a target building. More than three hundred rooms are considered and the total area is around 26,000 m2. According to the Hong Kong Code of Practice for Energy Efficiency of Electrical Installations, the commercial electrical load density and cooling load density are determined as 25 $W/m^2$ and 153 $W/m^2$. Based on these assumed inputs, the annual dynamic electrical load profile of the hotel microgrid is then obtained.


Fig. 3. Overview of the case study location

### *3.2 Optimization results and economic analysis*

By using the introduced quantitative approach, the dynamic load profile is obtained. By using this profile and the presumed variables with setting constraints, the optimization was conducted. To obtain the local optimization points in different conditions, the constraints according to the ratios of reliability requirements and REP ratios are set. Three ratios of reliability requirements are considered while the REP ratio from 0% to 100 % are considered. The REP ratio interval is set as 10% including two boundaries as 0% and 100%. Thus, a total of twelve points in one ratio of the reliability requirements are obtained. Then, the regression analysis is calculated based on these clusters of local optimization points.

Fig. 4 shows the optimization results of the system performance. The overall cost is increasing while the reliability ratio is increasing. If the obtained system has a better performance in energy balance with the same REP, a high overall cost is needed. Besides, the overall cost has a similar trending according to the difference of the REP ratios. Around 40%-60% REP is the recommendation because in the range, the lowest overall cost appears when the reliability is constant.

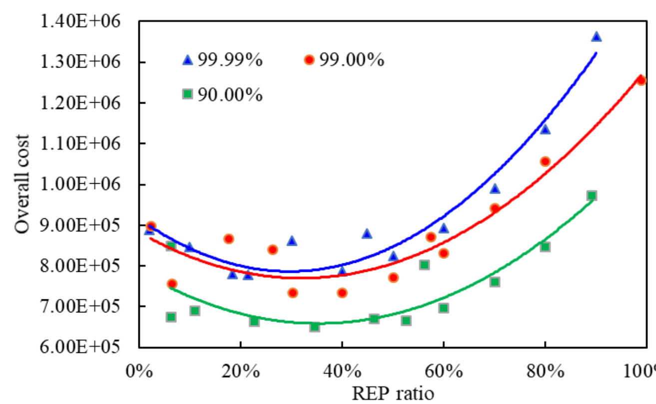


Fig. 4. Optimization results of the system performance

Fig. 5 shows the comparison results of the cost-saving. Three types of cost comparisons are presented If the system has a constant requirement of reliability, it has been proved that a large promising potential of the cost-saving can be achieved by adopting the proper REP ratio. More than 60% of the cost-saving can be achieved in the 90% reliability requirement of the system performance. If the reliability requirement of the system performance is higher than 99%, the cost-saving ratio is less than 45%. Meanwhile, the comparison results of the cost-saving in terms of the 100% REP ratio and 0% REP ratio are also shown in Fig. 5. Reasonable REP for the system can increase the cost-saving, compared with no


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renewable power generation and all power generation from the renewable power generation. In addition, especially in lower requirements of reliability, the fluctuations of the renewable power generation in the power supply based on its uncontrollable features can be addressed. Compared to the reliability requirement as 99% and 99.99%, the cost-saving of the system setting the reliability requirement as 90% is higher (up to 35%).

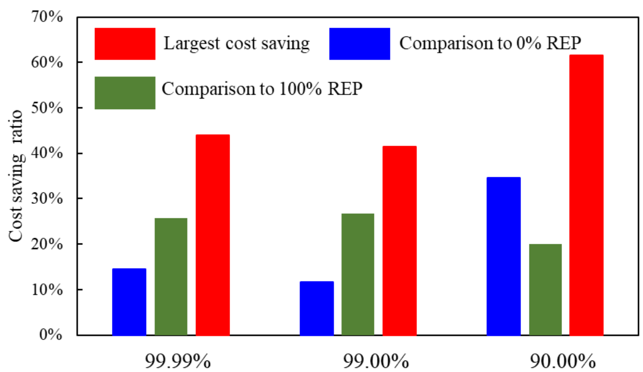


Fig. 5. Overview of the case study location

## 4. CONCLUSIONS

In this study, a quantitative approach is proposed to evaluate the microgrid performance at the planning stage. Three key indicators (REP, reliability, and cost) are involved. It is found that the proposed approach can directly present the microgrid performance, which is a valuable and vital guideline at the planning stage. A case study has been tested and verified in this study. Other major conclusions and recommendations of this case study are drawn as follows:

- Renewable power generation at 0% and 100% are both not the best options while the recommended range of the REP ratio is at 40%-60%;
- Different REP ratios have a large promising potential to decrease overall cost, where the largest cost-saving is at 61.5%;
- A high-reliability ratio leads to a high overall cost. Lower requirement of the reliability (from 99.99% to 90%) can increase the cost-saving (at 35%) by using the REP in power generation.

## 5. FUTURE WORK

The proposed quantitative approach has many advantages to provide the guideline at the planning stage for the system determination, especially considering the three major indicators of the system performance simultaneously. However, some further investigations especially comparing with other existing methods (exhaustive method) are still needed to conduct. A trade-off between the prediction accurately and computation cost is needed to consider.


## ACKNOWLEDGEMENT

The research presented in this paper is financially supported by a general research grant (152079/18E) of the Research Grant Council (RGC) of Hong Kong SAR and a research grant under strategic focus area (SFA) scheme of the research institute of sustainable urban development (RISUD) in The Hong Kong Polytechnic University.


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