Development of the Process for Deploying Optimal Photovoltaic System

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Abstract

As global warming and environmental pollution become one of the widespread concerns, there is a growing interest in nearly zero energy building (NZEB) in the construction industry worldwide. In order to achieve NZEB, it is crucial to apply the new renewable energy (NRE) to the building. Among the common NREs, the solar energy is an unlimited energy source having the highest potential. However, the current process for deploying PV systems has some limitations: (i) lack of information and analysis of the target facility; (ii) lack of sensitivity analysis of key factors affecting system performances; and (iii) Lack of optimization process.

This study develops the process for deploying PV system which makes it possible for potential users and installers to maximize the performance of each system. The proposed process consists of the following 4 steps: (i) establishing the basic information for the system installation; (ii) selecting key factors affecting system performances; (iii) estimating system energy output of the possible system alternatives; and (iv) selecting the optimal system through the life cycle cost (LCC) and life cycle CO\textsubscript{2} (LCCO\textsubscript{2}) analysis.

The results of this study could help potential users and installers to install a PV system in several ways: (i) maximize the financial benefit of the system; (ii) maximize the efficiency and utilization of the system; (iii) select the optimal PV system according to the target facility and the users’ preference.

1. Introduction

There is a critical need for a new renewable energy (NRE) system to achieve nearly zero energy building (NZEB), which is considered great solution against global warming and environmental pollution [1]. Among the common NREs, the photovoltaic (PV) system that generates electricity from solar energy

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has the highest potential with an unlimited energy source [2]. However, the current process for deploying PV systems has some limitations: (i) lack of information and analysis of the target facility; (ii) lack of sensitivity analysis of key factors affecting system performances; and (iii) Lack of optimization process.

Therefore, this study developed a new process for deploying optimal PV system, which can overcome the limitations listed above: (i) by understanding the target facility, it is possible to select the PV system suitable for the target facility; (ii) by conducting sensitivity analysis of key factors affecting system performances, it is possible to maximize the utilization of the system; and (iii) through the life cycle cost (LCC) and life cycle CO2 (LCCO2) analysis, it is possible to maximize the financial benefit of the system.

2. Development of the Process for Deploying Optimal Photovoltaic System

This study aims to develop a process for deploying optimal PV system. By applying the proposed process of PV system deployment, the user will be able to install optimal system with respect to economic and environmental aspect. The details of the proposed process are described below.

2.1. Step 1: Establishing the basic information for the system installation

Before installing a PV system, basic information for the system installation should be established. This basic information is categorized in Fig 1 and details are described below.

![Fig. 1. basic information for the system installation](image)

First, basic information regarding region, facility and system should be determined. Depending on this information, there can be a significant difference in performance and initial investment cost of the system.

Second, Different types and amount of financial incentives are given in different region, facility, and system. Since each country or city has different incentive policies and schemes, it is crucial to know and understand what kind of financial incentives are available in the region where a system will be installed.

Finally, some constraints should be considered when planning and designing a PV system. The two main constraints are the area and size limit: (i) the installation area limit should be enough for installing the desired system size; and (ii) to prevent oversizing of the PV system, the system size should not exceed the system size limit considering the electricity consumption of the target facility.

2.2. Step 2: Selecting the key factors affecting system performances

There are some key factors that affect the PV system performances. These factors should be considered in advance in order to estimate system energy output and economic benefits under variable conditions. These key factors are categorized in Fig 2 and details are described below.
First, the energy output of a PV system is greatly affected by the regional factors such as the monthly average daily solar radiation (MADSR) and monthly average air temperature (MAAT). Since the MADSR and MAAT varies depending on the region, it is very crucial to determine these regional factors accurately and find out whether a certain region is appropriate for deploying the system.

Second, the energy output of a PV system is influenced by some design factors such as the orientation and tilt of the PV panel. The orientation and tilt of the PV panel determines how much energy that a PV system captures from the solar radiation [3]. In general, the PV system performs best when the panel is facing south (orientation: 0°), and worst when the panel is facing north (orientation: 180°). Between these two extremes, the optimal tilt of the panel is usually determined by the latitude of the target region [4].

Third, the energy output of a PV system is influenced by system factors like the types of PV panel and the inverter. The PV panel can mainly be categorized into two types considering their materials and efficiencies: crystalline silicon and thin film [5]. The Crystalline silicon accounts for the majority of solar cell production with high efficiency. High efficiency module implies less PV systems’ installation area in comparison with lower efficiency module having same capacity under Standard Test Conditions (STC) rating [6]. Meanwhile, DC to AC conversion efficiency varies depending on the inverter type and selecting the inverter with high efficiency can minimize the loss of electricity associated with conversion.

Finally, there can be miscellaneous losses of energy output due to some uncertainties. These miscellaneous losses should be considered before installing a PV system; otherwise actual system energy output could be far less than expected energy output. The typical reduction factors of each miscellaneous losses is as follows [7]: (i) Snow: varies by region; (ii) dirt and soiling: 93%; (iii) efficiency decrease by temperature: 89%; (iv) shading: varies by case; (v) module mismatch: 98%; (vi) wiring losses: 97%; and (vii) degradation: the performance of the system degrades 0.8% every year (about 20% for 25 years).

2.3. Step 3: Estimating System Energy Output of the Possible System Alternatives

By considering the key factors affecting PV system performances, possible alternatives for selecting the optimal scenario can be established. Possible alternatives should satisfy two constraints: area limit and size limit as mentioned in step 1. When possible alternatives are all set, annual system energy output can be estimated using NRE simulation program such as RETScreen or Transys.

2.4. Step 4: Selecting the Optimal System through the Life Cycle Cost and Life Cycle CO₂ Analysis

The optimal system among possible alternatives established in the previous step can be selected through LCC and LCCO₂ analysis. Basic assumptions for LCC and LCCO₂ analysis should be defined as follows: (i) real discount rate considering the inflation rate, the electricity price growth rate, and the CO₂
emissions trading price growth rate; (ii) analysis period; and (iii) significant cost of ownership. Finally, LCC and LCCO\textsubscript{2} analysis results can be presented in terms of net present value (NPV), saving to investment ratio (SIR), and break-even point (BEP) [8].

3. Case Application

A typical residential PV system in Newark, New Jersey (NJ), U.S. was selected for the case application. This study assumes that a typical residence in Newark has following characteristics [9,10]: (i) monthly electricity consumption per household: 691 kWh; (ii) household size: 223 m\textsuperscript{2}; and (iii) roof type: pitched roof (7:12). By applying the proposed process of this study, the optimal PV system has been selected and the LCC and LCCO\textsubscript{2} results are shown in table 1. The selected optimal PV system size is 4.5 kW; and the NPV, SIR, and BEP came out to be $2,846, 1.184, and 20 years, respectively. By implementing optimization algorithms and automation process to this case application, it is possible to develop a decision support model for selecting the optimal photovoltaic system in the future research.

Table 1. LCC and LCCO\textsubscript{2} analysis result of the optimal PV system in Newark, NJ, U.S.

| Selected optimal system factors | NPV (\$) | SIR | BEP (yrs) |
|-------------------------------|---------|-----|-----------|
| System size | Installation area | Orientation | Tilt | Initial investment cost | Maintenance cost | Financial incentives | Electricity production benefit | Total | |
| 4.5 kW | 29 m\textsuperscript{2} | 0° | 30° | -23,400 | -6,240 | 14,177 | 18,309 | 2,846 | 1.184 | 20 |

4. Conclusion

In this study, a new process for deploying optimal PV system was proposed, which considers the characteristics of target facility, the key factors affecting system performances, the possible system alternatives and LCC and LCCO\textsubscript{2} of the system. To conduct a case application for the proposed process, a typical residential PV system in Newark, NJ, U.S. was selected. The results of this study could benefit potential PV system users and give new value in terms of system application in several ways: (i) maximize the financial benefit of the system through the LCC and LCCO\textsubscript{2} analysis; (ii) maximize the efficiency and utilization of the system by considering key factors affecting system performances; and (iii) consequently select the optimal PV system according to the target facility and the users’ preference.

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Biography
Minhyun Lee is a graduate student in Department of Architectural Engineering, as well as a researcher in SUSTainable Construction Management (SUSCOM) Laboratory at Yonsei University in South Korea. She conducts various studies on economic, environmental, and social impacts and management skills during the life cycle of the construction projects.