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Potential analysis of a target area selection for photovoltaic-based distributed generation in cases of an existing city in Korea

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ABSTRACT

To promote the use of renewable energy, renewable energy systems should be installed in the existing urban context. However, there is a limit to the application of renewable energy to new buildings. This paper evaluates the potential application of photovoltaic systems in an urban context for distributed generation. After considering the physical characteristics that affect the potential application, complexes are categorized. Based on the concept of a district unit plan, urban types are divided into four categories of low-rise, mid/low-rise, multiple housing, and business complex areas. Representative building and complex archetypes are proposed based on the results of a present condition survey. These complex block archetypes are used to analyze the potential applicability of rooftop PV systems. The total potential of energy share is 21, 15, 7, and 2% for low-rise housing, mid/low-rise housing, multiple housing, and business complex, respectively. The revenues of RPS by unit complex area increase in the order mid/low-rise housing, multiple housing, low-rise housing, and business complex. The results will be utilized as basic data for setting targets of renewable energy.

1. Introduction

Because of global warming and the exhaustion of fossil fuels, some of the most urgent issues in the world today have become saving energy and reducing CO_2 emissions. With this in mind, the United Nations Framework Convention on Climate Change (UNFCCC) suggested regional greenhouse gas (GHG) emission reductions, and various efforts to put these into practice are being made in developed countries (Ashina & Nakata, 2008; Elzen & Höhne, 2008; European Commission, 2001; Junfeng, Wan, ö Ohi, 1997; Metcalf, 2009; Wynne, 1993). With the adoption of the Paris Agreement in 2015, all countries will have a GHG reduction obligation, and the shift from traditional energy systems to new energy industry should take place. To achieve this, various support systems and policies are being promoted in most countries. The Korean government also announced its 8th basic plan for long-term electricity demand and supply to drive energy transition, such as the reduction of nuclear power plants, reduction of coal-fired power plants, and expansion of renewable energy (RE). One of the strategies is to increase the RE share to 20% of primary energy consumption by 2030 (Ministry of Trade, Industry and Energy, 2017). Renewable energy systems will be expanded, focusing on solar energy systems and wind systems for distributed resources. To achieve the target RE share, the Korean government plans to carry out the following: 1) expansion of transmission and distribution infrastructure to connect renewable energy, 2) reinforcement of backup facilities, such as LNG combined-cycle power systems, pumped storage power systems, and energy storage systems, 3) development of an integrated control system for the real-time monitoring, prediction, and control of RE, and 4) improvement of the electric power market system.

The smart grid is a power grid that utilizes electricity, and information and communication technologies, to intelligently advance the grid to provide high-quality power service and maximized energy efficiency (Fang, Misra, Xue, ö Yang, 2012). Specifically, intelligent demand management, advanced metering infrastructure, energy storage system, and distributed generation, such as PV or wind power generation, will lead to a smart grid. The paradigm shift to distributed generation at the community level has since become commonplace (Manfren, Caputo, ö Costa, 2011), and many demonstration projects are ongoing in many countries. The Korean government also is pushing ahead with demonstration projects of the smart grid. For site selection, many factors of influence are considered, such as mandatory local policies, technical infrastructure, business strategies, and education (Ha, Huy, ö Ramachandaramurthy, 2017; Lee ö Oh, 2015); however, the appropriate urban physical characteristics are required prior to beginning site selection, in order to maximize energy production output by renewable energy systems (RESs).

The applicability of RESs should be evaluated to utilize RE through distributed generation. Distributed generation typically uses renewable energy, which includes photovoltaics, wind power systems, fuel cells, and geothermal systems. In this paper, we focus on the PV systems for

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distributed generation, because the Korean government promotes PV and wind power systems as renewable resources, and among these two systems, the PV system is more suitable in the urban environment. Photovoltaic systems are more influenced by the physical characteristics of urban context, than are any other RESs. To provide information about the area of applicability for PV, Ramachandra and Shruthi (2007) approached the issue on a regional level, and Benli (2013) approached it on a national level, using a geographic information system (GIS). The area of applicability for RESs was proposed, mapping the solar radiation, wind velocity, capacity, and distribution of small hydroenergy sources, and bioresource supplies to GIS. Grosso (1998) claimed that it had an effect on energy production, because the solar irradiance and wind velocity are affected by urban form (layout, density, shape, and orientation of buildings). Kanters and Horvat (2012) analyzed the possibility of producing energy using photovoltaic systems through an analysis of the solar irradiance reaching the elevation of buildings, according to a layout pattern of urban blocks and density. In contrast, Wiginton, Nguyen, and Pearce (2010) evaluated the possibility of producing energy by analyzing the applicable roof areas, focusing on rooftop photovoltaic systems. Campos et al. (2016) evaluated the potential of distributed photovoltaics to analyze the solar radiation and energy performance in the urban context. Horváth, Kassai-Szoó, and Csoknyani (2016) proposed a methodology for determining PV and solar thermal systems at urban level based on roof types. They assumed that roof characteristics influenced energy demand. However, in the case of Korea, most buildings have similar types of roofs; they are flat. Because the efficiency of PV varies with the physical characteristics of applied sites, and the use of building varies by complex types, the urban characteristics of Korean buildings urban characteristics need to be investigated. The other researchers (Daud, Kadir, Gan, Mohamed, ö Khatib, 2016; Rau ö Wan, 1994; Rosa, Teixeira, ö Belati, 2018; Sardi, Mithulananthan, ö Hung, 2017; Shakouri, Lee, ö Kim, 2017) focused on the technical or economical aspects to maximize electricity output, such as line-loss reduction, voltage profile improvement, cost savings, and so on, using a heuristic method. This method does not consider a building's physical characteristics. In the early planning stage, the urban features, including a building's physical shape and energy demand profile, should be considered.

Although newly planned cities and buildings can consider the application of RESs from an early design stage, existing cities are different. Furthermore, the new buildings constructed in the last five years in Korea constitute only about 5% of the total number of buildings (Korean Statistical Information Service, 2017). Accordingly, there is a limit to the application of renewable energy systems (RESs) to new buildings to promote GHG emission reductions. To overcome this limitation, increasing efforts have gone into the rational utilization of energy on an existing city scale, and the distribution and expansion of green energy (Cai, Huang, Yang, Lin, ö Tan, 2009; Kaygusuz, Keles, Alagoz, ö Karabiber, 2013; Mourelatos, Assimacopoulos, ö Papagiannakis, 1998; Walker ö Devine-Wright, 2008). Because the potential applicability of RESs in existing cities is determined by the physical characteristics of existing buildings, it is imperative to analyze these characteristics. Photovoltaic systems are more influenced than any other RESs by the physical characteristics of urban context. However, as there is a lack of research in this area, this study aimed to classify the types of existing buildings in an urban context by use zoning, investigate the characteristics of these buildings by type, and analyze the potential applicability of RESs. The applicable RESs are limited to rooftop photovoltaic systems, which are affected by the physical characteristics of buildings. Seoul is selected as a typical existing city to analyze the characteristics of buildings in Korea. In a Korean urban area, the building density is high, and multi-family housing units or condominiums are popular residential buildings. Some residential buildings contain stores on the ground floor. Residential areas are very close to downtown. The uses of buildings are mixed in a community. The urban complex type is defined by the zoning type, and Seoul has all of the zoning types.

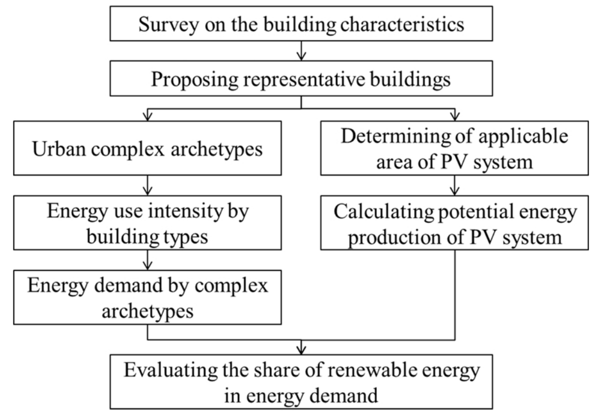

Fig. 1. The process of PV potential analysis.

In detail, this paper (a) proposes the process of potential analysis of rooftop PV systems, (b) surveys the characteristics of an existing city complex by investigating the building characteristics, (c) proposes representative building and urban complex archetypes, and (d) estimates the potential applicability of PV systems.

2. Methodology

To apply PV systems for distributed generation in an existing urban complex, it is first necessary to allocate space for its installation. Newly built cities are planned to suit PV, but PV systems in existing cities are planned based on the cities' physical characteristics. In this paper, the target system is limited to roof-top PV systems, excepting PV shading systems, wall types, and curtain wall PV systems. Fig. 1 shows the proposed process of potential analysis. Firstly, the building characteristics of the existing urban complex are surveyed by complex types. When considering PV application on an urban complex, physical characteristics like building density, building height, and urban building roughness should be examined. Building density is one of the factors that indicate the density of a city (Hui, 2001). Building densities are expressed by the building-to-coverage ratio (BCR) and floor area ratio (FAR; the ratio of the total building area to land area) of buildings. BCR and FAR have correlations with the heights of buildings, and have huge impact on the shape of a city. Generally, a lower BCR indicates that the separation distance between buildings is more available, which leads to a higher possibility of obtaining solar energy. This also indicates that nearby buildings have less effect, which is advantageous in terms of solar energy use (Kanters ö Horvat, 2012). The areas where PV systems can be applied are roofs, which are less affected by shading. Shading is affected by the spacing between adjacent buildings and their heights. It is assumed that the roof area is equal to the building area. The potential roof area is also affected by rooftop structures and the type of roof.

2.1. Survey on the physical characteristics of existing cities

Currently, the Korean government restricts the architectural density for building uses by use zoning proposed in the National Land Planning and Utilization Act (2013), and the standards vary for different localities. This paper selects a sample complex in accordance with the sub-classification proposed in "Use Zoning in Seoul," as listed in Table 1, and examines the real condition of the existing buildings within the scope of the sample complex.

The Class I exclusive residential area, as a detached and congested residential area, has an erratic organization of housing sites. The Class I general residential area and the Class II general residential area have the highest population densities, in comparison with other use areas, in

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