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Application of Geographic Information System to Power Distribution System Analysis

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Abstract

This paper presents a new application of Geographic Information System (GIS) in the field of electric power engineering. GIS can analyze and visualize information related to Geography. Recently photovoltaic (PV) generation is introduced in the power system day by day for the needs of clean energy. If it is installed in large quantities, voltage variation occurs with a risk of worsening electric power quality. In this context the limit of introducing PV in the power system should be correctly grasped. This research focuses on distribution system with large amount of PV. In order to grasp the limit of introducing PV in the distribution system, PV generation should be evaluated correctly and analyze the state of the distribution system. Although PV generation is proportional to solar radiation, the amount of solar radiation is affected by the shadow of the building, the angle, and the direction. Therefore, it is difficult to grasp solar radiation falling on the PV panels accurately and calculate PV generation. GIS can solve the problem. GIS can model actual townscape and analyze the amount of solar radiation. By executing solar radiation analysis to the modeled townscape, the amount of solar radiation on any places in the town can be evaluated. Using the result of the analysis, PV generation installed on any places in the town can be estimated and more proper distribution system analysis can be performed than conventional analysis.

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Keywords: Geographic Information System; distribution system; photovoltaic; smart grid

1. Introduction

In Japan, there is a great demand of renewable energy triggered by the suspension of nuclear power plants after Great East Japan Earthquake in 2011. Highly expected renewable energies in the world are solar power and wind power. Solar power has high potential. If the whole area of Gobi Desert is covered with solar cells, all energy consumed in the world can be provided [1]. But photovoltaic can't produce energy constantly because it depends on

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solar radiation. Wind power also has high potential. If wind turbines are installed on the place where has good wind conditions, they can generate electric energy greatly and constantly. But it's not easy to find the good locations and install wind turbines because wind conditions in Japan are difficult to be estimated due to changes of the seasons and typhoons [2]. The location of photovoltaic system can be more easily chosen so it is more suitable for narrow land of Japan. [3] Therefore, in Japan, solar power is demanded more than wind power. In addition, such as introduction of Feed in Tariff (FiT) and reduction in equipment prices are spurring the introduction of photovoltaic. By 2030, cumulative introduction amount of PV will reach more than 100 GW. Photovoltaic for residential use is expected to be installed constantly [4].

If photovoltaic is largely installed in distribution system, voltage variation will occur especially at the end of the distribution network. It is possible to transcend stipulated voltage (101V±6V). Due to the over voltage, output of PV system is limited by power conditioners [5]. To Avoid this situation, the amount of photovoltaic may be strictly regulated by electric utility in the future. For that reasons grasping the introduction limit beforehand is necessary. In order to achieve this purpose, PV generation should be properly calculated and the state of the distribution system should be evaluated.

The amount of PV generation is related to the installation situation of PV panel like direction, degree, shadow caused by high buildings and trees. In other words, the factors influencing the PV generation are geospatial data. In order to calculate PV generation, Geographic Information System (GIS) is used in the research. GIS can manage, analyze, and show the geospatial information. One of the application of GIS is solar radiation analysis. Solar radiation analysis is usually used to estimate the area/period of road freeze [6]. However, this function is applied to calculate PV generation in this paper.

Section 2 describes GIS technologies. Section 3 of this paper talks about the utilization of GIS in power system and some analysis and result. Section 4 concludes.

2. Geographic Information System

Geographic Information System (GIS) is a technology for the creation, management representation, search, analysis and sharing of geospatial information [7]. GIS manages data in a film called layer. The layer consists of position information and attributes information. As shown in Fig.1, GIS constitutes a model of the real world by superimposing layers, which reveals the geographical distribution and geographically related data. Data used in GIS called geospatial data is based on a so-called big data with a variety of functions. Typical features and geospatial data of GIS is shown in Fig. 2, where Digital Surface Model (DSM) is considering the height of trees and buildings, while Digital Elevation Model (DEM) is representing ground surface in details. Tracking function handles the trajectory of the acquired position information by GPS. Spatial statistics functions aggregate the objects in the view. Geocoding is responsible about coding the text address. 3D function handles the three-dimensional data. Network analysis function performs the analysis of the network data. Finally, Spatial analysis function simulates the events which might occur in the targeted area, for example, simulating the tsunami[8].

To evaluate PV power generations in the distribution system, DSM as the geographical data and 3D and Spatial analysis as the function of GIS are used. DSM is used to measure the directions and degrees of PV panels for solar radiation analysis on panels. 3D is used to express the height of buildings and trees. Spatial analysis includes, for example, solar radiation analysis tool which calculates the amount of solar radiation falling on PV panels and describing tool which can express grid network and installed equipment on the map [9]. To combine the geospatial data with the function of GIS, distribution system analysis is supported.

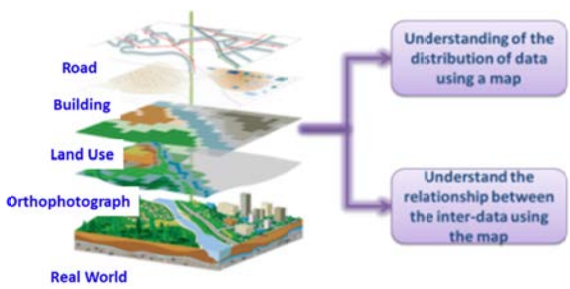

Fig.1. The basic principle of GIS

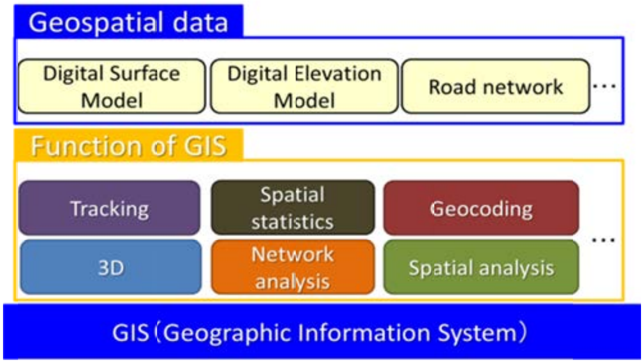

Fig.2. Geographical data-function of GIS

3. Calculating PV power generation using solar radiation analysis tool

When objects like trees cast a shadow on PV panels, power generation is greatly dropped because of deterioration in solar radiation. It is important to consider shadow effect on PV power generation. The effect can be calculated with power generation considering solar radiation analysis, by using the functions of GIS with Digital Surface Model (DSM). Through the DSM data shadow effect on solar radiation analysis can be taken in account as shown in Fig.3.

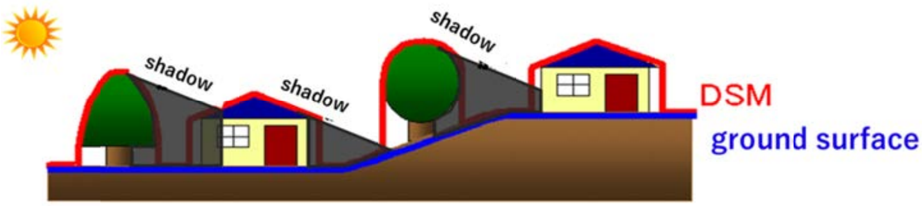

Fig.3. Image of Digital Surface Model

Fig.4 describes townscape using DSM as the geographical data and 3D as the function of GIS. The height of buildings is expressed by the brightness of color, that is, the brighter describes the higher. Solar radiation measuring point surrounded by high buildings is shown in Fig.4. To clarify the shadow effect at the measuring point, the two different DSM data are used. One is the original townscape shown in Fig.4, the other one is the building to have the measuring point. This condition is made by clipping the original townscape using one of the function of GIS. The result of solar radiation analysis is shown in Fig.5. The one line shows the solar radiation at the measuring point without surroundings and the other line shows the solar radiation in the case where there are high buildings around the measuring point. This figure means that the solar radiation is deteriorated by the shadow made by a high building next to the measuring point as shown in Fig.6. In the figure the measuring point is marked with a concentric circle.

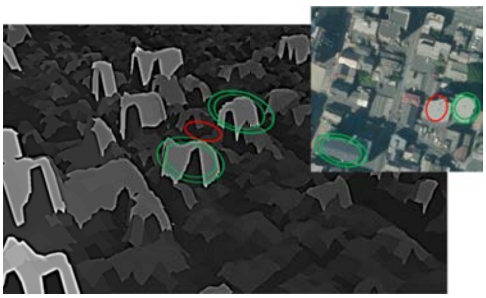

Fig.4. Solar radiation measuring point (marked with a circle) surrounded by high buildings (marked with double circles)

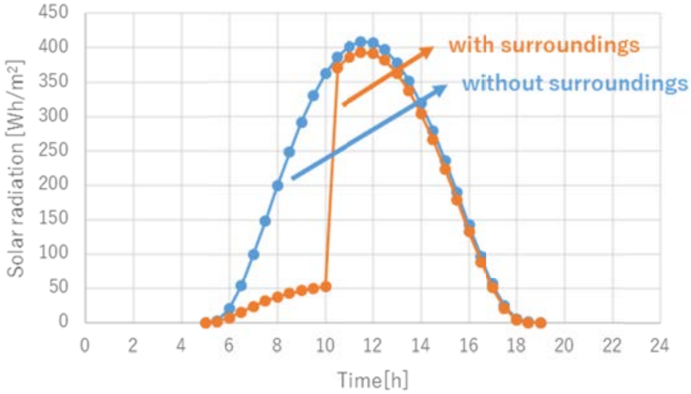

Fig.5. The result of solar radiation analysis

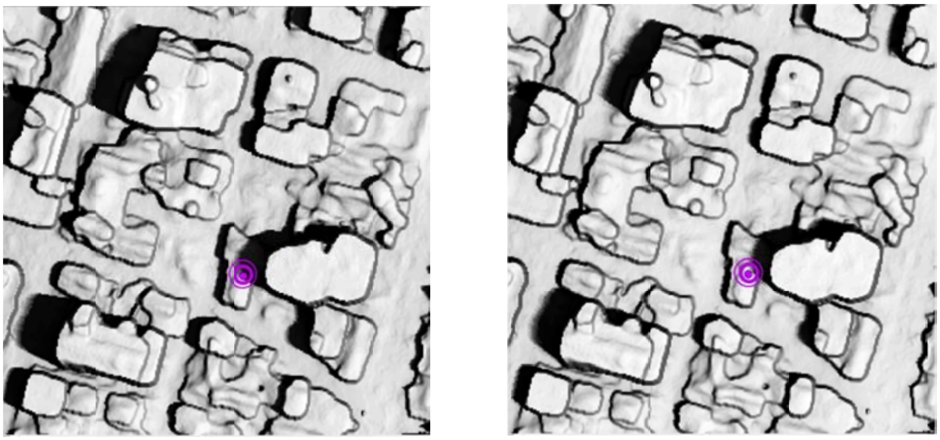

Fig.6. (a) Visualization of solar radiation around the measuring point at 10:00, (b) At 10:30

In addition, solar radiation varies greatly depending on the weather. However, solar radiation analysis which considers weather change in GIS takes a long time for the computing process. Therefore, solar radiation analysis under the sunny condition and solar radiation meter is used in this research to consider the weather change. The solar radiation including weather and shadow effects at the measuring point is expressed by the following equation:

$$SR = SR_m \times k \quad (1)$$

SR[kW/m^2] is the solar radiation including weather and shadow effects. SR_m [kW/m^2] means the value which a solar radiation meter measures and as a result SR includes the weather effect. k means the ratio of analyzed solar radiation at the measuring point to that at the point where solar radiation meter is set. Using this equation PV power generation is expressed by following equation:

$$P_g = SR \times A_{panel} \times \eta \times \alpha = SR_m \times k \times A_{panel} \times \eta \times \alpha \quad (2)$$

where P_g[kW/m^2] is the calculated PV power generation, A_{panel} is the area of PV panel, η is the efficiency of power conversion, and α is temperature correction coefficient (TCC). Efficiency of power conversion includes efficiency of solar panel and that of power conditioning system (PCS). TCC represents the deterioration of efficiency due to high temperature, where the factor is only valid in the case of crystal silicon based solar cells [10]. In this calculation, TCC is assumed to be expressed as a linear function of temperature [11]. Calculated PV power generation with $A_{panel} = 50$ [m^2], η=0.15 is shown in Fig.7.

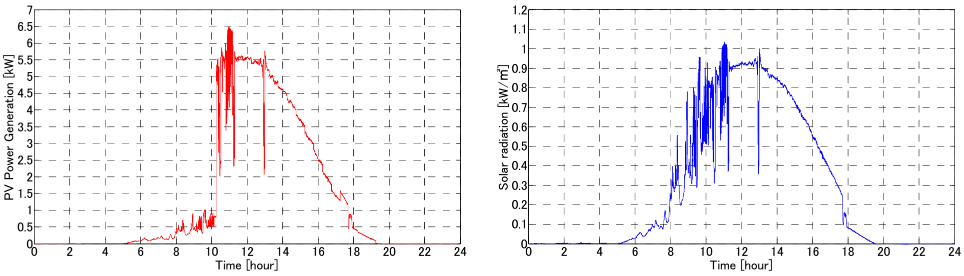

Fig.7. (a) Calculated PV power generation, (b) Solar radiation measured by solar radiation meter

It is found that the calculated PV power generation is low in the morning, which reflects the shadow effect at the measuring point. Using the solar radiation analysis and this calculation, PV power generation installed at any place can be grasped accurately. Applying this function to distribution system analysis, more proper simulation can be performed compared to conventional simulation. In addition, this function should be useful for a person who intend to install a PV panel on the roof top of his/her house, since expected power generation from the panel can be evaluated before installation.

4. Power distribution system analysis considering the shadow effect on PV generation

The distribution system model used in this paper is shown in the Fig.8. The analysis have been executed in the following conditions: Total route length of the distribution system is 4.14 [km], the number of house connected with the distribution system is 240 and the rate of PV generation introduction is 30 [%]. Every bus of this system contains the load and PV generation.

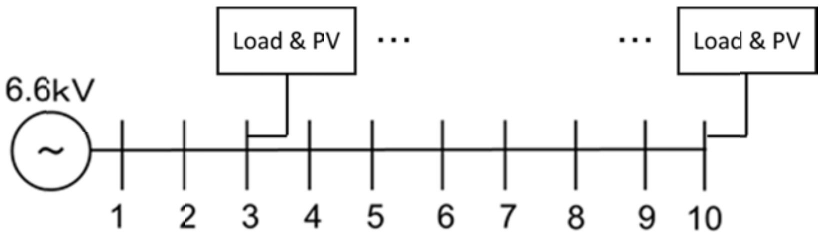

Fig.8. Distribution system model

In the analysis, two different situations are considered: One is that all PV systems are influenced by the shadow in the morning, the other one is that all PV systems are not influenced by the shadow. The result of voltage analysis is shown in Fig.9. The figure describes the shadow effect in the morning. The result of the simulation shows that distribution system analysis considering the shadow effect is possible. By obtaining solar radiation on the all PV systems using GIS, and grasping PV generation using the calculation method in this research, more proper simulation in the distribution system can be performed. This method can give the solution to evaluating the state of the distribution system.

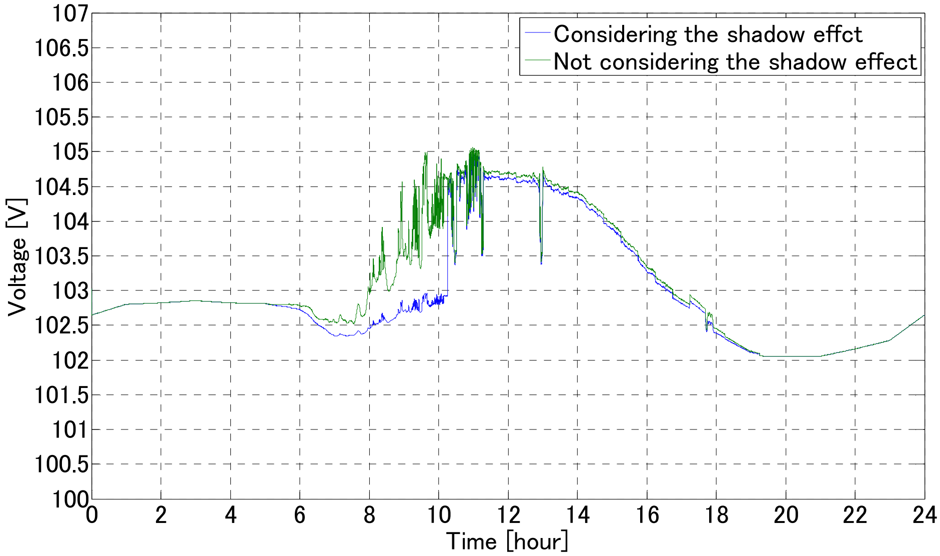

Fig.9. The result of distribution system analysis

5. Conclusion

This paper introduces an example of GIS application to electric power engineering field. Calculation method for PV power generation considering shadow effect is developed using solar radiation analysis tool in GIS. This calculation can be applied not only for power distribution system analysis but also for estimation of expected PV generation. To evaluate and manage the influence of large scale PV introduction in a power distribution system, the developed methods can monitor the dynamic behavior and steady state of distribution system and grasp the PV introduction limit in the system. This paper gives a solution for the best utilization of PV systems.

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