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# A Case Study on Suitable Area and Resource for Development of Floating Photovoltaic System

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***Abstract*—**In development of floating photovoltaic generation system, finding a suitable place of installation is as important as development of economically feasible and stable structure. Especially since floating photovoltaic system has its facility floating on water surface, it is extremely important to review the effects of weather conditions such as wind, water flow and floating matters, various factors (such as fogs) that can reduce generation efficiency, possibility of connection with power system, and legal restrictions. The method of investigating suitable area and resource for development of tracking-type floating photovoltaic generation system was proposed in this paper, which can be used for development of floating and ocean photovoltaic system in the future.

***Keywords*—**Floating PV system, On-site Survey, Resources Survey of Photovoltaic, Tracking-type Floating PV.

## I. INTRODUCTION

### A. Floating PV Plants Outline

A developed floating PV system results from the combination of PV plant technology and floating technology. This fusion is a new concept for technology development. As a new generation technology, it can replace the previous PV plant that installed on top of existing woodland, farmland and buildings. The floating PV plant consists of a floating system, mooring system, PV system and underwater cables as shown in Fig. 1 [1]-[10].

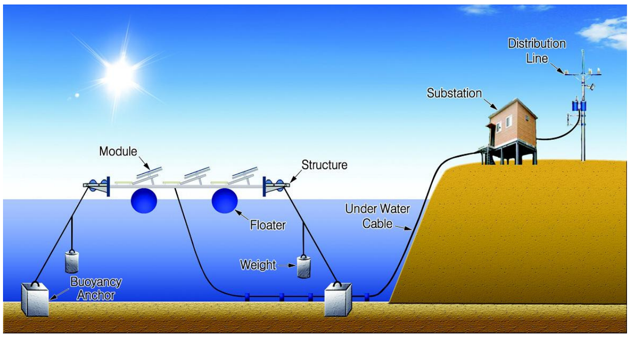


Fig. 1 Floating PV Plants Outline

a. Floating System: A floating body (Structure + Floater) that allows the installation of the PV module
b. Mooring System: Can adjust to water level fluctuations while maintaining its position in a southward direction
c. PV System: PV generation equipment, such as electrical junction boxes, that are installed on top of the floating system
d. Underwater Cable: Transfers the generated power from land to the substation

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### B. Selection of Installation Point

In development of floating photovoltaic generation system, it is as important to find suitable installation point as to develop economically feasible and stable structure. Especially as floating photovoltaic system has its facility floating on water surface, it is extremely important to review the effects of weather conditions such as wind, water flow and floating matters, various factors (such as fogs) that can reduce generation efficiency, possibility of connection with power system, and legal restrictions.

The most important matters that must be taken into consideration for selection of suitable area for installation of floating photovoltaic generation facility are as follows.

– Factors that directly affect generation (efficiency): Solar radiation, fog, occurrence of shade, etc.
– Factors that affect installation and maintenance: depth of water (water level fluctuation), frozen region, inflow of floating matters, accessibility, interference by dam facilities (water intake tower, waste-way), etc.
– Connection with power system: spare capacity of KEPCO (Korea Electric Power Corporation) distribution line, distance to distribution line, distance to load (receptor), etc.
– Legal restrictions: water source protection area (Water Supply and Waterworks Installation Act), special countermeasure area (Framework Act on Environmental Policy), waterfront area (related River Acts), Local Environment Preservation Act, Protection of Wild Fauna and Flora Act, fishing prohibition area, marine leisure activity prohibition area, civil complaints, excessive compensation expense, inducement of environmental problems, etc.

For selection of suitable area, diverse factors described above must be comprehensively considered for judgment. The aim of this paper is to present the method of surveying suitable area for development of tracking-type floating photovoltaic generation system, along with a case study.

## II. SELECTION OF INSTALLATION POINT FOR TRACKING-TYPE FLOATING PHOTOVOLTAIC SYSTEM

### A. Selection of Installation Point

1. Survey by drawing

The tracking-type floating photovoltaic generation plant of this study was decided to be installed nearby Main Dam Water

Culture Center of Hapcheon Dam with desirable accessibility for maintenance, for use in promotion of landmark creation project in the floating photovoltaic region of Hapcheon-gun. The expected position of installation was indicated as shown in Fig. 2, and property survey was performed on this point. For the property survey, water depth data in the Hapcheon Lake Sediment Report prepared in 2012 was used.


Fig. 2 Installation position of substantiation-plant

As shown in Fig. 3, direct installation area of the demonstration plant is 2,830m$^2$(53.2m×53.2m), and occupied area with consideration on mooring vessel was estimated to be about 3,240m$^2$.

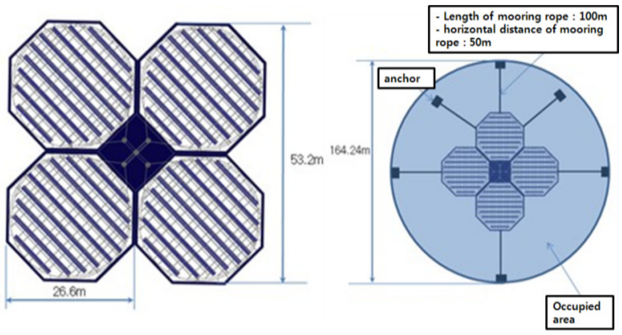



Fig. 3 Calculation of occupied area for substantiation-plant

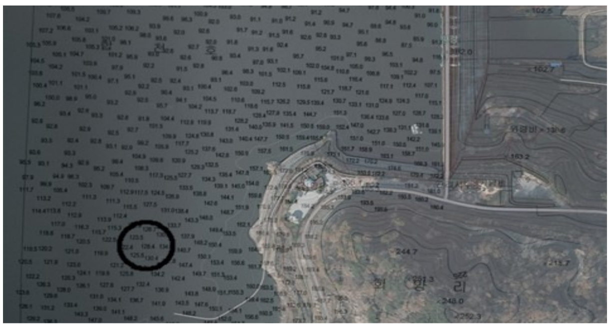
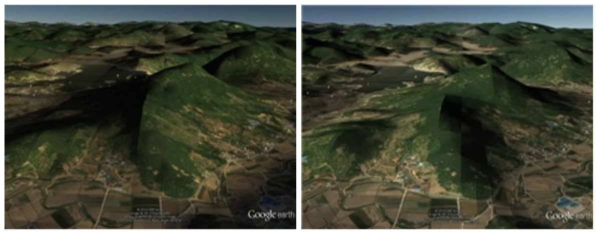


Fig. 4 Depth-map of Hapcheon Dam

As a result of surveying water depth map shown in Fig. 4, flood water level of Hapcheon Dam is EL178m and low water level is EL140m. Water depth distribution of the candidate site is EL110m~EL120m, maintaining stable water depth of about 20m at low water level. This site is considered to have extremely favorable conditions.

Sunlight distribution of the candidate site during winter season was surveyed using Google Earth as shown in Fig. 5. As a result, shadow seems to be created in the early morning due to surrounding mountains, but there was no problem after 9 o'clock. Also, as there are no obstacles, photovoltaic generation can be done until late time in the afternoon.



(a) 8:00AM (b) 4:00PM

Fig. 5 Hourly distribution of daylight in the winter (a) 8:00AM (b) 4:00PM

According to the data of National Institute of Meteorological Research as shown in Fig. 6, Hapcheon-gun area was found to be a region with extremely good annual cumulative solar radiation.

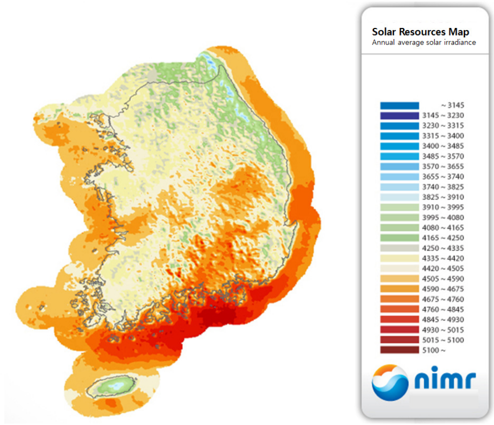



Fig. 6 Korea Solar Resources Map [11]

2. On-site Survey

On-site survey was conducted on water depth, inflow of floating matters, and points of connection with power system of the candidate site, and solar radiation was analyzed using Solar Pathfinder. The analysis result is as shown in Table I.

TABLE I
RESULTS OF FIELD SURVEYS

| | Candidate | remarks |
|---|---|---|
| Average Depth | 25m | Ultrasonic measurement |
| Floating matters influx | Not affected | Observer |
| Ease of grid-connected power | Good | Need more distribution lines(100m) |
| Work space | Some poor | Need more work space |

TABLE II
SOLAR PATHFINDER ASSISTANT

| | |
|---|---|
| latitude | 35°32' |
| east longitude | 128°16' |
| Azimuth | 180°(southward) |
| Tracking system | Fixed |
| Electricity Sales Price | 462.69won/kWh |
| Installed capacity | 100 kW |
| Inverter Derate | 0.960 |
| Panel | 310W × 320EA |

Input conditions and results of analysis on the shade on the round dome using Solar Pathfinder are as in Tables II, III and Fig. 7. Analysis with Solar Pathfinder is a simple analysis tool used to examine the degree of effect (shade) of shadow on the candidate area during early stage of survey on suitable area, and accurate analysis on economic feasibility must be additionally performed.

TABLE III
ANALYSIS OF SOLAR PATHFINDER

| Division | Value | Candidate |
|---|---|---|
| The ideal efficiency of the installation point (%) | 99.44 | |
| The actual efficiency of the installation point (%) | 99.19 | |
| Estimated annual electricity generation(kWh) | 130,553 | |
| Estimated annual revenue (thousand won) | 60,396 | 462.69won/kWh |

< Solar Pathfinder Assistant Summary Data>

| Month | Ideal Unshaded AC Energy (KWH) Azimuth=180.0 Tilt=35.32 | PV Solar Cost Savings 462.69 (\/KWH) | PVWatts Unshaded % Actual Site Azimuth=180.0 Tilt=33.00 | Actual Site Efficiency% Azimuth=180.0 Tilt=33.00 | Ideal Site Efficiency % Azimuth=180.0 Tilt=35.32 |
|---|---|---|---|---|---|
| January | 9,540.00 | \4,354,050 | 99.87% | 98.32% | 99.55% |
| February | 10,191.00 | \4,687,050 | 99.87% | 98.83% | 99.48% |
| March | 11,013.00 | \5,091,626 | 99.34% | 99.34% | 99.29% |
| April | 13,144.00 | \6,096,985 | 99.06% | 99.66% | 99.06% |
| May | 12,793.00 | \5,994,612 | 99.91% | 100.00% | 99.94% |
| June | 9,900.00 | \4,654,661 | 99.97% | 100.00% | 99.77% |
| July | 9,090.00 | \4,266,464 | 99.89% | 100.00% | 99.96% |
| August | 12,021.00 | \5,585,583 | 99.75% | 99.59% | 98.70% |
| September | 9,680.00 | \4,483,370 | 98.84% | 99.10% | 98.69% |
| October | 12,253.00 | \5,630,989 | 99.35% | 98.90% | 99.41% |
| November | 10,258.00 | \4,867,434 | 99.59% | 98.29% | 99.55% |
| December | 10,670.00 | \4,863,335 | 99.90% | 98.26% | 99.83% |
| Totals | 130,553.0 | \60,396,159 | 99.53% Unweighted Yearly Avg | 99.19% Unweighted Yearly Avg | 99.44% Unweighted Yearly Avg |

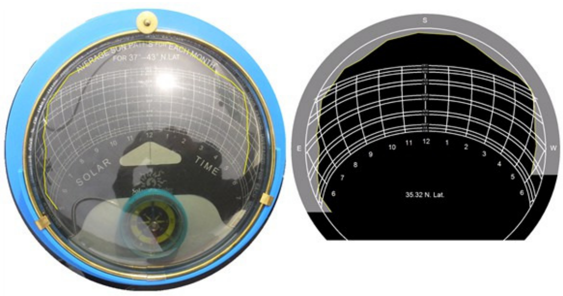


Fig. 7 Shaded contour tracking of Solar Pathfinder

### B. *Survey on the Effect of Floodgate Opening during Flood*

Since the installation point of tracking-type floating photovoltaic generation system is close to the waste-way floodgate of Hapcheon Dam and is likely to be affected by opening of floodgate during flood season, 2-dimensional simulation on the size of water flow upon opening of floodgate was performed to reflect flow on the design of mooring system and structure. Hapcheon Dam discharged water once in 1998, 2000 and 2002. Review was carried out based on the floodgate data for 2002.

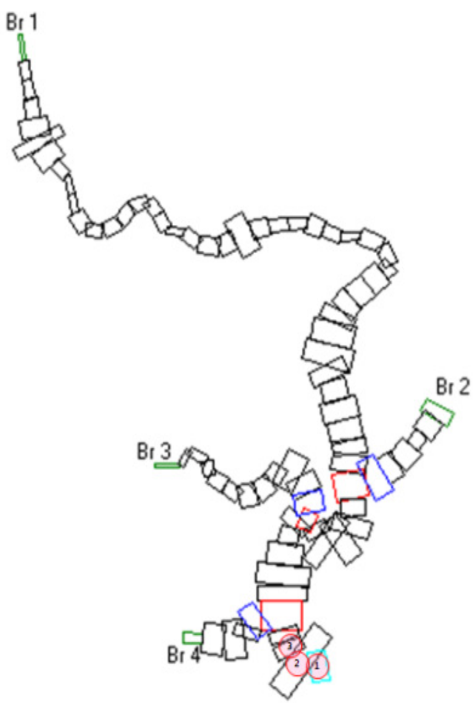



Fig. 8 Installation point of the floating photovoltaic (No.2)

Area 2 in Fig. 8 is the position of plant installation. As a result of simulation shown in Fig. 9, maximum flow was analyzed to be 0.36m/sec. As mooring system and structure of the plant were designed for sustaining flow of 1 m/sec, there is no large influence by opening of floodgate.

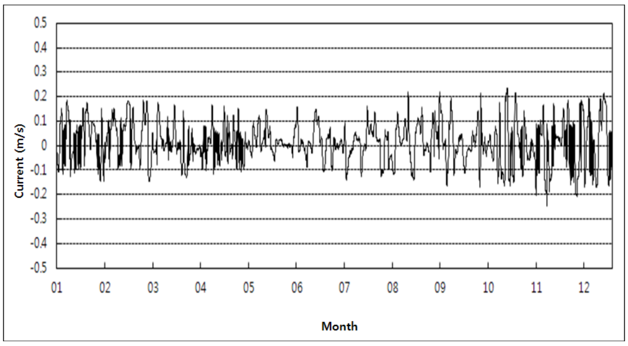



Fig. 9 Result of monthly current-modeling of the prototype at the installation position

## C. *Survey of System Connection*

Land survey is largely divided into system connection for each section of the candidate area, entry road status of each section, and area of work site. Items of land survey are as follows.

- Name of distribution line (electric pole number, distance from the expected installation site)
- Connectivity with electric facility of existing dam (review of connectivity with electric facility of existing dam)
- Conditions of work site (area, utility, open-air site, access to existing road)
- Nearby road status (road width, road length)
- Inflow of floating matters
- Current usage status of nearby facilities, etc.

Power generated by this tracking-type floating photovoltaic plant will be sent to Yongju D/L located nearby Hapcheon Dam, and current spare capacity of the line is 560kW. There is no problem in system connection. However, additional supplementation of facility will be required if voltage of the distribution line increases depending on the result of application for approval of electricity use.

# III. Selection of Optimal Tilt Angle

## A. *Survey of Photovoltaic Resource*

Installation angles generally applied to fixed-type photovoltaic modules of Korea were shown in Table IV and Fig. 10. Optimal installation tilt angles for photovoltaic arrays around the nation have distribution of about 24°~36°, and optimal installation tilt angles for photovoltaic arrays around the nation excluding Jeju-do were found to be about 30°~36°.

When two rows or more of photovoltaic arrays are installed, they must be installed so that the shadow of arrays in the front row does not affect arrays in the back row. In general, the formula used to find minimum interval of fixed-type photovoltaic array is as follows.

$$X = L\left[\cos(tilt) + \frac{\sin(tilt)}{\tan(alt)}\right]$$

Here, X: minimum separation distance of arrays, L: length of module in tilt direction, tilt: tilt angle of array, and alt: altitude of the sun.

TABLE IV
Korea Regional Optimum Tilt Angle

| Area | Optimum tilt angle | Area | Optimum tilt angle | Area | Optimum tilt angle |
|---|---|---|---|---|---|
| Gangneung | 36° | Cheongju | 33° | Daegu | 33° |
| Chuncheon | 33° | Daejeon | 33° | Busan | 33° |
| Seoul | 33° | Pohang | 33° | Gwangju | 30° |
| Wonju | 33° | Jinju | 33° | Mokpo | 30° |
| Seosan | 33° | Jeonju | 30° | Jeju | 24° |

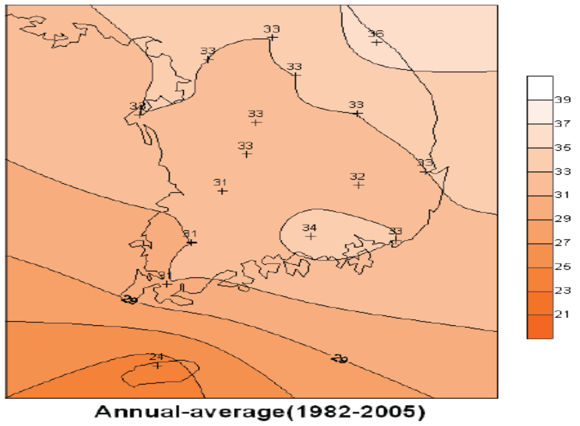



Fig. 10 Korea regional distribution of the optimal tilt angle [12]

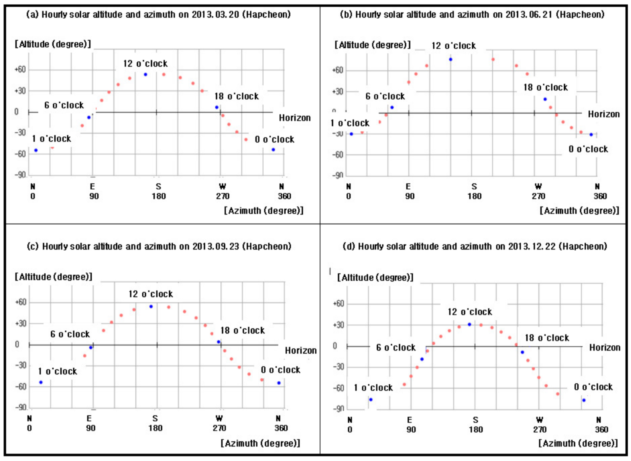



Fig. 11 Seasonal and hourly solar elevation of Hapcheon (a) Hourly solar altitude and azimuth on 2013.03.20 (b) Hourly solar altitude and azimuth on 2013.06.21 (c) Hourly solar altitude and azimuth on 2013.09.23 (d) Hourly solar altitude and azimuth on 2013.12.22 [13]

## B. *Selection of Module Tilt Angle and Separation Distance*

The tracking-type floating photovoltaic plant of this study will be installed by mixing the variable slope method and fixed method. In this case, there is a disadvantage of extremely large separation distance between arrays in the morning and late afternoon when altitude of the sun is low. This causes increase of structure size, and excessive installation expense is expected. Therefore, optimal tilt angle must be selected with consideration on economic feasibility, and the size of structure must be determined based on tilt angle. Optimal tilt angle in general is known as 45° when only horizontal tracking is taken into account. In this case, minimum separation distance is 3.35m with altitude of the sun in Hapcheon region being 15° at 9 AM based on Fig. 11 and vertical length (998cm) of 310W photovoltaic module. Since there is a problem of excessive increase in installation expense due to increased size of structure when identical capacity is installed, tilt angle for this demonstration plant was chosen as 33° with consideration on economic feasibility. In this case, minimum separation distance is 2.9m.

TABLE V
THE SOLAR ALTITUDE HAPCHEON AT WINTER SOLSTICE

| Time | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|
| Altitude (deg) | 4 | 15 | 26 | 29 | 30 | 29 | 28 | 20 | 14 | 3 |

- Separation distance when tilt angle of the module is 45°

$$\mathrm{X} = L\left[\cos(45^o) + \frac{\sin(45^o)}{\tan(15^o)}\right] = 3.35L$$

- Separation distance when tilt angle of the module is 33°

$$\mathrm{X} = L\left[\cos(33^o) + \frac{\sin(33^o)}{\tan(15^o)}\right] = 2.87L$$

## IV. CONCLUSION

In development of floating photovoltaic system, finding an appropriate installation point is as important as development of economically feasible and stable structure.

In this paper, property survey, on-site survey, and photovoltaic resource survey were conducted with the case of 100kW tracking-type floating photovoltaic system in Hapcheon Dam. Water depth (data and actual measurement), solar distribution, shade analysis (analysis of Solar Pathfinder), effect of floodgate opening during flood (flow modeling), and system connection were reviewed, as well as connectivity with power system. In addition, altitude of the sun in the installation point was surveyed for each season and hour to select optimal tilt angle and separation distance for photovoltaic arrays.

The suitable area and resource survey method presented in this paper can be utilized as basic data for development of floating and ocean photovoltaic generation systems in the future.

## ACKNOWLEDGMENT

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