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Recent Advances in Liquid Type PV/T Configurations

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***Abstract*: The liquid type PV/T system is a new concept in energy technology to meet the needs. The liquid based PV/t collectors are practically more desirable and effective than air based system. Temperature fluctuation is more in air based PV/T collectors compared to liquid based PV/T collectors. This system has 11% better efficiency than the air based system This paper gives a brief overview of the liquid type PV/T technology, their efficiency, applications, advantages, limitations and research opportunities available.**

***Keywords*: Floating photovoltaic system, PV generation efficiency**

1. Introduction

Recently, the market for solar-energy is expanding due to introduction of the RPS (Renewable Portfolio Standard). Thus, vigorous research is held on alternatives against the lack of sites to install overland PV systems. The floating PV system demonstrated in this paper is a new method of solar-energy generation utilizing water surface available on dams, reservoirs, and other bodies of water. This method has an advantage that allows efficient use of the nation's soil without bringing damages to the environment, which the pre-existing PV systems cause when it is installed in farmlands or forests. Until 2012, Korea applied REC (Renewable Energy Certificate) value of 1.0 to floating PV systems similar to general PV systems. However, recognizing the technological value and necessity of floating PV systems, Korea has announced that the REC value will be 1.5 for floating PV systems, the same value as BIPV (Building Integrated Photovoltaic System), from year 2013. This paper will briefly introduce the 100kW and 500kW floating PV systems which K-water developed and installed, and analyze its utility compared with overland PV systems on the basis of its generation performance since its installation. Also, effect of wind speed, and waves on floating PV system structure was measured to analyze the effect of the environment on floating PV system generation efficiency.

2. Literature review

A. *Concept of Floating PV System*

A developed PV floating power generation 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 existing PV plants that are installed on top of woodland, farmland and buildings. The PV floating plant consists of a floating system, mooring system, PV system and underwater cables.

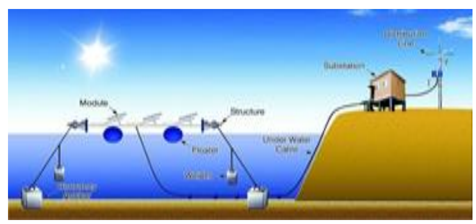

Fig. 1. PV Floating plants outline

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, similar to electrical junction boxes, that are installed on top of the floating system
d) *Underwater Cable:* Transfers the generated power from land to the PV system

B. *K-water 100kW, 500kW Floating PV Systems*

K-water has installed a 100kW floating PV system on the water surface of Hapcheon dam reservoir in October 2011 for operation. After successfully installing the 100kW floating PV system, K-water additionally installed a 500kW floating PV system on another location nearby in July 2012. The electricity generated by the two floating PV systems installed in Hapcheon dam reservoir are generating profits by being sold to the national power grid. Figure 2 displays the view of the 100kW and 500kW floating PV systems.

Fig. 2. K-water PV floating plants outline

C. *Performance Analysis of Floating PV System*

1) 100kW Floating PV System

The 100kW floating PV system in Hapcheon is forming a 33° tilt and its installed capacity is 99.36kW, composed of 414 240W modules. Figure 3 represents the generation quantity and capacity factor of the Hapcheon 100kW floating PV system based on the data acquired between January 2012 to December 2012. The standards for generation quantity was the amount read on the meters at VCB, and the capacity factor was calculated under the following equation (1).

$$\text{Capacity Factor (\%)} = \frac{\textit{Generated Quantity Duration Analysis Period (kwh)}}{\textit{Installed Capacity (kw)} \times \textit{Analysis Period (h)}} \times 100 \quad (1)$$

Monthly average generated quantity during January 2012 to December 2012 was 10,853kWh, and the average capacity factor was 14.9%. The maximum monthly generated quantity was 13,792kWh in October and the minimum was 8,224kWh in December. For capacity factor, the maximum capacity factor was 18.7% in October and the minimum was 11.1% in December.

Fig. 3. Hapcheon 100kW Floating PV System performance analysis graph

2) 500kW Floating PV System

The 500kW floating PV system in Hapcheon is forming a 33° tilt and its installed capacity is 496.8kW, composed of 2070 240W modules. Figure 4 displays the generation quantity and capacity factor of the Hapcheon 50kW floating PV system based on the data acquired from October 2012 to March 2013. The standards for generation quantity was the amount read on the meters at VCB, and the capacity factor was calculated under the above equation (1).

Monthly average generated quantity during October 2012 to March 2013 was 55,028kWh, and the average capacity factor was 15.2%. The maximum monthly generated quantity was 76,748kWh in March and the minimum was 41,684kWh in November. The maximum capacity factor was 20.8% in March and the minimum was 11.7% in November.

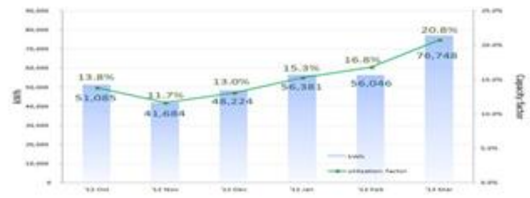

Fig. 4. Capacity factor in November

3. Discussion

For a comparative analysis of the generation performance of Hapcheon floating PV system, the system was compared with a 1MW overland PV system installed in Haman - gun. Haman was chosen as the comparison target as the Haman 1MW overland PV system is installed 60 kilometers southeast from Hapcheon, where the solar radiation and temperature is similar, and also has similar date of installation (2012). Haman 1MW overland PV system forms a fixed 30° tilt and its installed capacity is 935.9MW, while composed of 4,000 250W modules.

First of all, for a more accurate comparison analysis between the 100kW floating PV system and the 1MW overland PV system, days with blackouts, maintenance, and data-error were excluded from comparison. The analysis period consisted of one year starting from February 2012 to January 2013, while data from 185 days of the period were used for analysis. Hapcheon 100kW and Haman 1MW's daily generation quantity was 421kWh/day and 3,486kWh/day each.

To compare the two power plants with different capacity, "Daily average generation quantity of Haman 935.9kW overland PV system when converted into 99.36kW" was calculated and compared with the "Daily average generation capacity of Hapcheon 99.36kW floating PV system." As the result, the coefficient of utilization of the 100kW and 1MW were 17.6% and 15.5% respectively, which means that Hapcheon 100kW floating PV system's value is 13.5% higher than that of Haman 1MW system. Figure 5(a) compares the daily generation capacity of the 100kW and 1MW system (converted into 100kW system). Secondly, we analyzed performance of 500kW and 1MW with same method.

The analysis period was six months starting from October 2012 to March 2013, while data from 122 days were used for analysis. Hapcheon 500kW and Hama MW's daily generation quantity was 2,044kWh/day and 3,491kWh/day each.

To compare the two power plants with different capacity, "Daily average generation quantity of Haman 935.9kW overland PV system when converted into 496.8kW" was calculated and was compared with the "Daily average generation capacity of Hapcheon 496.8kW floating PV system." As the result, the coefficient of utilization of the 500kW and 1MW shown 17.1% and 15.5% respectively, presenting that Hapcheon 500kW floating PV system's value is 10.3% higher than that of Haman 1MW system. Figure 5(b) compares the daily generation capacity of the 500kW and 1MW system (converted into 500kW system).

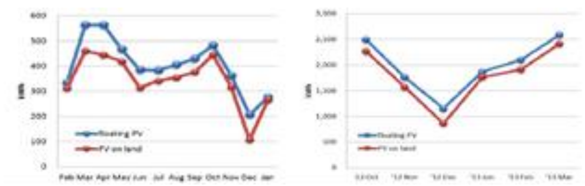

Fig. 5. Comparison of daily average generation capacity

A. 2.4kW Floating PV Operation Characteristics Analysis

Korea's first floating PV system was constructed in Juam Dam in August of 2009. In 2010, overland PV plant was constructed near floating PV plant site.

Juam 2.4kW floating and overland PV system are fixed at an angle of 11 ° and consist of twelve 200W modules. Figure 6 is a graph is displaying amount of power generated and percentage of facility use, based on data acquired from Juam 2.4kW floating and overland PV system from January to July of 2012. The greatest amount of power generated and percentage of facility use was in May and the least in January. The percentage of floating PV use in May was 15.39% higher than the overland PV system. Also, the average percentage of floating PV use from January to July was 14%, while that of overland PV was 13%, which means that the percentage of floating PV use was 7.6% higher than that of overland PV. Table 1 shows the daily power generation by Juam 2.4kW floating PV system and Table 2 shows the daily power generation of Jam 2.4kW overland PV system.

Fig. 6. Comparison Graph of Juam Dam Floating-overland Power

B. Generation

Power Generation Performance Cause Analysis through Analyzing Temperature of PV Module. Figure 6 illustrates temperature of Juam 2.4kW floating and overland PV module. It can be seen that during daytime, which is time capable of solar power generation, temperature of floating PV module was lower than overland PV module's.

This is obviously estimated due to the reflection of the light from the water and the cooling effect on PV modules resulting from the water surface which keeps the PV modules' temperatures lower.

C. Environmental Impact Analysis of Floating PV System

In developing floating PV system, effect of wave and wind on the structure must be considered. For the case of Hapcheon 100kW floating PV system, the site is surrounded by mountains in north and south. The maximum wind drift distance is approximately 700m from east.

4. Conclusion

This paper compares and analyzes the empirical data of the floating PV system, which K-water has installed, with that of the existing overland PV and has verified that the generating efficiency of floating PV system is superior by 11% and more. During analysis, data acquired when the floating PV system was rotated and moved by wind was not used. Research on a mooring system that can completely fix the buoyant structure of the floating PV system on the water surface is continually needed. Also, order to enlarge the generating efficiency, development of a solar -tracking floating PV system that can change its azimuth and tilt angles is required. Currently, K -water is researching and developing a 100kW solar-tracking floating PV system, which has superior generating efficiency compared to the stationary floating PV system, and it is expected that development of such system will open a new chapter in the solar -energy market. Also, 20kW marine floating PV system is being installed in order to analyze corrosion effect of seawater on module and PV structure and its relation with generation efficiency.

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