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An Experimental Study on Ground Resistivity and Grounding Resistance of Water Environment

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수상환경의 대지저항률 및 접지저항 측정의 실험적 연구

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Abstract Main ground net of power plant is formed to protect human body from increase in potential gradient caused by grounding current during ground fault. Calculations during ground design are generally performed according to IEEE Std-80-2000 (Kepco Design Standard 2602). However, it is difficult to apply this Standard to water environment, and a grounding technology is required to secure grounding resistance of floating photovoltaic system. Therefore the aim of this paper is to investigate and analyze ground resistivity on the water surface and underwater of reservoir using Wenner 4-pin method, a general method of measuring ground resistivity. Also, grounding resistance of floating photovoltaic systems currently in operation was measured and analyzed using the voltage drop method suggested in the international standard (IEEE Std-81) to propose a grounding method for stable grounding of floating photovoltaic system. The resistivity at 1m below the surface of water (126.3969[Ω · m]) is mostly higher than resistivity at the river bed (97.5713[Ω · m]). Also the proposed grounding anchor method was determined as the most effective method of securing stable grounding resistance in floating photovoltaic systems and is expected to be utilized as a ground method for future floating photovoltaic generation systems.

요 약 지락사고 시 지락전류에 의한 전위경도 상승으로부터 인체를 보호하기 위하여 발전소의 주 접지망을 구성한다. 이를 위한 접지설계시 일반적으로 IEEE Std-80-2000(한전설계기준 2602)에 의하여 계산한다. 그러나 이는 수상환경에서 적용하기 힘들어 수상태양광의 접지저항 확보를 위한 접지기술이 명확하지 않다. 그런데 500kW 수상태양광의 모듈표면 및 금속덕트에 정전기가 발생하고 있고, 안정적인 접지확보를 위해서는 수상환경의 접지방식에 대한 구체적인 방안이 필요한 실정이다.
따라서 본 논문에서는 수상환경에서 Wenner 4 전극법으로 대지저항률을 조사.분석하였으며, 현재 운영중인 수상태양광의 접지저항을 국제규격(IEEE std-81)에서 제시하는 전압강하법으로 측정 분석하여 안정적인 접지확보를 위한 수상태양광 접지방안을 제시하였다. 수면 1m 수중의 저항률이 (126.3969[Ω · m]) 하상의 저항률(97.5713[Ω · m])보다 대체로 높은 것을 측정 분석되었고, 제시한 접지앵커 접지방안은 수상태양광의 더욱 안정된 접지저항 확보를 위해 경제적으로 가장 효과적인 방법으로 판단되며, 향후 수상태양광 발전의 접지방법으로 활용될 것으로 기대된다.

Key Words : Floating PV, Grounding Resistance, Water Resistivity

1. Introduction

Main ground net of power plant is formed to protect human body from increase in potential gradient caused by grounding current during ground fault. Calculations during ground design are generally performed

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according to IEEE Std-80-2000 (Kepco Design Standard 2602). However, it is difficult to apply this Standard to water environment, and a grounding technology is required to secure grounding resistance of floating photovoltaic system.

A floating photovoltaic power generation results from the combination of PV plant technology and floating technology, K-water is operating the first domestic 100kW floating photovoltaic system for commercial power generation (Oct 2011) and the world's largest (at the time of its completion) 500kW floating photovoltaic system (Jun 2012). In addition, it is expanding the scope of research and business on floating photovoltaic system by recently installing a 100kW tracking-type floating photovoltaic system (Dec 2013)[1-4].

Static electricity is generated on the module surface and metal duct of the 500kW floating photovoltaic system during power generation. Specific means of grounding in water environment is deemed necessary to secure stable grounding of floating photovoltaic system, which can become an important part of photovoltaic generation.

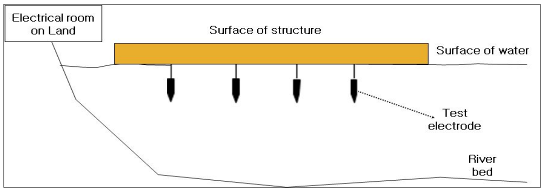
The most important factor in grounding system design is measurement of ground resistivity. Accordingly, the aim of this paper is to investigate and analyze ground resistivity on the water surface and underwater of reservoir using Wenner 4-pin method, a general method of measuring ground resistivity. Also, grounding resistance of floating photovoltaic systems currently in operation will be measured and analyzed using the voltage drop method suggested in the international standard (IEEE Std-81) to propose a grounding method for stable grounding of floating photovoltaic system.

2. Measurement of Ground Resistivity in Water Environment

2.1 Measurement of Ground Resistivity

Ground resistivity at the installation point of 500kW floating photovoltaic system in Hapcheon dam was measured 1m below the surface of water and at the river bed under the structure as shown in Fig. 1 and [Fig. 2]. The measurement was done using Wenner 4-pin method at intervals of 2, 4, 8, 12, 16, 20, 24, and 30m, and ground layer (water layer) structure was analyzed using ground resistivity analysis program.

measurement instrument (ACE company Super Sting R8 IP)	installation of test cable



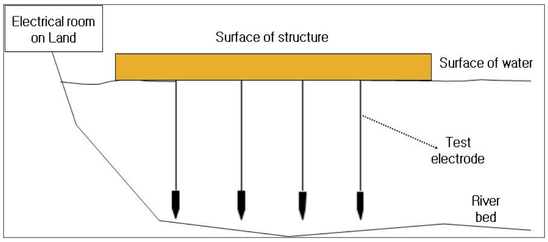
[Fig. 1] Measurement of ground resistivity 1m below the surface of water

The measurement values obtained by Wenner 4-pin method are shown as ground resistance, and these measurement values (R) and interval (a) are multiplied by 2ρ ($2\pi aR$) to obtain ground resistivity (ρ). (Unit: Ω-cm or Ω-m)

Water resistivity based on the measurement and calculation is as shown in [Table 1].

[Table 1] Ground resistivity 1m below the surface of water according to equidistant interval of grounding electrode

equidistant interval of grounding electrode	measurement 1m below the surface of water	
	measurement values [Ω]	ground resistivity [Ω·m]
2	6.212	78.06229
4	4.432	111.3883
8	1.887	94.85097
16	1.048	105.3565
24	0.739	111.4386
30	0.669	126.1035



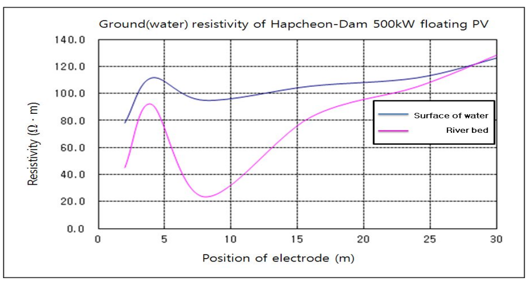
[Fig. 2] Measurement of ground resistivity at the river bed

Water resistivity was calculated as shown in Table 2 using the method described above based on resistance measured using Wenner 4-pin method

[Table 2] Ground resistivity at the river bed according to equidistant interval of grounding electrode

equidistant interval of grounding electrode	measurement at the river bed	
	measurement values [Ω]	ground resistivity [Ω·m]
2	3.580	44.98761
4	3.659	91.9607
8	0.466	23.42372
16	0.819	82.33486
24	0.695	104.8035
30	0.680	128.177

Fig. 3 compares resistivity at 1m below the surface of water and at the river bed. Resistivity at 1m below the surface of water was mostly higher than resistivity at the river bed in the current floating photovoltaic systems with grounding facility.

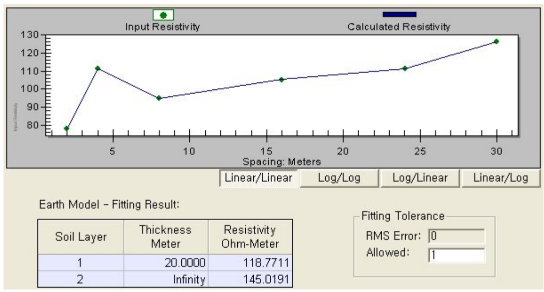


[Fig. 3] Comparison of ground resistivity

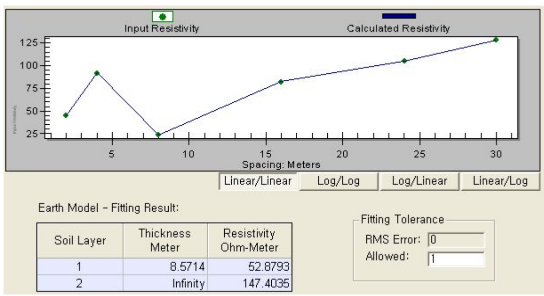
2.2 Analysis of Ground Resistivity

Representative factors known to affect ground resistivity include type of soil, amount of moisture, temperature, substances dissolved in the soil moisture, concentration of such substances, and size or density of soil particles. Therefore, since resistivity differs according to the measurement place and time, it is difficult to defined the value of resistivity. Water environment is also expected to show difference in resistivity according to temperature and impurities underwater, but water environment is not expected to be affected by as diverse environmental factors as ground.

In case of 500kW floating photovoltaic system of Hapcheon dam, ground resistivity data measured by Wenner 4-pin method was entered into ground layer analysis program of GroundMat to interpret ground(water) structure using two-story model, and the result is shown in Fig. 4, Fig. 5 and [Table 3].

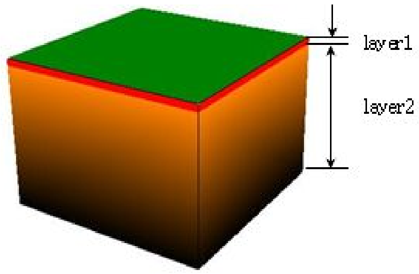


(a) 1m below the surface of water



(b) river bed

[Fig. 4] Ground(water) layer structure analysis below floating photovoltaic system(GroundMat)



[Fig. 5] Ground layer (water layer) structure model

[Table 3] Result of analysis on ground resistivity of each ground layer structure(GroundMat)

Layer	1m below the surface of water		river bed	
	Thickness (m)	Resistivity (Ω·m)	Thickness (m)	Resistivity (Ω·m)
Layer1	20	118.7711	8.5714	52.8793
Layer2	Infinity	145.0191	Infinity	147.4035

2.3 Calculation of Equivalent Ground Resistivity

Ground resistivity analyzed using two ground structures was equalized as ground resistivity of single ground layer up to 30m using Equation (1) and shown in [Table 4].

$$\rho_L = \frac{H}{\frac{h_1}{\rho_1} + \frac{(H-h_1)}{\rho_2}} [\Omega.m] \qquad (1)$$

where, H = 30m, h_1 = Layer 1 Thickness(m), ρ= Resistivity (Ω·m)

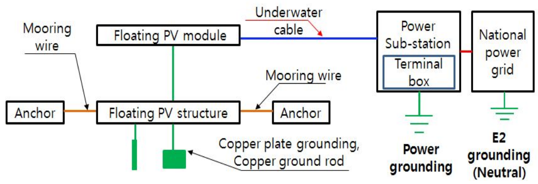
[Table 4] Equivalent Ground Resistivity

Equivalent Ground Resistivity Simulation	1m below the surface of water [Ω · m]	river bed [Ω · m]
GroundMat	126.3969	97.5713

3. Measurement of Grounding Resistance for Floating Photovoltaic System

3.1 Floating Photovoltaic Grounding System

For grounding of 100kW and 500kW floating photovoltaic systems and 100kW tracking-type photovoltaic system currently in operation, grounding rod and cooper plate were immersed in water from the grounding terminal of the structure as shown in [Fig. 6].

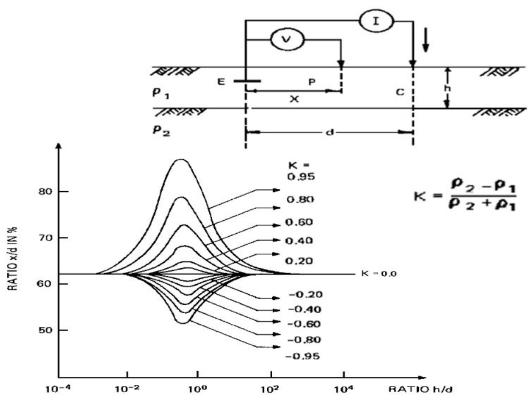


[Fig. 6] Floating photovoltaic system diagram and grounding[5]

3.2 Measurement and Analysis of Grounding Resistance

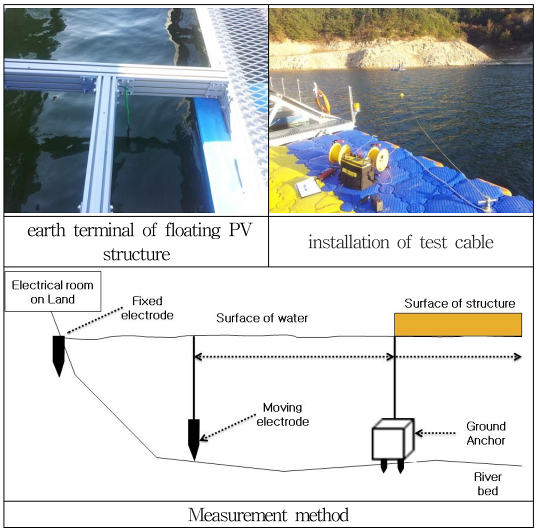
IEEE Std 81-1983 suggests that there is a position of potential electrode which represents the true value of grounding electrode impedance being measured.

As shown in Fig. 7, the value is differentiated according to structure of ground resistivity for each ground layer. The measurement value is more stable in smaller grounding system. The separation distance x of the potential electrode (if the electrode is located between grounding electrodes E and C and the ground is uniform) is positioned at x/a = 0.618. This fact was demonstrated by E. B Curdts about electrodes on small hemispheres.



[Fig. 7] Position of potential electrode demanded in two-story ground structure

The measurement result of ground resistance about the grounding terminal of 500kW floating photovoltaic system in Hapcheon dam is as shown in Fig. 8 and Table For performance test on the grounding anchor considered as a core grounding method used in floating photovoltaic system, measurement was separately done about the case in which grounding anchor is not connected to the grounding terminal (grounding for the current systems) and case in which grounding anchor is connected.

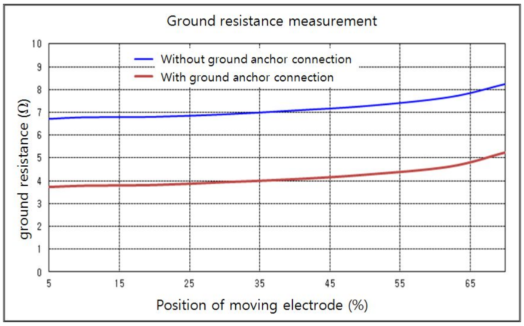


[Fig. 8] Measurement of ground resistance for 500kW floating photovoltaic system in Hapcheon dam

[Table 5] Result of ground resistance for 500kW floating photovoltaic system in Hapcheon dam

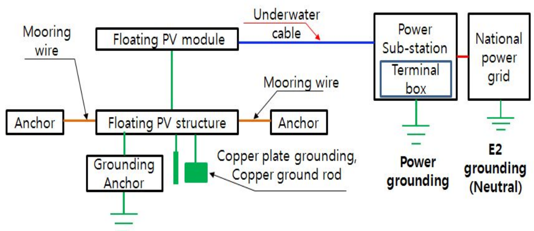
Position of moving electrode(%)	5	10	20	30	40	50	61.8	70
present floating PV	6.719	6.784	6.809	6.917	7.087	7.279	7.671	8.248
case of grounding anchor connected	3.732	3.786	3.819	3.944	4.071	4.27	4.624	5.248

As a result of ground resistance measurement, ground resistance at 61.8% of grounding electrode was measured as 7.671Ω without grounding anchor connection and 4.624Ω with grounding anchor connection. Fig. 9 shows a graph that compares the two resistivities.



[Fig. 9] Comparison of ground resistance

Methods of constructing common grounding system according to the KS C IEC Standard include laying of grounding wires to reach the electric room from photovoltaic module and use of shield grounding wires of underwater cable[5]. However, the former requires large increase in grounding wire laying expense and the latter cannot be applied because UW cable currently in use does not include shield grounding wires. Therefore, the most economically feasible and effective method of securing stable grounding resistance in the floating photovoltaic system is to use grounding anchor as in [Fig. 10].



[Fig. 10] Diagram of floating PV ground anchor installation

3. Conclusion

In this paper, general method of ground resistivity measurement called Wenner 4-pin method was used to suggest that resistivity at 1m below the surface of water (126.3969[Ω · m]) is mostly higher than resistivity at the river bed (97.5713[Ω · m]). In addition, a grounding method for floating photovoltaic system was proposed to secure stable grounding by analyzing the voltage drop method suggested in the international standard (IEEE Std-81). The proposed grounding anchor method was determined as the most effective method of securing stable grounding resistance in floating photovoltaic systems and is expected to be utilized as a ground method for future floating photovoltaic generation systems.

References

[1] Y.K Choi, N.H Lee, K.J Kim, Empirical Research on the efficiency of Floating PV systems compared with Overland PV Systems, Advances in Information Technology and Computer Science, CES-CUBE 2013, ASTL Vol. 25, pp. 284 - 289, 2013

[2] K-water, Groundwork research for Commercialization of Floated Photovoltaic System, 2011.

[3] Y.K Choi, N.H Lee, A.K Lee, K.J Kim, A Study on Major Design Elements of Tracking-Type Floating Photovoltaic Systems, IGCE, Vol. 3, No.1, pp. 70 - 74, January 2014

[4] Y.K Choi, J.S Yi, The Technique of Installing Floating Photovoltaic Systems, Jounal of The Korea Academia-Industrial cooperation Society, Vol. 14, No.9, pp. 4447 - 4454, Sep. 2013

[5] Y.K Choi, N.H Lee, K.J Kim, Analysis of the Grounding System of Floating Photovoltaic Systems, ISGCE2013 ETCP-1169, July 2013

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<Research Interests>
Renewable Energy, Photovoltaic System, Energy Saving, Electrical Fire