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

Young-Kwan Choi
K-water Institute, Korea Water Resources Corporation

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 (126.3969Ω·m) is mostly higher than resistivity at the river bed (97.5713Ω·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.

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 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 (126.3969Ω·m) is mostly higher than resistivity at the river bed (97.5713Ω·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.
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.

2. Measurement of Ground Resistivity in Water Environment

2.1 Measurement of Ground Resistivity

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 (2πaR) 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>
<thead>
<tr>
<th>equivalent interval of grounding electrode</th>
<th>measurement 1m below the surface of water</th>
<th>ground resistivity [Ω·m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6.212</td>
<td>78.06225</td>
</tr>
<tr>
<td>4</td>
<td>4.432</td>
<td>111.388</td>
</tr>
<tr>
<td>8</td>
<td>1.887</td>
<td>94.8507</td>
</tr>
<tr>
<td>16</td>
<td>1.048</td>
<td>145.3965</td>
</tr>
<tr>
<td>24</td>
<td>0.739</td>
<td>111.489</td>
</tr>
<tr>
<td>30</td>
<td>0.669</td>
<td>126.1035</td>
</tr>
</tbody>
</table>
An Experimental Study on Ground Resistivity and Grounding Resistance of Water Environment

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

<table>
<thead>
<tr>
<th>equidistant interval of grounding electrode</th>
<th>measurement at the river bed</th>
<th>ground resistivity [Ω·m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3.380</td>
<td>41.3976</td>
</tr>
<tr>
<td>4</td>
<td>3.699</td>
<td>91.9047</td>
</tr>
<tr>
<td>8</td>
<td>0.496</td>
<td>23.4252</td>
</tr>
<tr>
<td>16</td>
<td>0.819</td>
<td>82.3346</td>
</tr>
<tr>
<td>24</td>
<td>0.695</td>
<td>104.8035</td>
</tr>
<tr>
<td>30</td>
<td>0.680</td>
<td>128.177</td>
</tr>
</tbody>
</table>

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.

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.
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].

\[
\rho_e = \frac{H}{\rho_1 + \frac{(H-h_1)}{\rho_2}} \quad [\Omega \cdot m]  
\]

where, \( H = 30m \), \( h_1 = \) Layer 1 Thickness(m), \( \rho = \) Resistivity (\( \Omega \cdot m \))

**Table 4** Equivalent Ground Resistivity

<table>
<thead>
<tr>
<th>Equivalent Ground Resistivity Simulation</th>
<th>Ln below the surface of water ([\Omega \cdot m])</th>
<th>River bed ([\Omega \cdot m])</th>
</tr>
</thead>
<tbody>
<tr>
<td>GroundMat</td>
<td>126.3969</td>
<td>97.5713</td>
</tr>
</tbody>
</table>


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].

![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.

![Position of potential electrode demanded in two-story ground structure][5]
An Experimental Study on Ground Resistivity and Grounding Resistance of Water Environment

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 5. 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.

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

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].

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(\(\Omega \cdot m\))) is mostly higher than resistivity at the river bed (97.5713(\(\Omega \cdot m\))). 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


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