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Research paper

Study on the Insulation Resistance Detection Technique of Photovoltaic Power Generation Facilities

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Abstract

Background/Objectives:This paper explains the insulation resistance detection technology to secure electrical safety as there is possibility of electricity disaster in the case of insulation failure in DC power line of photovoltaic power generation facilities.
Methods/Statistical analysis:An algorithm was developed to measure and calculate insulation performance of each power line by using an asymmetric high resistance circuit for voltage size generated in a live condition. It calculates total insulation resistance including DC power facilities by using an asymmetric voltage measurement circuit, and then insulation resistance of each (+)/(-) power line by using a symmetric voltage measurement circuit. A failure location can be assumed based on the ratio of calculated insulation between (+) and (-) power lines.
Findings:In the case of DC power facilities, realtime monitoring of insulation condition is not possible as leakage current cannot be measured by using ZCT. Currently, the megger is used for measurement in a power-off condition. However, test in a live condition can detect photovoltaic panel failure or insulation condition of power lines. In this paper, we developed an algorithm for insulation performance by using an asymmetric high resistance detection circuit as well as technology to detect failure location of string based on the characteristics of photovoltaic power facilities. Accordingly, we suggested methods to secure electrical safety with realtime monitoring of DC power facilities and testing equipment.
Improvements/Applications:The future development of insulation monitoring equipment in a live condition and state diagnosis device using the DC power line insulation performance algorithm will contribute to electrical safety of DC power facilities.

Keywords: *DC Power Line, Insulation Resistance, Electrical Safety, Asymmetric Detection Circuit, Ground fault, Photovoltaic Facilities.*

1. Introduction

The domestic photovoltaic market is rapidly expanding with the policy support of the government. The size of the domestic market is a mere 5% of the global market, but it has grown at an annual rate of 145.3% for recent five years with policy support as shown in the table 1. Currently, approximately 200 companies are participating in the market, and the number of companies is large compared to the market size especially in module including solar cell as well as system installation/operation, making competition more intense. Likewise, the photovoltaic power generation facilities are in an expanding market, but its safety foundation is not strong enough[1]. Likewise, new and renewable energy will be rapidly expanded following the “renewable energy 3020” policy by the government, and there are ongoing studies on increased supply and improved performance of existing new and renewable energy. Moreover, active enforcement of the Renewable Portfolio Standard(RPS) has constantly increased the number of photovoltaic power facilities, leading to a growing number of fire incidents every year. The number of fire incidents is increasing following an increase in photovoltaic facility installation, and the main causes of fire are assumed to be deterioration of facilities installed at an early stage and insulation destruction in DC power lines, which highlights the necessity of insulation condition monitoring on DC power lines [2-3].

Table 1: New/Renewable Energy Supply Ratio in Total Electricity Production under the Second Basic Plan

(Unit : MWh)

Classification	2008	2010	2015	2020	2030
Solar heat	30(0.5)	40(0.5)	63(0.5)	342(0.2)	1,885(5.7)
Photovoltaic	59(0.9)	138(1.8)	313(2.7)	552(3.2)	1,364(4.1)
Sum	89(1.4)	178(2.3)	376(3.2)	894(3.4)	3,249(9.8)

In addition, when it comes to the risk of electric shock from DC power exceeding DC 60V, AC and DC powers have similar impact on human body although their electric shock current values are different as shown in IEC60479-1. Thus, it verifies that an insulation performance test is required to prevent electric shock from DC power as well as electricity incidents due to leakage current[4-6].

Accordingly, we designed insulation performance detection circuits of photovoltaic facilities and suggested an insulation performance calculation algorithm. It is judged that the suggested algorithm can be used for insulation performance verification of photovoltaic facilities and enhanced electrical safety.

2. Development of Insulation Performance Measurement Algorithm

For existing insulation resistance measurement, a megger is used to apply DC test voltage. A megger applies DC test voltage to an insulation measurement target, detects the current (leakage current) inside a measuring device, and converts it into test voltage/current for measurement[7].

AC and DC powers are mixed in most new and renewable power generation facilities, and while insulation resistance (or leakage current) of AC power is measured in a live or blackout condition according to existing regulations, that of DC power line is measured after separating power line from the energy source. In the case of photovoltaic facilities, there are some cases where a megger cannot apply test voltage as voltage is being output while electricity is generated during the daytime[8-10].

In this paper, we developed an algorithm to measure voltage and calculate insulation performance of each power line by using an asymmetric high resistance circuit for voltage size generated in a live condition.

The asymmetric high resistance voltage measurement circuit is as displayed in the figures 1~3, and the measurement is in three steps

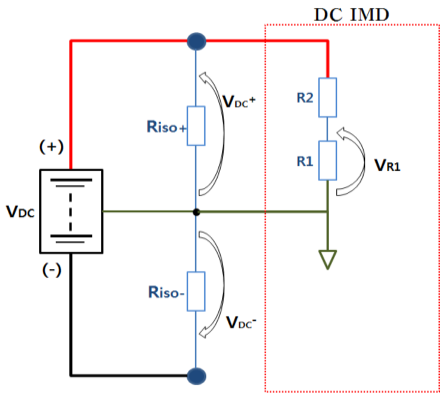


Figure 1: Schematic of detection circuit for STEP 1

STEP1 : In a circuit like Figure 1, if the insulation resistance between each (+)/(-) power line and GND is R_{ISO}^{+} and R_{ISO}^{-} respectively, the resistance R_a between V_{DC}^{+} and GND is same as formula (1).

$$R_a = \frac{1}{\frac{1}{R_{ISO}^{+}}+\frac{1}{R_1+R_2}} = \frac{R_{ISO}^{+}(R_1+R_2)}{R_{ISO}^{+}+R_1+R_2} \quad (1)$$

And the resistance R_b between V_{DC}^{-} and GND is $R_b = R_{ISO}^{-}$, the voltage V_a between V_{DC}^{+} and GND can be displayed as formula (2).

$$V_a = \frac{R_a}{R_a+R_b} \times V_{DC} \quad (2)$$

Therefore, the voltage V_{R1} that is applied to R_1 can be calculated as formula (3).

$$V_{R1} = \frac{R_1}{R_1+R_2} \times V_a = \frac{R_1}{R_1+R_2} \times \frac{R_a}{R_a+R_b} \times V_{DC} \quad (3)$$

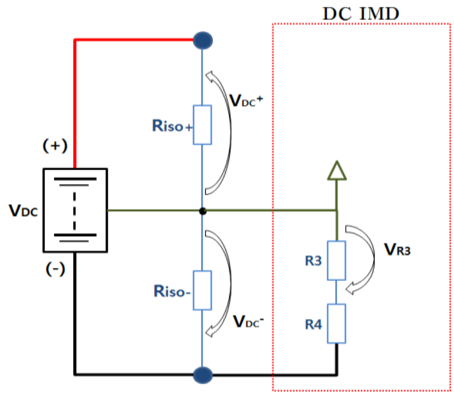


Figure 2:. Schematic of detection circuit for STEP2

STEP2 : In a circuit like Figure2, as the resistance R_c between V_{DC}^{+} and GND is $R_c = R_{ISO}^{+}$, the resistance R_d between V_{DC}^{-} and GND is same as formula (4).

$$R_d = \frac{1}{\frac{1}{R_{ISO}^{-}}+\frac{1}{R_3+R_4}} = \frac{R_{ISO}^{-}(R_3+R_4)}{R_{ISO}^{-}+R_3+R_4} \quad (4)$$

And the voltage V_b between V_{DC}^{-} and GND can be displayed as formula (5).

$$V_b = \frac{R_d}{R_c+R_d} \times V_{DC} \quad (5)$$

Therefore, the voltage V_{R3} that is applied to R_3 can be calculated as formula (6).

$$V_{R3} = \frac{R_3}{R_3+R_4} \times V_b = \frac{R_3}{R_3+R_4} \times \frac{R_d}{R_c+R_d} \times V_{DC} \quad (6)$$

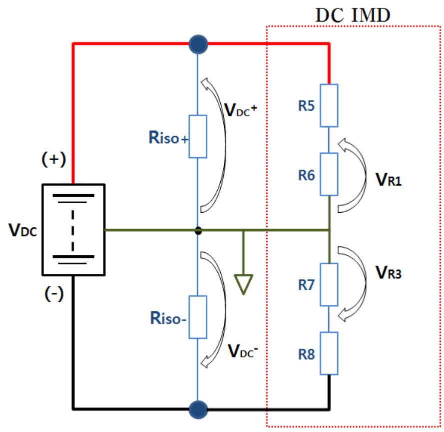


Figure 3:. Schematic of detection circuit for STEP3

STEP3 : In a circuit like Figure3, the resistance R_α between V_{DC}^{+} and GND is same as formula (7).

$$R_\alpha = \frac{1}{\frac{1}{R_{ISO}^{+}}+\frac{1}{R_5+R_6}} = \frac{R_{ISO}^{+}(R_5+R_6)}{R_{ISO}^{+}+R_5+R_6} \quad (7)$$

The resistance R_β between V_{DC}^{-} and GND is formula (8),

$$R_\beta = \frac{1}{\frac{1}{R_{ISO}^{-}}+\frac{1}{R_7+R_8}} = \frac{R_{ISO}^{-}(R_7+R_8)}{R_{ISO}^{-}+R_7+R_8} \quad (8)$$

and the voltage V_α between V_{DC}^{+} and GND can be calculated as formula (9).

$$V_\alpha = \frac{R_\alpha}{R_\alpha+R_\beta} \times V_{DC} \quad (9)$$

Therefore, the voltage V_{R6} that is applied to R_6 is displayed as formula (10).

$$V_{R6} = \frac{R_6}{R_5+R_6} \times V_\alpha = \frac{R_6}{R_5+R_6} \times \frac{R_\alpha}{R_\alpha+R_\beta} \times V_{DC} \quad (10)$$

The voltage V_β between V_{DC}^- and GND is same as formula (11),

$$V_\beta = \frac{R_\beta}{R_\alpha + R_\beta} \times V_{DC} \tag{11}$$

and accordingly, the voltage V_{R7} that is applied to R_7 is calculated as (12).

$$V_{R7} = \frac{R_7}{R_7 + R_8} \times V_\beta = \frac{R_7}{R_7 + R_8} \times \frac{R_\beta}{R_\alpha + R_\beta} \times V_{DC} \tag{12}$$

The method to calculate insulation resistance by using the voltage calculated throughout step 1 to 3 is to detect V_{R1} at step 1, V_{R3} at step 2, and calculate $V_{R1} + V_{R3}$.

After calculating back to $R_{ISO}^+ + R_{ISO}^-$, which is the value of $V_{R1} + V_{R3}$, calculate total insulation resistance (R_{ISO}).

Calculate insulation resistance of each power line, R_{ISO}^+ and R_{ISO}^- by using the ratio of V_{R6} and V_{R7} to the total insulation resistance (R_{ISO}) at step 3.

Figure 4 displays voltage detection characteristics of V_{R1} and $V_{R1} + V_{R3}$ to the total insulation resistance, and Figure 5 shows characteristic curve of V_{R6} and V_{R7} on the R_{ISO}^+ / R_{ISO}^- ratio at step 3. Figure 4 explains that voltage detection characteristic of the total insulation resistance value is not redundant, while Figure 5 describes that each characteristic can be classified by insulation characteristics of (+) and (-) power lines.

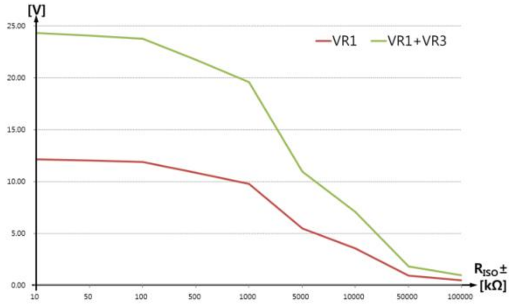


Figure4: V_{R1} and $V_{R1} + V_{R3}$ characteristic curve depending on total insulation resistance value (R_{ISO})

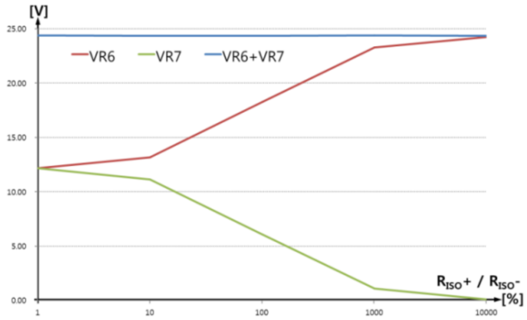


Figure 5: V_{R6} and V_{R7} characteristic curve on R_{ISO}^+/ R_{ISO}^-ratio

In addition, it is possible to assume the location of power line defect as GND has a similar characteristic of moving following the ratio of R_{ISO}^+ and R_{ISO}^- at the time of insulation abnormality, since GND is in a floating state depending on photovoltaic facility characteristics

3. Performance Verification of the Developed Algorithm

In order to verify the algorithm to detect insulation performance of photovoltaic facilities, we made an asymmetric high resistance detection circuit as shown in Figure 6 with switches for measurement throughout step 1 to 3. Moreover, mock tests with insulation defects were carried out for measurement, using a single photovoltaic panel of 50V output as shown in Figure 7.

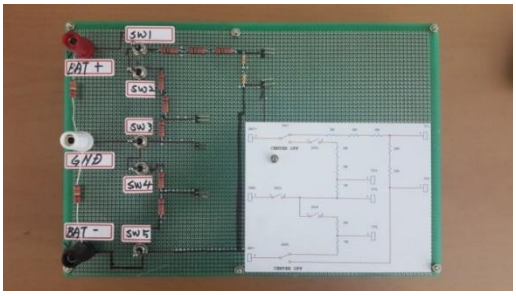
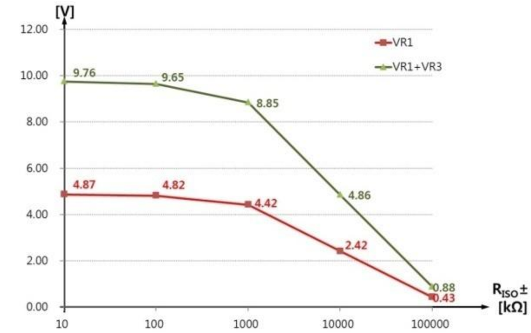


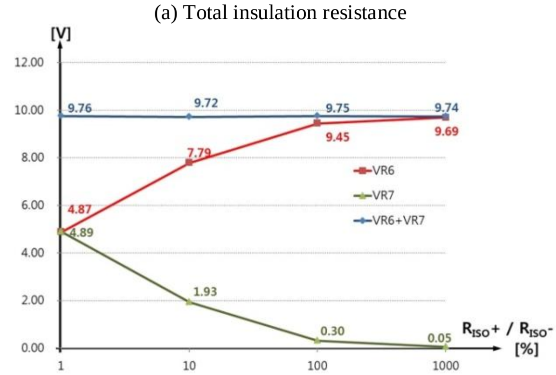
Figure 6: Insulation Performance Detection Circuit

Figure 7: Photovoltaic Facility for Performance Verification

As a result of performance verification, the 50V output voltage was measured per different insulation condition as displayed in Figure 8, confirming values similar as algorithm analysis.



(a) Total insulation resistance



(b) Insulation resistance ratio of (+)/(-) power line

Figure 8: Performance Verification Result

4. Results and Discussion

We confirmed that insulation performance of photovoltaic facilities can be measured in a live condition with performance verification through mock test on the algorithm suggested by this paper and the asymmetric high resistance measurement circuit. It was revealed that safety and accuracy of switching circuits to implement circuits from step 1 to 3 are important factors when designing an insulation resistance detection circuit since real photovoltaic facilities have diverse output voltage from 50V to 1000V.

Moreover, it should be considered to apply an insulation resistance calculation method to apply pulse voltage to a closed loop between insulation resistance of a monitored circuit and the ground, and measure applied voltage of detection resistance following changes of insulation resistance, in order to check insulation performance in a condition without output of voltage.

5 .Conclusion

In this paper, we suggested an asymmetric high resistance measurement algorithm to measure insulation resistance of photovoltaic facilities. As a result of verifying characteristics of insulation performance detection by making detection circuits with the suggested algorithm applied, we confirmed effective characteristics.

It is possible to check insulation condition of photovoltaic facilities on the inspection site by using a measuring device to which the developed algorithm applied. Moreover, it is judged that remote monitoring system can be developed by adopting a realtime monitoring device with better durability to secure electrical safety of photovoltaic facilities.

In addition, it is also possible to prevent accidents by monitoring insulation conditions of DC and AC with existing technologies, which can enhance facility efficiency.

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References

[1] Won-Pyo Hong. A Matlab/Simulink-Based PV array-Supercapacitor Model Employing SimPowerSystem and Stateflow Tool Box. Journal of the Korean Institute of Illuminating and Electrical Installation Engineers. 2014Dec;28(12):18-29.

[2] Xiaomeng Su, Yaojie Sun, and Yandan Lin. Analysis on Leakage Current in Transformerless Single-Phase PV Inverters Connected to the Grid, Power and Energy Engineering Conference, pp.1-5, 2011.

[3] Mandeep Singh, Rajeev Khurana, Prateek Jain. Low Cost High Voltage Battery String Monitoring System. 2015; 2015 Intl. Conference on Computing and Network Communications (CoCoNet'15), Dec. 16-19.

[4] IEC. IEC 60479-1; Effects of current on human beings and livestock – Part1: General aspects 2005.

[5] T. Tran-Quoc, H. Colin, C. Duvauchelle, B. Gaiddon, C. Kieny, C. LE Thi Minh, et al.Transformerless Inverters and RCD: What’s the Problem?. 2010; 25th European Photovoltaic Solar Energy Conference and Exhibition, pp.4554-4559.

[6] Hee-Sun Kim, Song-Yop Hahn, Hoo-Sek Han. Development of DC Leakage Current Sensor for Solar Power Generation System. The Transactions of the Korean Institute of Electrical Engineers. 2014;63(6), pp. 828～833.

[7] F. L. Hunt. Megger and other tests on suspension insulators. Proceedings of the American Institute of Electrical Engineers. 2013;35(6):861-864.

[8] Ministry of Trade, Industry and Energy. Electric Utility ACT. https://elaw.klri.re.kr, last accessed 21 MAR 2017.

[9] Jishun Jiang, Hua Ji. Study of Insulation Monitoring Device for DC System Based on Multi-switch Combination. 2009 Second International Symposium on Computational Intelligence and Design.2009:429-433. DOI:10.1109/ISCID.2009.115

[10] Kyu-Tae Kim, Kwang-Min Yu. A New Methodfor Insulation Resistance Measurementat Low Voltage Levelusing Changeof Effective Resistance. XIX IMEKO World CongressFundamental and Applied MetrologySeptember 6−11, 2009, Lisbon, Portugal. pp.958-959