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A NEW METHOD FOR INSULATION RESISTANCE MEASUREMENT AT LOW VOLTAGE LEVEL USING CHANGE OF EFFECTIVE RESISTANCE

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Abstract − Test of insulation resistance is pre-requisite for leakage effect evaluation in many electrical measurements. Especially high resistance measurement at low working voltage is often required for evaluation of high precision measurement system. The high resistance measurement at low voltage level with portable hand-set is a challenging task. Here we suggest a simple and convenient method to measure the insulation resistance of up to 10 TΩ order using the principle that effective resistance changes when insulation resistor under test is connected to a reference resistor. A prototype demonstration shows 10 % accuracy level can be easily achieved for 10 TΩ measurement with 10 V test voltage.

Keywords: insulation resistance

1. INTRODUCTION

In electrical metrology, the insulation resistance plays an important role for isolation between signal carrying components when any leakage can affect the measurement result. For example, in precision measurement of DC voltage where 1 kΩ series resistance is a component carrying signal current, 10 TΩ or higher isolation to ground is required for achieving 10^{-8} (~ 1 kΩ /10 TΩ) relative leakage error [1]. Conventional measurement of this high insulation resistance is often straightforward, that is, leakage current is measured under voltage applied, and consumes considerable time and efforts because leakage current to be measured is so small that system noise overrides the signal to be measured which makes the current reading fluctuating between plus and minus. So, in case of conventional measurement, test equipment tends to employ rather high voltage level to overcome the noise problem. However, the insulation resistance can significantly change depending on the applied voltage [2], and besides that the high voltage can be dangerous to such high precision measurement circuits designed for the low working voltage. The insulation resistance measurement at the low working voltage requires sophisticated instrument with bench-top type. However, in order to test a complicated system with immobile parts of high precision, a hand-set type portable tester with separate battery power source is more convenient and free of ground-leakage interference to the system. Here we suggest a simple and convenient method, which enables to realize portable and compact tester to measure the insulation resistance of up to 10 TΩ order. The operation principle is based on effective resistance changes when insulation resistor under test is connected in parallel to a reference resistor. A dual-source bridge technique [3] was well-suited for the purpose. A hand-held prototype was successfully fabricated for implement of the principle into practical demonstration. The measurement demonstration will be also presented with estimated uncertainty level.

2. PRINCIPLE AND METHOD OF MEASUREMENT

The basic principle is explained by (1), which shows the effective resistance change when insulator under test is connected to a reference resistor. If resistance of the insulator and the reference resistor is denoted by R_x and r_2, respectively, then the change of effective resistance ΔR_{eff} is given by

$$\begin{aligned}\Delta R_{eff} &= r_2 R_x \big/ \left(r_2 + R_x\right) - r_2 \\ &\simeq r_2\left(1 - r_2/R_x + r_2^2/R_x^2\right) + r_2 \\ &\simeq -r_2^2/R_x\end{aligned} \quad (1)$$

Here we assumed $R_x >> r_2$.

In order to sensitively detect the effective resistance change, the higher reference resistance r_2 would be preferred. A Wheatstone bridge can be used to detect the off-balance caused by the effective resistance change. However, in the Wheatstone bridge, the bridge detector is far from ground and tends to pick up common mode noise. This noise effect becomes dominant especially for rather high reference resistance, while it is preferred for extremely high insulation measurement. Therefore, we chose the double-source bridge [3] instead of the Wheatstone bridge. In the double-source bridge, two DC voltage sources of the same voltage are used as a current supply to the bridge arms (r_1 and r_2 where $r_1 \simeq r_2$) with well-defined ground point at centre of the two voltage sources. Thus, as shown in Fig. 1, the detector common mode potential is clearly defined as the ground point, reducing the common mode noise effect. The potentiometer (r) at the centre of the resistance arms is for zero adjustment of bridge balance. It is used for balance the bridge before the insulation resistance measurement so that the detector reading may become zero without device under test (DUT) connected.

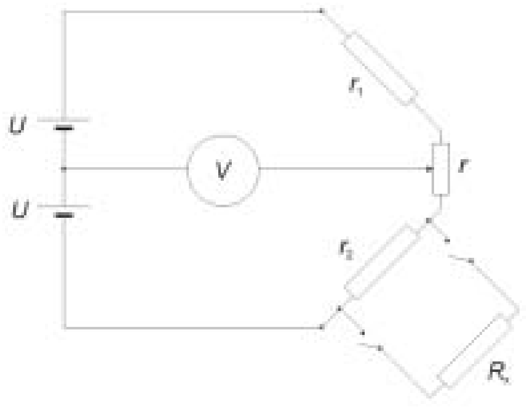

Fig. 1. Dual-source bridge for measurement of insulation resistance (R_x). *V* denotes detector reading.

After the pre-adjustment of bridge balance, DUT (R_x) is connected to the reference resistor (r_2), then the off-balance reading (V) should be given by

$$V \simeq \frac{U}{2}\frac{r_2}{R_x} \tag{2}$$

Here we assumed $R_x >> r_2$. Therefore the resistance to be measured can be calculated by

$$R_x \simeq \frac{U}{2}\frac{r_2}{V} \tag{3}$$

For real application, the relation between V and R_x can be calibrated to provide interpolation information.

3. PROTYPE AND DEMONSTRAION OF MEASUREMENT

A hand-held type compact tester was fabricated for demonstration of the proposed concept of measurement. Two small 12 V alkaline batteries (A23 type) were used for bipolar power source with regulators of nominal output 10 V. A variable gain op-amp whose output was directed to a panel meter (0.1 mV resolution) used as a detector. Two 1 MΩ resistors were used for resistance arms so that the theoretical maximum range corresponds to 10 TΩ.

A set of reference resistors in the range of 2 GΩ to 10 TΩ was measured with the fabricated hand-held type compact tester. The reference resistors were megohm decade (Biddle megadek) for the range below 100 GΩ, and fixed standard resistors (Guildline 65206) of 1 TΩ and 10 TΩ. The measurement result is shown in Fig. 2. In the low range up to 60 GΩ, the inverse law of (2) was satisfactorily confirmed. A slight deviation from the inverse law was found for upper resistance range. The hypothesis is put forward that the deviation is attributable to the nonlinearity of the detector at low voltage.

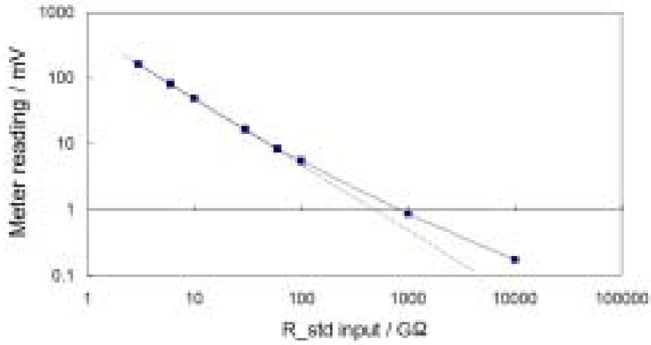

Fig. 2. Calibration of the prototype insulation resistance tester.

4. CONCLUSIONS

The proposed concept of new measurement method using double-source bridge was demonstrated by a prototype hand-held tester fabricated with compact portable case. The calibration data was experimentally obtained for the prototype. Although there is a slight deviation from the inverse law at extremely high resistance range, it is valid that a calibration will provide a possible way for interpolations up to 10 TΩ. The overall uncertainty of measurement with the interpolation is estimated to be less than 10 %.

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