Implementation and Application of an Automated High-Resistance Calibration System

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1. Background & Introduction

In the operation, maintenance, and equipment inspection of electrical power systems, measurements of high-insulation resistance — such as those performed on transformers, cables, and switchgear — provide a key indicator of insulation degradation and support operational safety. To ensure the accuracy and reliability of data obtained from field insulation testers and high-resistance meters, including megohmmeters and terohmmetera, power metrological calibration laboratories must establish ultra-high-precision, traceable high-resistance standards and calibration systems.

Traditional calibration of high-resistance standard resistors (100 kΩ to 100 TΩ, at test voltages from 1 V to 1000 V) relies heavily on manual switching of test leads and individual configuration of test voltages. This process is tedious and highly susceptible to human operational errors, electrostatic interference from personnel, and fluctuations in ambient temperature and humidity. Because leakage currents in high-resistance measurements can be as small as picoampere (pA) or femtoampere (fA), even minor disturbances can affect the measurements; frequent manual rewiring therefore not only prolongs calibration time but may also compromise measurement stability.

To enhance the level of automation, testing efficiency, and data reliability in high-resistance calibration, this work introduces the Guildline 6540 Dual Measurement High Resistance Bridge, paired with the Guildline 6564 High Resistance Scanner, to build a fully automated high-resistance calibration system for the Guildline 6636 Temperature Stabilized Resistor Set. The system enables automated high-resistance measurement under computer control, multi-channel scanning, and automated data processing, providing an efficient and precise solution for power metrological calibration.

2. Program-Controlled Test System Architecture

This automated high-resistance calibration system primarily consists of a high-resistance meter (the 6540) and a high-resistance scanner (the 6564), working in conjunction with a control computer to measure the standard high-resistance resistor set (the 6636) and other resistors under calibration. The system architecture and key technical features of each component are described below.



Source: Instrumentation Section, Power Research Institute

Figure 1. Automated High-Resistance Calibration System

(1) Core Equipment Functions and Key Specifications

A. Guildline 6540 High Resistance Meter: Serving as the measurement and control core of the system, the 6540 offers an extremely wide measurement range (90 kΩ to 200 TΩ standard; expandable to 20 PΩ) with ultra-low measurement uncertainty. The instrument features dual measurement modes — Direct Mode and Bridge Mode — and ten standard test voltages ranging from 1 V to 1000 V DC, together with precision temperature control to stabilize internal integrator and reference

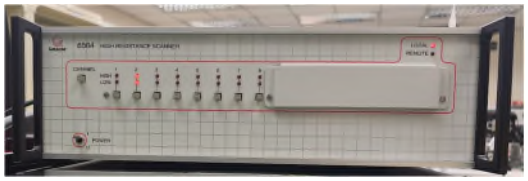
circuits. It supports IEEE-488 (GPIB) and RS-232C communication interfaces and can be controlled using SCPI programmable commands.



Source: Instrumentation Section, Power Research Institute

Figure 2. Guildline 6540 High Resistance Meter

B. Guildline 6564 High Resistance Scanner: Serving as the interface for multichannel switching, the 6564 is specifically designed for high-resistance measurements and low-current signals. It provides high interchannel insulation resistance (> 10^{15} Ω) and low leakage current. Each scanner module supports multichannel switching of high-voltage and low-current signals and uses relays with low thermal EMF and high insulation resistance to minimize switching-induced interference and parasitic capacitance effects, enabling automated sequential scanning of multiple resistors under test.



Source: Instrumentation Section, Power Research Institute

Figure 3. Guildline 6564 High Resistance Scanner

C. Guildline 6636 Temperature Stabilized Resistor Set: Serving as a calibration reference, the 6636 contains multiple highly stable standard resistors ranging from 100 kΩ to 100 TΩ within a built-in precision electronically temperature-controlled enclosure maintained at 30°C ±0.01°C. This reduces the influence of ambient temperature fluctuations on resistance values and provides high long-term stability and a low voltage coefficient.



Source: Instrumentation Section, Power Research Institute

Figure 4. Guildline 6636 Standard High-Resistance Resistor Set

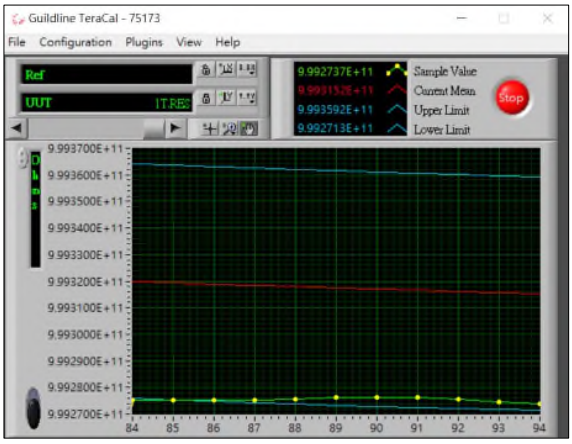
D. Updated Test Lead Specification: The test leads at the circuit input stage now employ Type N – Triax test cables, reducing leakage current and electrostatic interference to improve measurement stability.

(2) Program-Controlled Automated Measurement Workflow and Technical Details

During system operation, the host controller sends SCPI commands to the 6540 high-resistance meter and the 6564 scanner via the IEEE-488 (GPIB) interface. The system automatically collects 100 readings and averages the final 50. It also calculates the standard deviation and evaluates relative measurement uncertainty, expressed in ppm, incorporating calibration report data when such information has been entered in the resistor configuration file. The typical measurement workflow is as follows:

- Automated Channel Switching and Polarity Reversal: The 6564 scanner receives commands to switch to the designated 6636 standard resistor

channel. The 6540 automatically applies dual positive/negative polarity test voltages to eliminate the effects of thermal EMF and drift.



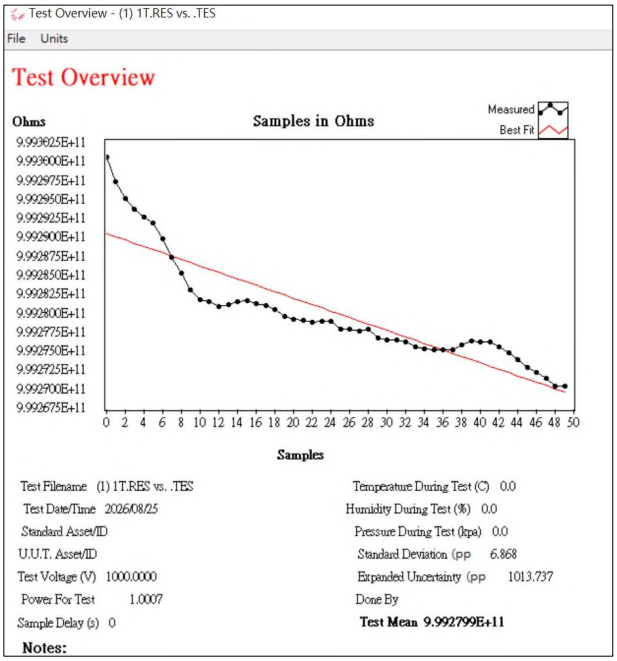
Source: Instrumentation Section, Power Research Institute

Figure 5. TeraCal Software — Test-in-Progress Screen

- Charge Stabilization / Soak Time: For high-resistance values and highly capacitive test samples, the system automatically sets an appropriate soak time to ensure that the charging current decays to a negligible level after high-voltage application.
- Integration Time and Resistance Calculation: The 6540 utilizes its internal integrating circuit to precisely measure the voltage transition time Δt based on the known test voltage V_{in}, integration capacitance C (27 pF, 270 pF, 2700 pF), and threshold voltage $V_{threshold}$ (0.1 V, 1 V, 10 V). The calculation formula is:

$$\mathbf{R = (Vin \times \Delta t) / (C \times \Delta Vout)}$$

- Automated Data Statistics and Analysis: The system automatically collects 100 readings, averages the final 50, calculates the standard deviation, evaluates relative measurement uncertainty in ppm, and outputs the measured resistance value.



Source: Instrumentation Section, Power Research Institute

Figure 6. TeraCal Software — Test Results Screen

3. Conclusion

This system successfully integrates the Guildline 6540 High Resistance Meter, the Guildline 6564 High Resistance Scanner, and the Guildline 6636 Standard High-Resistance Resistor Set to establish a fully automated high-resistance testing system. Compared with traditional manual testing, the system demonstrates the following outstanding benefits:

(1) Significant Improvement in Testing Efficiency and Unmanned Operation: Through multi-channel program-controlled switching, fully automated scanning tests across multiple

standard resistors are initiated with a single command, reducing manual waiting and wiring time by over 80%.

(2) Substantial Reduction in Human Interference and Measurement Uncertainty: Automated switching eliminates electrostatic interference and contact resistance variations caused by manual insertion/removal of high-resistance test leads. Combined with the 6636's precision temperature control, repeatability and reproducibility are markedly enhanced.

(3) Standardized Data Management and Enhanced Metrological Traceability: Test data are transmitted directly to the host computer via the GPIB interface, automatically generating trend charts and statistical analyses to ensure data integrity and tamper-resistance, in full compliance with ISO/IEC 17025 requirements.

In summary, the new equipment and technology deployed in this system not only maximize the performance of top-tier high-resistance instruments, but also establish a new benchmark for automated calibration in the fields of power metrological calibration and high-voltage insulation testing.