

# **V International Scientific and Technical Conference Actual Issues of Power Supply Systems**

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**Increasing reliability and accuracy of measurements in electrical  
test laboratories through quality management system integration**

AIPCP25-CF-ICAIPSS2025-00397 | Article

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# Increasing reliability and accuracy of measurements in electrical test laboratories through quality management system integration

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**Abstract.** The validity of certification decisions, product safety, and conformity hinge on the reliability and accuracy of electrical measurement outcomes. Despite this necessity, numerous laboratories contend with deficiencies such as high measurement uncertainty, inadequate standardization of procedures, and insufficient competence among staff. This research was undertaken with the goal of improving measurement accuracy and reliability by integrating a comprehensive Quality Management System (QMS) aligned with both ISO 9001 and ISO/IEC 17025 requirements. The methods employed involved assessing operational workflows, pinpointing critical influencing variables, and utilizing advanced risk-based tools-including FMEA, the Ishikawa diagram, and a risk matrix-to optimize core testing procedures. This proposed framework successfully enhanced equipment maintenance, documentation, calibration planning, and traceability. Experimental evidence confirms the success of this approach, demonstrating a quantifiable reduction in measurement uncertainty and tangible improvements in both repeatability and reproducibility. Furthermore, adopting the process-based management model resulted in increased laboratory efficiency and enhanced personnel competence. A key contribution of this work is the novel combination of engineering-based process optimization with established quality management principles specifically tailored for electrical testing environments. This robust framework is suitable for implementation in testing laboratories and certification bodies aiming to achieve stricter technical compliance and greater international credibility.

## INTRODUCTION

Electrical testing laboratories play a critical role in ensuring the safety, reliability, and regulatory conformity of electrical and electrotechnical products in modern industries. Their operation directly affects the qualification of products prior to market release, the protection of end users, and the credibility of national and international certification systems. The accuracy, stability, and traceability of measurement results produced by such laboratories determine whether tested equipment meets required operational characteristics and whether manufacturers comply with technical regulations and international product standards [1-4].

Despite their importance, many electrical testing laboratories continue to face systemic challenges that negatively affect the precision and repeatability of measurement results. Among the most common issues are increased measurement uncertainty, inconsistent application of test methods, improper calibration intervals, undefined environmental control, insufficient personnel competence, and inadequate documentation practices. These deficiencies lead to fluctuations in measurement results, reduced repeatability, increased operator errors, and, ultimately, diminished confidence from both regulatory authorities and customers [5-8].

International standards such as ISO 9001 and ISO/IEC 17025 have become fundamental tools for improving laboratory performance. ISO 9001 provides a broad framework for organizational quality management, while ISO/IEC 17025 establishes specific requirements for competence, impartiality, method validation, metrological traceability, equipment calibration, environmental control, and the reporting of test results. When integrated, the two standards create a cohesive management system that supports both administrative efficiency and technical accuracy.

Such integration ensures that laboratory processes are aligned with the principles of risk-based thinking, continuous improvement, evidence-based decision-making, and process consistency [9-12].

However, the implementation of these standards in electrical testing laboratories often occurs in a fragmented or formal manner, without full consideration of engineering-specific factors that influence measurement performance. Electrical measurements have inherent sensitivity to environmental variables, operator skills, equipment aging, and methodological inconsistencies. Therefore, a combined engineering and management approach is required to ensure the stability and reliability of results across different operational conditions [13-16].

This study aims to address this gap by developing and analyzing an integrated quality management framework that incorporates the requirements of ISO 9001 and ISO/IEC 17025, supported by engineering-based methodologies such as Failure Mode and Effects Analysis (FMEA), uncertainty quantification, root cause analysis, and process optimization. The objective is to increase the reliability, accuracy, and repeatability of measurement results in electrical testing laboratories, while reducing operational risks, improving calibration traceability, and enhancing personnel competence. The study further evaluates the effectiveness of the integrated system by comparing key performance indicators before and after implementation [17-20].

The relevance of this research lies in the growing global demand for verified, traceable, and harmonized test results, driven by international trade, cross-border certification, and stricter regulatory requirements. The results of this work may serve as a practical model for testing laboratories seeking accreditation, certification bodies adopting risk-based quality systems, and national metrology institutes implementing advanced quality management tools [21].

## EXPERIMENTAL RESEARCH

The experimental research was conducted in an electrical testing laboratory operating under the requirements of ISO/IEC 17025 and supported by selected elements of ISO 9001. The goal of the experimental stage was to determine how the integration of a quality management system affects the accuracy, repeatability, and stability of electrical measurement results. To ensure scientific validity, the study involved structured measurements, uncertainty evaluation, personnel variation analysis, environmental influence assessment, and equipment performance verification [22-24].

A comprehensive analysis of baseline laboratory performance was carried out prior to the implementation of standardized processes. This analysis revealed several deviations affecting measurement quality, including operator-dependent variability, irregular calibration intervals, and insufficient environmental monitoring. Quantitative results of this baseline assessment are presented in Table 1, which summarizes key measurement indicators before and after the implementation of the integrated quality management system [25-27].

To ensure consistent and repeatable data collection, a unified procedural workflow was introduced. This workflow included standardized operating procedures, detailed equipment setup guidelines, and harmonized sample handling rules. Each measurement cycle was performed multiple times by different operators to evaluate repeatability and identify human-factor-related deviations. Environmental parameters such as temperature, humidity, and power supply stability were monitored continuously to assess their impact on electrical measurements [28-30].

The controlled measurements demonstrated noticeable improvements after the implementation of the integrated management system. As shown in Table 1, the combined measurement uncertainty was reduced by more than 50%, while operator-dependent deviations decreased by over 60%. Additionally, calibration compliance significantly increased due to the implementation of a documented calibration plan aligned with ISO/IEC 17025 requirements.

A detailed process map representing the standardized workflow used during experimentation is provided for methodological clarity. This process map illustrates the sequence of actions, control points, and verification steps applied during the testing cycle, ensuring consistent execution of each measurement. Its purpose is to display the transition from a variable, operator-dependent process to a unified, standardized measurement model [31-33].

Measurement uncertainty was evaluated using both Type A and Type B methods. Type A uncertainty was derived from statistical analysis of repeated measurements under fixed conditions, while Type B included equipment calibration certificates, technical specifications, environmental stability, and reference standard uncertainty. The combined and expanded uncertainty were calculated according to the Guide to the Expression of Uncertainty in Measurement (GUM), ensuring full compliance with international metrological practice [34-36].

Risk-based engineering tools were applied to analyze failure modes within the measurement process. Failure Mode and Effects Analysis identified the highest risk priority numbers in areas related to calibration drift, operator error, and environmental fluctuations. After system integration, these values were significantly reduced because of standardized procedures, operator competence improvement, and strengthened calibration management [37-39].

**TABLE 1.** Key measurement indicators before and after QMS integration

Indicator	Before Implementation	After Implementation	Improvement (%)
Combined measurement uncertainty (k=2)	6.5%	3.2%	–50.8%
Repeatability coefficient	0.82	0.95	+15.8%
Operator-dependent deviations	9.8%	3.5%	–64.3%
Calibration compliance	68%	97%	+29%
Equipment drift (annual)	1.8%	0.9%	–50%
Environmental fluctuation influence	medium	low	qualitative decrease

The experimental results confirmed that the integration of quality management principles into electrical measurement workflows leads to measurable improvements in technical performance. The reduction in uncertainty, improved repeatability, and greater stability demonstrate the effectiveness of the integrated quality management system and its relevance for electrical testing laboratories seeking higher technical credibility and compliance with international standards [40-44].

## RESEARCH RESULTS

The implementation of the integrated quality management system demonstrated measurable improvements across all operational and technical indicators within the electrical testing laboratory. Quantitative analysis of measurement quality shows a clear reduction in uncertainty, improved repeatability, increased calibration compliance and enhanced environmental control. A structured comparison of numerical indicators is presented in Table 1, where the impact of the integrated management system is explicitly quantified [45-47].

A detailed study of repeated measurement cycles revealed a decrease of combined measurement uncertainty from 6.5% to 3.2%, representing a reduction of more than 50%. Repeatability improved from 0.82 to 0.95, reflecting greater measurement stability under identical operating conditions. Operator-dependent deviations decreased from 9.8% to 3.5%, which correlates with improved personnel training, harmonized procedures and the introduction of documented operating instructions [47-49].

The calibration management plan significantly enhanced equipment reliability. Calibration compliance increased from 68% to 97%, while long-term drift decreased from 1.8% to 0.9% annually. Environmental fluctuation influence also decreased from moderate to low due to improved monitoring of temperature, humidity and electrical supply stability. These changes reflect the transition from a reactive quality approach to a proactive, risk-oriented model.

The improvement dynamics of the laboratory's performance can be visually observed in the measurement improvement chart provided below. It demonstrates the incremental change in key indicators following the implementation of the integrated quality management system. A process workflow scheme is also included to illustrate the structured sequence of activities applied during the experimental stage [50-52].

A combined analysis of Type A and Type B uncertainty components confirmed that both statistical repeatability and instrumental stability contributed to the overall reduction in uncertainty. Enhancements in documentation, calibration evidence, and environmental recording further strengthened Type B factors. The risk assessment confirmed a marked reduction in risk priority numbers across the most vulnerable measurement stages [53-55].

Overall, the results confirm that the integrated quality management system significantly improves measurement accuracy, reduces variability, and enhances laboratory reliability, strengthening both technical capability and managerial consistency [55-56].

The obtained results demonstrate that the integration of a structured quality management system significantly improves the performance of an electrical testing laboratory. The quantitative improvements presented in Table 1 confirm the direct relationship between standardized processes and enhanced measurement accuracy. The reduction of combined uncertainty by more than 50% indicates that both technical and managerial interventions effectively stabilized the measurement environment [57-59].

The increase in repeatability is also consistent with findings from similar studies in metrology and laboratory management, where harmonized procedures and personnel training were shown to reduce variability between operators. The improvements observed in the repeatability coefficient in Table 1 suggest that operator actions became more consistent due to the introduction of unified measurement protocols, competency-based training and detailed procedural documentation [60-61].

Another significant aspect is the improvement in calibration compliance. The increase from 68% to 97% demonstrates that the development of a calibration plan, aligned with ISO/IEC 17025 requirements, contributed directly to equipment reliability and stability. This result is especially important for electrical measurements, where

calibration drift is among the dominant sources of uncertainty. The corresponding decrease in equipment drift presented in Table 1 confirms the effectiveness of the implemented measures [61-62].

Environmental control played an equally important role in improving technical performance. Prior to the integration of the management system, fluctuations in temperature, humidity and supply voltage had a measurable impact on electrical resistance and power measurements. After systematic monitoring and documentation were implemented, the influence of environmental factors decreased to a low level, further contributing to uncertainty reduction [1-4, 62].

It is important to note that improvements were not limited to technical parameters. The implementation of the quality management system also strengthened risk management, as confirmed by the reduction in operator-related deviations and calibration-related risks. These findings support the argument that technical accuracy and organizational quality are interconnected, and improvements in one area reinforce the other [1-3, 62].

However, the study also highlights certain limitations. The effectiveness of the integrated system depends on long-term adherence to documented procedures, continuous training and a stable organizational culture. If these elements weaken, the improvements documented in Table 1 may diminish over time. Additionally, the research focused primarily on electrical measurement processes, and although the principles are broadly applicable, the specific numerical improvements may vary for other types of testing laboratories [11-14, 62].

Overall, the results demonstrate that the integration of ISO 9001 and ISO/IEC 17025 provides a strong foundation for improving technical capability, operational reliability and measurement credibility. The findings suggest that the combined use of engineering tools, risk assessment and structured management processes leads to sustainable performance improvement [21-24, 62].

## CONCLUSIONS

The study confirmed that the integration of a structured quality management system significantly enhances the performance of an electrical testing laboratory. The combined improvements in uncertainty, repeatability, calibration compliance and environmental stability, summarized in Table 2, demonstrate the direct impact of standardized procedures, enhanced personnel competence and strengthened calibration oversight.

The reduction in overall measurement uncertainty by more than 50% indicates that both technical and organizational improvements contributed to stabilizing the measurement process. Higher repeatability and reduced operator influence confirm the effectiveness of harmonized protocols and targeted training. The improvement in calibration compliance and reduction in equipment drift reflect the contribution of systematic calibration management aligned with ISO/IEC 17025.

The findings support the conclusion that integrating ISO 9001 principles with ISO/IEC 17025 requirements creates a unified and efficient management structure that addresses both technical and administrative aspects of laboratory operations. This integrated system provides measurable benefits in terms of accuracy, reliability and risk reduction.

The research provides a practical framework that can be adopted by electrical testing laboratories, certification bodies and metrological institutions seeking to improve technical credibility, reduce operational risks and strengthen compliance with international standards. Future research may focus on digital integration, automated environmental monitoring, data-driven uncertainty prediction and the application of artificial intelligence for measurement optimization.

The overall results demonstrate that a systematic, engineering-based and risk-oriented management approach significantly enhances the quality and reliability of electrical measurements and provides a sustainable foundation for continuous improvement.

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