Advancements and Innovations in Accelerated Aging Test Methods for Smart Meters

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1. Introduction

Smart meters are the core devices of Advanced Metering Infrastructure (AMI), and their long-term operational reliability directly affects metering accuracy and distribution system stability. Under Taipower's Y500(109-03) material specification for Modular Smart Electronic Meters, meter suppliers are required to submit accelerated aging test reports for review prior to delivery. However, a review of historical third-party test reports revealed that most evaluations focus primarily on visual inspections and failure counts, with insufficient continuous monitoring of metering drift, display anomalies, pushbutton failures, or other functional degradation occurring during aging, and without establishing lifetime prediction models. Consequently, such reports fail to fully characterize the reliability of smart meters under actual service conditions.

To enhance reliability assessment capabilities, the Taiwan Power Research Institute (TPRI) established its own accelerated aging test facility and conducted a six-month aging program. By systematically collecting failure data, analyzing failure modes, and estimating lifetime characteristics, the study developed a more discriminative accelerated aging methodology to serve as a technical basis for future revisions of smart meter material specifications and quality management practices.

2. Collection and Analysis of Test Data

Testing was conducted with reference to IEC 62059-31-1, using a 50% confidence level and a 5% failure fraction as the basis for lifetime estimation. Two environmental stress conditions— 85°C/95%RH and 75°C/95%RH—were each evaluated over 2,000 hours under a continuous load of 10% reference current at unity power factor. Failure modes were categorized into cumulative metering abnormalities, LCD display anomalies, and pushbutton failures. Functional verification and failure statistics were recorded at 100-hour intervals. Upon completion, accuracy tests were performed to assess the impact of high-temperature/high-humidity exposure on metering performance, establishing baseline reliability data and revealing degradation trends throughout the accelerated aging process.

3. Advancements and Innovations

Initial Weibull-based lifetime estimation was found to be highly sensitive to limited failure samples, producing significant variability and results occasionally inconsistent with field experience. Therefore, test results from five manufacturers and multiple meter models were consolidated to re-examine the correlations between test conditions and failure data, identifying the key criteria with genuine discriminative power for product quality assessment.

The analysis results demonstrated that the 85°C/95%RH condition more effectively exposed latent defects and differentiated product quality compared to the 75°C/95%RH condition. Under 85°C/95%RH, meters that exhibited no failures within the first 1,000 hours showed a very low probability of subsequent failure, indicating that the

first 1,000 hours is sufficient to discriminate reliability differences among products. Post-test accuracy verification—particularly the ambient temperature variation test specified in CNS 14607 Section 9.1.12—was also found to be highly effective in identifying latent metering anomalies.

Based on these findings, the recommended method adopts a single stress condition of 85°C/95%RH for 1,000 hours with a sample size of 70 units. Continuous failure monitoring is maintained throughout the test, and post-test ambient temperature variation verification on sampled meters is required to confirm metering stability, thereby enhancing the credibility and representativeness of the test results. (Figure 1)

In addition to optimizing the test conditions, this study introduced improvements to the test fixture design. It was observed that when meters are removed from the high-temperature/high-humidity chamber and restored to ambient conditions, rapid changes in temperature and humidity can induce condensation. Horizontal placement may allow condensation to accumulate on PCB surfaces, potentially causing unexpected electrical failures, which deviates from actual vertical installation practices in the field. To address these issues, a custom rack-type fixture was designed to suspend meters vertically during aging, reducing the condensation risk and improving chamber space utilization. The fixture also incorporates a pallet-style base for forklift handling, significantly improving operational efficiency and safety when transferring large quantities of meters. (Figure 2)

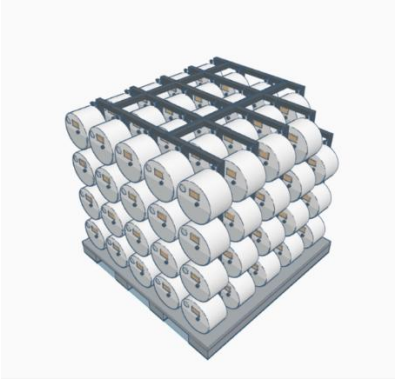

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Figure 2. Demonstration of the Rack Fixture for 99 Single-Phase Smart Meters

4. Conclusions and Future Work

By establishing in-house accelerated aging capabilities and conducting long-term reliability validation, this study developed the fundamental datasets and failure analysis capabilities required for smart meter aging assessment, and proposed a more practical and operationally viable accelerated aging methodology. The findings demonstrate that the integration of optimized test conditions, failure criteria, and post-test metering verification significantly enhances product screening effectiveness and better reflects real-world operational conditions.

Future work will expand the reliability database with data from additional manufacturers and generations of smart meters, investigate electronic component degradation mechanisms and failure modes, and evaluate the incorporation of communication monitoring and advanced data analytics to further improve reliability assessment accuracy—serving as an important technical foundation for future smart meter quality management and material specification enhancement, and ultimately supporting Taipower in improving the overall reliability of AMI equipment and the quality of electricity supply services.

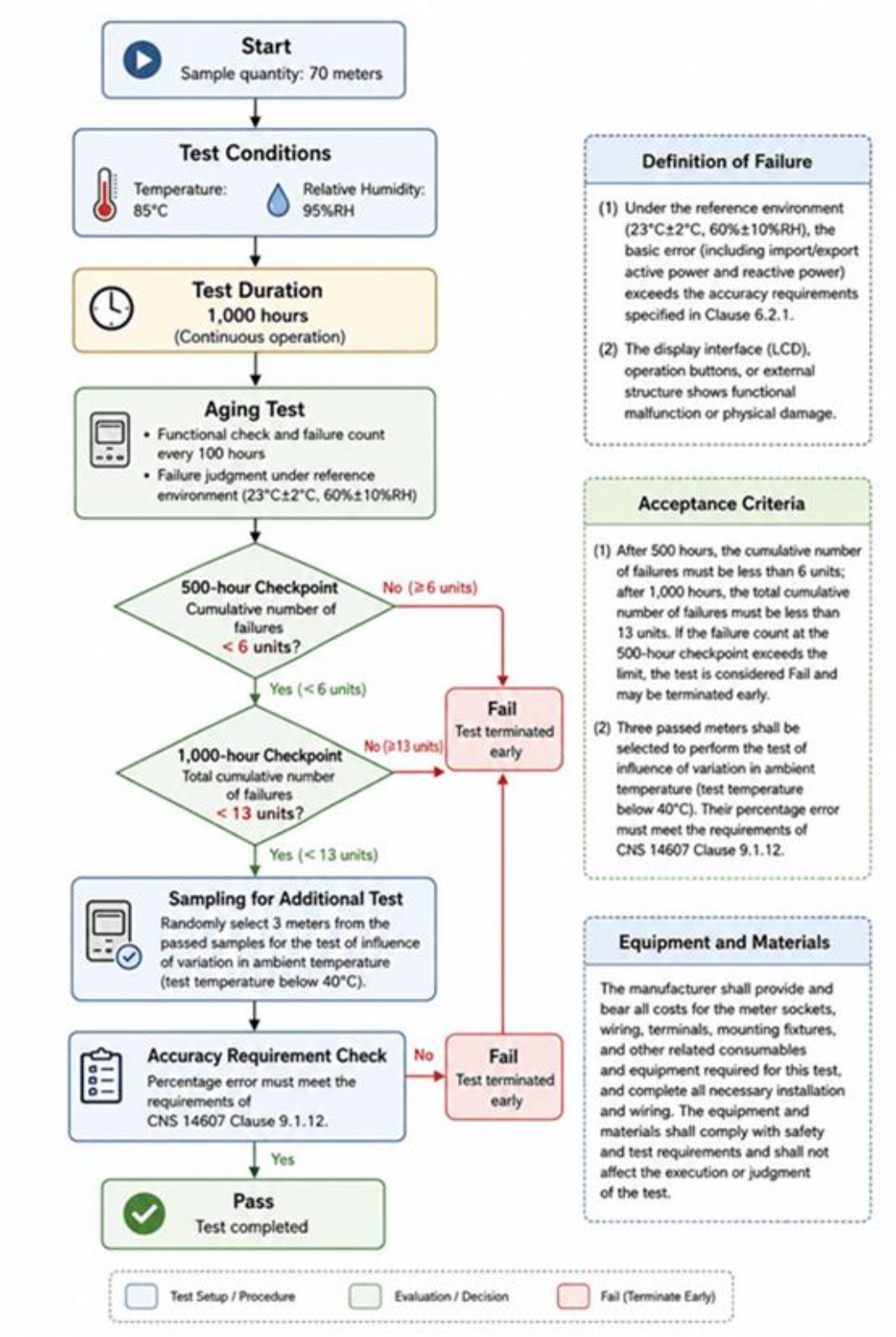

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Figure 1. Flowchart of the Accelerated Aging Test Procedure