Reliability Enhancement Methods for MMIS in Plant Operational Phase

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Abstract

This paper proposes a systematic methodology to improve the reliability of Nuclear Power Plant (NPP) Man-Machine Interface Systems (MMIS) during the operational phase. By integrating the safety function verification requirements of IEC 61513 and the reliability management principles of IEC 60300, this study establishes a framework to ensure both the technical maturity and operational performance of MMIS.

The analysis focuses on the APR1400 reactor's safety and non-safety MMIS components—such as controller I/O modules, Human-Machine Interfaces (HMIs), networks, time synchronization systems, software, alarm systems, maintenance procedures, change management protocols, and supply chain management—to derive targeted reliability enhancement strategies. Comparative evaluations between the Operational and Maintenance (O&M) requirements of IEC 61513 and IEC 60300 are conducted to recommend contextually appropriate adaptations for nuclear plant environments.

Furthermore, an integrated management strategy is established to harmonize the safety-centric methodologies of IEC 61513 with the reliability-oriented frameworks of IEC 60300, thereby achieving the dual objectives of enhanced system trustworthiness and economic efficiency.

1. Introduction

To enhance the reliability of NPP MMIS during the operational phase, it is necessary to integrate the safety function verification requirements of IEC 61513 with the Reliability, Availability, Maintainability, and Safety (RAMS) management principles of IEC 60300 [1, 2]. This integrated approach establishes a core framework for concurrently achieving technical robustness and operational excellence in MMIS.

As digital Instrumentation and Control (I&C) systems become increasingly complex, preventive reliability management across both design and operational phases has grown critically important. Nevertheless, prior research has predominantly centered on functional safety assurance during design and verification phases, resulting in comparatively underdeveloped O&M reliability management frameworks [3].

This study proposes targeted reliability enhancement strategies for key APR1400 MMIS subsystems, encompassing safety and non-safety controller I/O modules, HMIs, networks, time synchronization, software, alarm systems, maintenance and change management, and supply chain logistics. These strategies leverage the synergistic application of the IEC 61513 and IEC 60300 standards. The outcomes aim to advance operational reliability and establish cost-effective maintenance strategies for digital system replacements and prolonged operational lifecycles.

2. Comparison of IEC 61513 and IEC 60300 from an Operational Perspective

2-1. Key Differences

NPP MMIS serves as a critical interface between operators and I&C systems. Its O&M activities must balance nuclear safety assurance with reliability and economic efficiency. From this perspective, we compare the O&M requirements of IEC 61513 and IEC 60300 to derive practical implementation strategies for NPPs.

While both standards address O&M aspects, they differ fundamentally:

- IEC 61513: Focuses on securing the determinism, independence, and verifiability of safety functions within nuclear I&C systems.
- IEC 60300: Emphasizes an industry-wide RAMS management framework to achieve continuous performance improvement and lifecycle optimization.

2-2. Application Strategy

IEC 61513 prioritizes safety assurance and regulatory compliance during MMIS O&M, whereas IEC 60300 targets RAMS performance and cost-effectiveness. Thus, NPP MMIS should adopt IEC 61513 as its primary reference standard while leveraging IEC 60300 as a complementary framework to enable reliability data-driven maintenance optimization and cost efficiency.

3. Reliability Enhancement Strategies using Standard Application Methodology

When designing practical implementation strategies, IEC 61513 should serve as the foundational safety benchmark, while IEC 60300 acts as a complementary tool for optimizing asset performance:

- Apply IEC 61513: To ensure full-lifecycle management and safety assurance for safety-related I&C systems, including MMIS.
- Apply IEC 60300: To leverage the RAMS framework for maintenance optimization and Life Cycle Cost (LCC) reduction.

As MMIS represents the primary interface between operators and safety I&C systems, any degradation in reliability directly degrades safety. Consequently, an integrated strategy that combines IEC 61513's safety-centric governance with IEC 60300's reliability-focused management is essential to sustain operational resilience while achieving cost-efficient lifecycle outcomes.

4. Conclusions

This study proposes a systematic approach to enhancing the reliability of NPP I&C systems during the operational phase.

By analyzing the IEC 61513 and IEC 60300 standards, we confirmed that IEC 61513 prioritizes regulatory compliance for safety assurance, while IEC 60300 focuses on operational efficiency and lifecycle cost optimization. Thus, adopting IEC 61513 as the primary standard—with IEC 60300 as a complementary management tool—provides a balanced framework for NPP MMIS operation and maintenance.

The findings offer valuable technical bases for future digital I&C system retrofits and replacements. In particular, integrating IEC 61513's safety protocols with IEC 60300's reliability management will bolster long-term operational reliability, support cost-effective maintenance strategies, and enhance regulatory compliance.

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