Considerations on Safety Evaluation of Safety grade Smart Transmitter in Nuclear Power Plants

Hyung Tae Kim * and Choong heui Jeong
Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon, Korea, 305-338
**Corresponding author: k719kht@kins.re.kr*

1. Introduction

As its nuclear power plants age, the electric power industry is focusing on the development of replacements for many obsolete components used in instrumentation and control (I&C) systems. Smart transmitters are digital I&C equipment which can replace analog transmitters. Non-safety grade smart transmitters have been used for I&C systems of NPPs(Nuclear Power Plants). Smart transmitter is a microprocessor-based device including software and provides capability for digital signals to be communicated on top of the 4-20 mA analog signals. Recently, smart transmitters have been used for safety grade I&C systems as well as non-safety grade I&C system for SKN 3&4. Due to potential benefits of smart transmitter, it is anticipated smart transmitters will be widely used safety-related applications at NPPs. For those reasons, smart transmitter's technology and characteristics need to be investigated. So we surveyed EPRI report, NRC event report, and SKN 3&4 related to smart transmitter to get useful information. This paper addresses considerations on safety evaluation of safety grade smart Transmitter in NPPs.

2. Generic Qualification of the Rosemount 3051N

EPRI has qualified commercial Rosemount Pressure Transmitter for use in safety-related applications. EPRI-1001468 report summarizes the methods and results of a series of tests and evaluations performed to qualify a smart transmitter for use in safety-related applications [1].

2.1 Overview

The smart transmitter Rosemount 3051C was manufactured as a commercial device by Rosemount, Inc., Measurement Division (RMD). The qualified version of the 3051C by commercial grade dedication has been given a new model designation, 3051N, by Rosemount Nuclear Instruments, Inc. (RNII). The Rosemount 3051N is considered acceptable for mild environment nuclear safety-related and non-safety-related plant applications. The 3051N qualification activities addressed the generic functional and application requirements established by an EPRI working group.

2.2 Commercial Grade Dedication Activities

The results of the commercial grade survey and the qualification and dedication activities are considered to provide reasonable assurance that the 3051N will perform in accordance with the specifications provided in the 3051N Transmitter Product Data Sheet. Table I summarize the critical characteristics of 3051N.

Table I: Critical Characteristics of Smart Transmitter 3051N for Commercial Grad Dedication

Item	**Critical Characteristics**
Performance Specifications	• Reference Accuracy, Drift • Dynamic Performance(Dead Time, Update Rate) • Seismic • EMC(EMI/RFI) and Power Supply Effect • Ambient Temperature, Static Pressure, Overpressure and Mounting Position Effect
Specification Limits	• Sensor Limits – Minimum Span • Static Pressure, Overpressure, Burst Pressure Limits • Turn on Time
Dependability	• Quality of Design and Manufacture • Failure Modes and Failure Management • Problem Reporting • Reliability • Configuration Control
Physical Configuration	• Pressure Type, Range code, Output Code • Process connections, Isolating Diaphragm etc

2.3 Lessons Learned from Critical Digital Review

As a digital, microprocessor-based device the 3051C transmitter is relatively simple in its architecture, hardware, and software. Its primary function is to transmit a single 4-20 ma signal in response to a single process measurement. Although the smart transmitter provides capability of digital communication, nuclear applications are not expected to make use of this feature. Use of digital communications during operation, while the 3051N is performing its safety function, was not addressed by the generic qualification activities.

Critical Digital Review (CDR) to assess the design integrity, built-in quality, and dependability of the 3051C was performed. Some examples of the kinds of information developed in the CDR for the Rosemount 3051N transmitter are given in Table II.

Table II: Important information on smart Transmitter

Item	**Important Application Information**
Access control & Security	• To minimize the risk of making unintended changes to the wrong 3051N, there should be clear procedural guidance for calibration and configuration of the 3051N. • Administrative procedures for making configuration changes, and use of security features to prevent changes, should be considered
Behavior on power-up	• Behavior of the output during the powerup transient and the time required to reach a final, accurate reading should be considered for each application of the transmitter.
Dependability	• The effect of the transmitter's digital signal (riding on top of the analog 4-20 ma signal) on other process loop components should be evaluated.
Fail-safe	• For each application, the desired action to be taken under "failsafe" conditions should be determined, and the transmitter configured accordingly.
Coverage of self-diagnostics	• Coverage of the internal self-diagnostics (i.e., which faults are detected, and which are not) should be considered.

3. Survey of failures of smart transmitter

According to U.S NRC Operations Center Event Report, two events (Event # 44082, # 46085) related to smart transmitter were reported by RNII pursuant to 10 CFR Part 21 [2]. Failures of 3051N were about manufacture defects of application-specific integrated circuit (ASIC) which performs Digital to Analog Conversion (DAC) and sensor module. There were no reported incidences of microprocessor failure or software bugs.

3.1 Event # 44082

RNII reported that a limited number of Model 3051 N pressure transmitters may exhibit erratic, unstable output prior to an off-scale failure. The Model 3051N pressure transmitter contains an ASIC which performs the DAC. A limited number of Model 3051N pressure transmitters manufactured between January 2002 and October 2002 have DAC ASICs which may contain phosphorus as the encapsulation material. Failure analysis identified the phosphorus-containing encapsulation material of the DAC ASIC as the cause of failure for these transmitters.

3.2 Event # 46085

RNII reported that a limited number of Model 3051 N pressure transmitters may exhibit non-linear and non-repeatable performance. Model 3051N pressure transmitters (Ranges 1, 2 and 3) manufactured between August 2002 and September 2006 have sensor module castings that were not solution annealed, and therefore may contain elevated levels of hydrogen in the sensor module fill fluid. Due to hydrogen bubbles in the sensor module, pressure transmitters may exhibit non-linear and non-repeatable performance.

4. Review experiences of safety-grade smart transmitter in SKN 3&4

3.1 Overview

For SKN 3&4, safety grade smart transmitters have been used for safety I&C systems. KINS are reviewing use of safety grade smart transmitter in SKN 3&4 [3]. The smart transmitter was developed as safety grade equipment for harsh environment nuclear safety-related plant application. The Smart transmitter is used in safety and non-safety applications in SKN 3&4. The transmitters for SKN 3&4 have not been used for providing input variables for RTS or ESFAS. Only input variables from analog transmitters are used for Plant Protection System (PPS). Use of digital communications of a safety-grade smart transmitter during operation was not permitted.

3.2 Review Activities of safety-grade smart transmitter in SKN 3&$

Safety-grade smart transmitter shall meet the requirements of IEEE Std. 603 and IEEE Std. 7-4.3.2 and be qualified in accordance with the requirements of IEEE Std 323, etc as digital equipment [4,5,6]. Unlike analog transmitter which is hardware-only equipment, smart transmitter for safety-related applications involves more than the environmental and seismic testing used for hardware-only equipment. It is important to review software characteristics as well as hardware characteristics of smart transmitter for nuclear safety-related applications. It includes assessment of such things as software quality, software V&V, and other issues that need special attention for digital technology.

Smart transmitter has the possibility that a design error in the software in redundant safety system channels could lead to a common-cause failure the safety system function. SKN 3&4 have used same smart transmitters for safety and non-safety grade I&C systems unlike previous NPPs. In accordance with NUREG 0800 BTP 7-19, applicant shall assess the defense-in-depth and diversity of the proposed I&C system to demonstrate that vulnerabilities to common mode failures have adequately been addressed [7]. Smart transmitters have microprocessor and software, so the error of software can be a potential source of CCF. It was required to assess potential vulnerability that could result from software CCFs of safety grade and non-safety grade smart transmitters and to assess that these CCFs could not lead to an adverse safety function by KINS [3].

3. Conclusions

Smart transmitters have been used for safety grade as well as non-safety grade I&C system since SKN 3&4. Due to potential benefits of smart transmitter, it is anticipated smart transmitters will be widely used safety-related applications at NPPs. For those reasons, smart transmitter's technology and characteristics need to be investigated. To get useful information about that, we surveyed EPRI qualification report, NRC event report, and SKN 3&4's review.

Through the surveys, we reviewed considerations on safety Evaluation of safety grade smart transmitter as followings.

- Critical Characteristics in Table I
- Important application information in Table II
- Failures such as DAC and sensor module
- Common Cause Failure etc.

We have future research plan to execute proof tests about those considerations and develop safety review guide for smart transmitters.

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REFERENCES

[1] EPRI-1001468, "Generic Qualification of the Rosemount 3051N Pressure Transmitter: Summary of Activities and Results", June 2001
[2] U.S. NRC Event report # 44082, 46085, www.nrc.gov
[3] Y.M. KIM and C. H. JEONG, "Regulatory Experience on Safety Smart Transmitter's CCF of SKN 3&4", Transactions of the Korean Nuclear Society, October 2014
[4] IEEE Std. 603-1998, IEEE Standard Criteria for Safety Systems for Nuclear Power Generation Stations.
[5] IEEE Std. 7-4.3.2-2003, IEEE Standard Criteria for Digital Computers in Safety Systems of Nuclear Power Generating Stations
[6] IEEE Std. 323-1983, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations
[7] U.S.NRC NUREG-0800 BTP 7-19, Guidance for Evaluation of Diversity and Defense-in-Depth in Digital Computer-Based Instrumentation and Control Systems.