SIF Proof Testing Yields Process Sector Reliability Data

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Abstract

ANSI/ISA 84 requires periodic proof testing of SIFs to demonstrate the correct operation of the loop elements along with sufficient historical documentation to support analysis of discrepancies and validation of the SIF integrity and reliability. The analysis of proof test records is an important element of the quality assurance process necessary to support continued use of installed equipment. The CCPS Process Equipment Reliability Database (PERD) project has developed failure data taxonomies which provide a structure to capture data to support chemical process data collection and analysis.

SIS-TECH® has been distributing a device failure rate database for more than 10 years. This paper describes how SIS-TECH® will collect device performance data under a quality plan during periodic SIF proof testing. This data will be contributed to PERD for review and analysis so that SIL Solver® failure rates can be validated against operating environment data.

Introduction

Safety Instrumented Systems (SIS) rely on many devices that must work as designed at a specific point in a hazard scenario to stop propagation of the hazardous event. ANSI/ISA 84.00.01-2004 (ISA 84) relies on a quality assurance process to assure that the SIS achieves the performance necessary to adequately reduce risk throughout the process equipment life. The performance target for this quality process is defined in the standard as the safety integrity level (SIL). Field performance data is required to validate the device performance assumptions used during system design. The Plan, Do, Check, and Act process of the Shewhart cycle [3] provides a structure to discuss the various quality assurance activities necessary to achieve safe operation.

In the Plan phase process risks are assessed and independent protection layers (IPL) are implemented as necessary to reduce identified risk. When a Safety Instrumented Function (SIF) is selected as an IPL, a target SIL is assigned as the performance requirement for the SIF.

In the Do phase the detailed engineering of the SIF is directed at achieving this performance target in a cost-effective manner. ISA 84 Clause 11.9 requires that the SIL be verified by quantitatively using data that represents the device performance in the operating environment. The SIL Verification calculation uses device failure rates and test intervals to ascertain the average probability of failure on demand (PFD_{AVG}). Proof tests should be periodically conducted using a written procedure to validate SIF operation.

In the Check phase proof test and inspection results are analyzed to verify that actual performance matches expectations. ISA 84 clause 5.2.5.3 requires "assessing whether dangerous failure rates of the safety instrumented system are in accordance with those assumed during the design." Manufacturer notices and updates should also be reviewed to verify that the device failure modes and rates used in the SIL Verification calculation are still appropriate.

The Act phase identifies the need for changes to the SIF, whether motivated by performance deficits or continuous improvement opportunities. ISA 84 clause 16.3.1.5 states: "At some periodic interval (determined by the user), the frequency of testing shall be re-evaluated based on various factors including historical test data, plant experience." The recommendation for a SIF change is fed back into the Plan phase as the basis for a new quality improvement cycle.

Proof Test Data Reporting

Demand mode functions must be tested periodically to validate their operation and availability. The acceptance criteria for the proof test establish the minimum threshold for successful operation of the SIF. Passing the proof test directly validates the SIF at the time of the test. It is important to remember that some degree of inspection and maintenance is also expected, concurrent with the proof test, to ensure that SIS components are 'as good as new' when the SIF is returned to service.

Proof test results will be pass/fail for the tested portions of the SIF. When the proof test is completed satisfactorily each device within the proof test scope can be considered as passing. A method is needed to assign the proof tests results to the devices comprising the SIF. The Safety Requirements Specification (SRS) required by ISA 84 Clause 10.3.1 provides that linkage as it lists the devices comprising the SIF.

In the event of a proof test failure the failure cause should be tracked to the device level. In the field the failed device would be identified (by manufacturer, model, and serial number) then repaired or replaced to put the SIF back in service. To support the Check phase of the quality cycle this failure result must be analyzed to verify that the device performance matches the expectations in the SIL Verification calculations.

There is a gap between the manufacturer, model, and serial number structured information from the field and the technology type (e.g. pressure transmitter) information used during design. Device results must be grouped to allow technology performance evaluation. To bridge this gap the device-technology hierarchy established in the SIL Solver® failure rate database will be used. Within SIS-TECH® the goal of proof test data collection and device performance evaluation is the validation of the device failure rates presented in the SIL Solver® database.

Comparison of the estimated failure rates with actual performance tracking results will allow operating companies to use proof test results to identify poor application selections and bad actor manufacturers within a technology type. Such analyses would ultimately drive new device specifications and improved operational safety.

Sharing with PERD

Technology failure rate data would also be shared with PERD. Currently, the SIL Solver® failure rate database technology listing is much more detailed than the PERD taxonomy (Table 1). For example, SIL

Solver® separately lists ten level measurement technologies. A quality plan will be developed to map the SIL Solver® device names to the PERD Loop Components list to support periodic upload of the accumulated test results to PERD. As PERD introduces taxonomies for specific component technologies the mapping of SIL Solver® device names to the PERD devices will be revised within the quality plan so that the accumulated data can best support the on-going PERD effort.

Practical Considerations

Simple pass/fail data will be reported to PERD as the outcome of the proof tests. These results will be captured in greater detail in our internal database, but initially reported to PERD as “Functioning Correctly” or “Interlock Fail to Function”. When the number of recorded failures of a particular technology warrants further investigation the PERD Loop Condition Listing (Table 2) will be used to support more detailed analysis of the failure results. Earlier test records will be analyzed to further categorize the failures within the listed conditions. The extra effort required for this evolution would be justified by the unexpected number of failures indicating a performance gap that should be resolved within the quality cycle.

Motivation

SIS-TECH® has been a part of the PERD initiative since 2004. As a process safety, reliability, and control solutions provider, SIS-TECH® supports owner/operators by supervising proof tests on safety systems and reporting the test results. While upgrading our test result reporting strategy we recognized an opportunity to use these proof test results to validate our internal failure rate database and to support PERD with proof test data. Adjustment of the SIL Solver® failure rate to reflect better or worse than predicted device performance is also possible. Supporting PERD is not completely altruistic – we recognize that it is challenging for a single organization to collect enough performance data to make statistically significant determinations. The PERD approach relies on multiple companies contributing datasets. We expect that access to PERD taxonomies for specific device technologies, populated with data from a variety of supporting companies, will yield increased confidence in the data estimates.

ISA 84 requires that the probability of failure on demand of each SIF be verified quantitatively. PERD taxonomies provide a collection strategy for test results - data that will validate the failure rates used in SIL Verification calculations. Data collection is the next step in the PERD effort to increase confidence in the data being used for SIL Verification in the process industry. Until PERD accumulates sufficient data owner/operators must continue to rely on expert judgment to estimate failure rates for many applications.

Currently wide variations for technology failure rates are reported in the CCPS IPS book (Table 3). A large body of device performance data has been captured to support reliability estimation beginning in the 1970’s with nuclear power and continuing with the efforts of OREDA in the 1990’s. Although the relevance of this data to process industry operations is often questioned, it is the best data that we have available. The covered device was subjected to different environmental stresses and different maintenance practices than were common in the process sector when the data was collected. Process sector device environments can vary widely, as can unit turnaround schedules. In general, industry today has moved to leaner maintenance budgets and higher throughputs. PERD will collect data that is relevant to the process industry as it is run today.

Managing Test Data

Our challenge is to transcribe field test findings into an auditable database – and to do so efficiently. If data collection is allowed to significantly impede the progress, or increase the cost of proof testing, the whole activity will likely be shelved. PERD will improve our future but we will be paying for the data collection today.

Consistency is the key. To support the Check phase of the quality management process at an operating company specific documentation and data must be transferred from the design database to the plant computerized maintenance management system (CMMS). Minimum data fields to be considered for transfer are: I/A device field tag number, the device or equipment group code for the technology measurement family (flow, pressure, temperature, etc.), the device or equipment type code for the specific measurement principle (e.g., for the flow measurement family: dp, coriolis, vortex), manufacturer, model number, location (used on drum, piping, exchanger, etc.), process service, the production plant location, production unit, and process unit, date placed into service.

Operating companies need to ensure that their internal reporting structure is followed through in the maintenance work process and documented in the CMMS. The proof test intervals should be loaded into the CMMS and the proof test procedures should be referenced from the CMMS. Observations, failures, and failure modes will be documented as part of performing the proof test. This additional information can be used by the reliability engineer to correctly categorize the failure during Root Cause Analysis to drive continuous improvement overall and verify/improve the performance and availability of the SIS.

When SIS-TECH® is contracted to perform proof tests on SIS we report the test results to the owner/operators for documentation in their CMMS. While upgrading our test result reporting strategy we recognized an opportunity to use these proof test results to validate our internal failure rate database and to support PERD with proof test data. The proof test procedure is generated in the latter stages of the Do phase. By this time a device listing is available for each SIF as part of the SRS. If the SIF has been in service, the results of last proof test are available. The Proof Test Report Template (Table 4) is preloaded so that each SIF proof test datasheet contains the device listing and last test data from CMMS.

In most cases, the SIF passes the proof test and the devices are credited with a pass. In the event that a failure occurs the failure cause is immediately investigated and subsequently repaired or replaced. The failed device is identified on a work order and on the Failure Report using the appropriate pre-populated failure cause for that technology. The status of the remaining devices is updated when the SIF passes the proof test conducted after completion of the repair/replacement. The failure comment description will use PERD PL_Loop_Condition terminology, where possible, to support subsequent data transcription.

The data accumulated during a set of proof tests is reported to the owner/operator for CMMS updates. This data is also archived within SIS-TECH. Each SIF device test result (and test interval) is recorded within the corresponding SIL Solver® technology dataset. Device failure documentation, the comment descriptions, and work order numbers is retained for later analysis if more detailed review is justified. SIL Solver® data is subjected to annual Delphi reviews as part of our quality management process – field performance information is an important consideration in these reviews. As the PERD data base grows this will be an increasingly valuable input for SIL Solver® validation.

Periodically the data accumulated by SIS-TECH will be uploaded to PERD. An owner/operator may choose to be identified with their data, or have the data reported anonymously. For anonymous data submissions, SIS-TECH will provide a pseudonym so that PERD can still identify the service environment and data source. This will support additional information submission when the owner/operator chooses to, but ensures that PERD has what is required to assure data quality.

Conclusions

Accumulating and analyzing proof test data supports the continuous improvement process for the failure rate estimates used in SIL Verification calculations. ISA 84 contains requirements which support the Plan, Do, Check, and Act process for SIFs. The same actions required for ISA 84 compliance support the improvement process – the remaining challenge is managing the data. Although the ultimate responsibility for hazard and risk reduction rests with the owner/operator, SIS-TECH® recognizes SIL Solver® data is often an important element in the risk reduction strategy. As the PERD data base grows this will be an increasingly valuable input for SIL Solver® validation.

SIS Proof testing must be carefully managed and the test results must be provided to the owner/operator in an auditable record. Collecting the proof test data under a quality plan for submission to PERD is a feasible extension of our work process. With sufficient input data PERD will provide a fundamentally and technically sound equipment reliability database that will benefit the process industry.

References

- Guidelines for Safe and Reliable Instrumented Protective Systems, American Institute of Chemical Engineers, NY, (2007).
- ANSI/ISA 84.00.01-2004, Functional Safety: Safety Instrumented Systems for the Process Industry Sector, Instrumentation, Systems, and Automation Society, NC, (2004).
- ISA TR84.00.04, Guidelines for the Implementation of ANSI/ISA 84.00.01-2004 (IEC 61511), Instrumentation, Systems, and Automation Society, NC (2005).

Table 1. Comparison between PERD Loop Components and SIL Solver Devices

PERD Loop Components
Sensing Element
Input Signal Conditioning
Control Logic Unit
Output Signal Conditioning
Final Control Element
Transmission System
Utility

SIL Solver® Devices
Sensing Element - 80
Input Signal Conditioning - 2
Control Logic Units - 23
Output Signal Conditioning - 4
Final Control Element - 50
Transmission System - 2
Utility – 8

Table 2. PERD Condition Taxonomy

Condition Found
Functioning correctly
Alarm Function Delayed
Alarm Fail to Function
Alarm Spuriously Function
Interlock Function Early
Interlock Function Delayed
Interlock Fail to Function
Interlock Spuriously Function
Interlock voting channel fail to function
Interlock voting channel spuriously functions
False Discrete Indication
Process Variable Indication Saturated High
Process Variable Indication High
Process Variable Indication Frozen
Process Variable Indication Erratic
Process Variable Indication Low
Process Variable Indication Saturated Low

Table 3. Failure rate data (CCPS IPS Book, 2007)

Description	$MTTF^{D}$ (years)	$MTTF^{SP}$ (years)
Analyzers	0.35 - 4.00	0.35 - 4.00
Flow Switches	25 -50	10 – 50
Flow Transmitters	50 - 175	25 – 80
Level Switches	25 - 125	25 – 75
Level Transmitters	25 – 250	15 – 150
Pressure Switches	15 - 80	15 – 80
Pressure Transmitters	75 - 200	75 – 125
Temperature Switches	10 - 100	10 – 50
Temperature Transmitters	75 - 250	25 – 100
Solenoid Valves (de-energize to trip)	30 - 100	10 - 30
Block Valves (failure to close)	25 – 100	50 - 200
Control Valves (failure to close)	15 - 60	30 - 100

Table 4. Proof Test Data Collection Form

Proof Test Report

Plant ID:	Loop ID:	Tag #:
Test Date:	Who Tested:	Test Procedure #
Calibration Pass/Fail/NA?	Test Pass/Fail?	

Failure Report

Previous Test Date:	Previous Pass/Fail?	Tag #:
Technology ID for previous failed device: ______________________		
New Failure Data:		
What was the effect of this failure? ☐ Failed to Operate according to specification ☐ Operated Without Cause		
What caused the failure? List generated per Technology ID. Transmitter Example: ☐ Sensor ☐ Process Connection ☐ Power Supply ☐ Electronic Transmitter ☐ Configuration List Tag # ____________________ ☐ Other (describe) ____		
Failure Tracking System Identification: ☐ Work Order #_______________ Assigned to:___________ Open/Closed ☐ MOC #_____________________ Assigned to:___________ Open/Closed ☐ Program fix #_______________ Assigned to:___________ Open/Closed		
Comments:		
Assessment led by: Date: (SIS Specialist or equivalent)		