An Overview of ISA 84 Standard for Safety Instrumented Systems (SIS) and the Safety Life Cycle

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ISA 84 Safety Instrumented Systems and the Safety Life Cycle

Agenda:
- Safety components, acronyms, and definitions
- ANSI/ISA 84.00.01 Standard for Safety Instrumented Systems
- Safety Life Cycle
- Incorporating safety systems into process design
- Workshop
Components, Acronyms, and Definitions

Components:
- Safety Instrumented Function (SIF)
- Safety Instrumented System (SIS)
- Safety Integrity Level (SIL)
- Safety Requirement Specification (SRS)
- Safety Life Cycle
- Independent Protection Layer (IPL)
Components, Acronyms, and Descriptions

- **SIF – Safety Instrumented Function**
  - Individual interlock or automatic trip function that is designed to alleviate or minimize an undesired hazard, as determined in the PHA/HAZOP and the SIL Selection/LOPA
  - Includes all instrumentation in the interlock function, from the sensor and transmitter through the control system all the way to the final element (e.g., isolation valve)
Components, Acronyms, and Descriptions

- **SIS** – Safety Instrumented System
  - A critical system that consists of one or more automatic Safety Instrumented Functions (SIFs) or interlocks
  - Example: Fired Heater burner management system (BMS)
Components, Acronyms, and Definitions

- **SIL** – Safety Integrity Level

Risk reduction levels:

<table>
<thead>
<tr>
<th>SIL</th>
<th>RRF</th>
<th>PFD (1/RRF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-10</td>
<td>$\geq 10^{-1}$</td>
</tr>
<tr>
<td>1</td>
<td>&gt;10 to $\leq$ 100</td>
<td>$\geq 10^{-2}$ to $&lt; 10^{-1}$</td>
</tr>
<tr>
<td>2</td>
<td>&gt;100 to $\leq$ 1000</td>
<td>$\geq 10^{-3}$ to $&lt; 10^{-2}$</td>
</tr>
<tr>
<td>3</td>
<td>&gt;1000 to $\leq$ 10,000</td>
<td>$\geq 10^{-4}$ to $&lt; 10^{-3}$</td>
</tr>
<tr>
<td>4</td>
<td>&gt;10,000 to $\leq$ 100,000</td>
<td>$\geq 10^{-5}$ to $&lt; 10^{-4}$</td>
</tr>
</tbody>
</table>
Components, Acronyms, and Definitions

- **SIL** – Safety Integrity Level
  - Level of risk reduction that a SIF must achieve
  - **Target / Required SIL** – amount of risk reduction determined as a need during PHA / HAZOP and then the level is determined during a simplified SIL Selection or elaborate LOPA (Layer of Protection Analysis)
  - **Achieved / Verified SIL** – calculated risk reduction utilizing Markov equations and includes all components of the interlock to determine the level of risk reduction (RRF) or 1/PFD (Probability of Failure on Demand)
Components, Acronyms, and Definitions

- **SIL** – Safety Integrity Level
  
  Levels of risk:
  - SIL 0 (none) – tolerable risk
  - SIL 1 – minimal risk
    - 95% of all SIL-rated interlocks
  - SIL 2 – medium risk
    - Less than 5% of all SIL-rated interlocks
  - SIL 3 – high risk
    - Less than 1% of all SIL-rated interlocks (typically found in the nuclear industry or off-shore platforms)
  - SIL 4 – highest risk (not likely in petroleum or chemical industry)
Components, Acronyms, and Definitions

- **SRS** – Safety Requirement Specification
  - Document containing detailed SIS interlock information

- **Safety Life Cycle** –
  - Activity designed to include all phases of the life of a SIF and SIS
    - *KEY NOTE*: It’s not enough to just *install* a SIS. It must be properly designed and maintained so it is available when the need arises!!!
  - ANSI/ISA 84 and Safety Life Cycle were developed to guide a safety system from the Risk Assessment “cradle” to the Decommissioning “grave”.

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ANSI/ISA 84.00.01 - Application of Safety Instrumented Systems (SIS) for Process Industries:

- Follows IEC 61511
- First version in 1996
- Second version approved in 2004 (included a “Grandfather Clause”)
- OSHA recognizes this standard as a RAGAGEP
- Defines Safety Instrumented System (SIS)
- Defines all phases required in Safety Life Cycle
ANSI/ISA 84 and Safety Life Cycle

Hazard & Risk Assessment (PHA, LOPA/SIL Analysis) -> Design (Execute & Evaluate) -> Installation, Commission, & Validate (FAT, SAT, Functional Proof Test) -> Operations and Maintenance -> Modification

Decommission "grave" -> "cradle"
Why SIS and Safety Life Cycle?

- Accidents/Incidents can and do occur, so in order to help minimize the frequency and/or severity -
- Safety Instrumented Systems and Safety Life Cycle are designed to minimize risk
- But if the Safety Life Cycle is stopped, this could occur...
BP Refinery - Texas City
Why SIS and Safety Life Cycle?

- 15 fatalities and 180 injuries that day in 2005
- Resulted in multitude of citations with a hefty fine of $21MM
- 2009 – Follow-up FTA inspection was conducted and $87MM fine was given; most of the FTAs related to PSVs and SIS
Why SIS and Safety Life Cycle?

- Due to public concern over the severity of the 2005 BP Texas City incident, OSHA initiated NEP (National Emphasis Program) inspections in petroleum refineries across the country in 2007
  - OSHA included SIS analysis in the NEP dynamic list for refineries (due to SIS and instrumentation failures considered as contributing causes of the BP incident)
  - OSHA more recently initiated a nationwide NEP directive for chemical facilities with PSM-covered chemicals in late 2011
Why SIS and Safety Life Cycle?

- ANSI/ISA 84.00.01 - Application of Safety Instrumented Systems (SIS) for Process Industries:
  - OSHA recognizes this standard as RAGAGEP (Recognized and Generally Accepted Good Engineering Practice) and has considered it to be within the scope of OSHA 1910.119 PSM regulation under Mechanical Integrity (MI)
Protection Layers

- **IPL – Independent Protection Layer**
  - Protective items, when used alone or in combination with diverse types, that are meant to reduce risk to personnel, the environment, or property
  - Examples: BPCS (control system), alarms and operator response, SIS, physical devices (PSVs, dual seals, dikes, flares, deluges, etc.), and other human mitigation (emergency response)
Protection Layers

- Process Hazards/Risk and IPLs (ups and downs)

Risk

- process risk
  - tolerable

Risk Process

- BPCS
  - alarms
  - SIS
  - mechanical
  - other
Protection Layers

Emergency Response
(Plant and then Community)

Mitigation (SIS, mechanical mitigation)

Prevention
(Alarms w/ intervention, mechanical protection)

BPCS

PROCESS
Protection Layers / SIFs / SISs

- Safety systems/interlocks are a vital protection layer between the hazards of the process and the public when inherent design is not enough.

- Safety Systems are added to the process design to minimize these risks to a tolerable level or ALARP (As Low As Reasonably Practical).
Safety Systems Design

Design (Execute & Evaluate)

Installation, Commission, & Validate (FAT, SAT, Functional Proof Test)

Modification

Operations and Maintenance

Decommission

“grave”

“cradle”

Hazard & Risk Assessment (PHA, LOPA/SIL Analysis)
Safety Systems Design

- SIF/SIS is added to a design during the “cradle” stage or PHA as a safeguard to mitigate or minimize a hazard.
- Each SIF is assigned a Safety Integrity Level (SIL) during the SIL Analysis or LOPA risk assessment.
  - SIL 0 – lowest risk
  - SIL 4 – highest risk
- Each incremental SIL must be more reliable and available to operate when required (thus installation and maintenance costs increase).
Safety Systems Design

Requirements when designing SIS:

- Separation:
  - Instrumentation – interlock instrumentation CANNOT be part of control logic
  - Safety Control System – requires safety logic solver that segregates its inputs and outputs

- Robust equipment options:
  - Examples:
    - Honeywell ST3000 Safety transmitter with HART 6.0
    - MAXON MM/MA series safety isolation valves
    - DeltaV Redundant SLS
Safety Systems Design

- Reliability and availability can also be achieved by:
  - **Architecture**
    - Using redundancy and voting logic of the initiators, safety control system, and/or final elements (e.g., 1oo2, 2oo3 required to achieve safe state)
  - **Installation** – per manufacturer’s guidelines
  - **Testing / Validation and Replacement** – both at initial startup as well as at specified testing intervals or after any modification (i.e., via PSSR)
Safety Systems Design

- When designing or modifying a SIS, keep in mind there are two types of failures:
  - Safe Failures
  - Dangerous Failures

- Safe Failures are the desired failure
  - Initiated (actual event)
  - Spurious (false – undesired but still safe)

- Dangerous failures are not desired
  - Inhibited (bypassed)
  - Dangerous operation (doesn’t trip when needed)
Safety Systems Design – Voting Logic

How to design for safe failures without dangerous failures or with minimal spurious trips?

Voting Logic

<table>
<thead>
<tr>
<th></th>
<th>Safe</th>
<th>Dangerous</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>1002</td>
<td>good</td>
<td>best</td>
</tr>
<tr>
<td>1002D</td>
<td>best</td>
<td>better</td>
</tr>
<tr>
<td>2002</td>
<td>better</td>
<td>good</td>
</tr>
<tr>
<td>2003</td>
<td>best</td>
<td>better</td>
</tr>
</tbody>
</table>

(Source: ISA & Exida)
Safety Systems Design - SIL Verification

- SIL verification involves multiple Markov model calculations to determine the achieved SIL range.

Interlock component data used for verification:

- MTTFS
- $\text{PFD}_{\text{avg}}$
- $\text{RRF}$ (inverse of PFD or $1/\text{PFD}$)
- $\beta\%$ (when using multiple components)
- $\lambda_{du}$ (undetected dangerous failures)
- $\lambda_{sp}$ (safe or spurious failures)
<table>
<thead>
<tr>
<th>Safety Integrity Level (SIL)</th>
<th>Safety Instrumented System Performance Requirements</th>
<th>Average Probability of Failure on Demand (PFDavg)</th>
<th>Risk Reduction Factor (RRF) RRF=1/PFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Safety Availability Required 90.00 – 99.00 %</td>
<td>10⁻¹ to 10⁻²</td>
<td>10 to 100</td>
</tr>
<tr>
<td>2</td>
<td>Safety Availability Required 99.00 – 99.90 %</td>
<td>10⁻² to 10⁻³</td>
<td>100 to 1,000</td>
</tr>
<tr>
<td>3</td>
<td>Safety Availability Required 99.90 – 99.99 %</td>
<td>10⁻³ to 10⁻⁴</td>
<td>1,000 to 10,000</td>
</tr>
</tbody>
</table>
Safety Systems Design - SIL Verification

- If the required SIL can not be achieved with the initial design, some options are:
  - More frequent proof testing
  - Add redundancy (i.e., initiating device, control system, final element)
  - Install “smarter” device (i.e., HART smart transmitter or transmitter vs. switch or relay, smart control/isolation valve with diagnostics and feedback and position indication vs. basic control valve)
  - Add other IPL(s)
Validation/Functional Proof Testing

Proof Tests **must** be performed at the frequency determined during SIL verification (and as stated in the SRS) to validate the reliability of the SIF

- Many facilities prefer to perform these tests during turnaround, so SIS may be designed to perform between 4-5 year testing frequency

- It should include the following information:
  - Test procedure
  - Date of test and all personnel performing the test
  - Control logic – version # (if available)
  - Results of entire test and any abnormalities found
General Concepts to Remember in Design

- Separation from control logic
- Two words in design to achieve lower MTTFS (PFD) or higher RRF to achieve the SIL:
  - Diagnostics, diagnostics, diagnostics, ...
  - Redundancy

Transmitters with diagnostics (i.e., HART) can detect problems before going awry or failing, making troubleshooting and repair much easier

- Hence, the desire for transmitters with diagnostics over switches
General Concepts to Remember in Design

- If using switch, solenoid, or relay (anything on/off or discrete), verify that it is normally energized during operation (fail safe)
- Use dedicated wiring to each device (as much as possible)
- Minimize common cause failures (i.e., common wires, instrument taps, or same controller or I/O card)
- Mechanical devices are the weakest link in the SIF. They can stick if not moved periodically (i.e., PSVs, valves, switches)
  - To remedy this issue: install dual isolation or modulating valves that can be partially stroked
Workshop – Fired Heater H-1 P&ID

What voting logic/redundancy options are used in this SIF? (hint: both initiators and final elements)
Final Review

Components
- IPL
- SIS
- SIF
- SIL
  - Required/ Target SIL
  - Achieved SIL
- SRS
- Safety Life Cycle
  - cradle to grave
Final Review

- Design of the SIF/SIS must be capable of achieving the target SIL
- Design of the SIF/SIS should minimize common cause and dangerous failures
- Employer must continue the Safety Life Cycle timelines as determined in the SRS to keep the SIF reliable and available to reduce risk
  - Functional Proof Test – at a specified interval or after any changes to hardware or software configuration
  - Mission Time – hardware replacement interval
  - Document any modifications to SIS or protection layers (MOC)
Introduction to PROCESS

**PROCESS Chemical Engineering Services**
- Process Design (FEL-0, 1, 2, and 3)
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- Under Budget
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