Maximize the Use of Your Existing Flare Structures

An ioMosaic White Paper

Introduction

Due to the design vintage of many petroleum refineries and petrochemical plants, existing pressure relief and flare systems may be overloaded because of:

- Prior unit expansions/upgrades have increased the load on the flare for combined flaring scenarios beyond the original design intentions
- The desire to connect atmospheric relief valves to the flare for environmental and safety consideration and to eliminate blow down drums [1]
- The addition of new process units that need access to flaring capacity

As a result, many petroleum companies are engaged in comprehensive flare systems evaluation and upgrading projects to ensure continuing safe operations, to MAXIMIZE the use of their exiting flare systems, and to MINIMIZE the need for modifying existing flare structures or building new ones. Achieving these goals presents several engineering challenges:

1. Which existing atmospheric relief devices present vapor cloud explosion and thermal radiation hazards and need to go to the flare?
2. What is the impact of the additional flaring loads on the existing flare header system and individual relief devices during combined flaring events (such as loss of power or cooling)?
3. Where and how many High Integrity Protection Systems (HIPS) should be employed to reduce the worst-case flaring load?
4. How should the HIPS components be configured to achieve the required safety integrity level (SIL)?

In order to properly and cost effectively address these design questions, specialized expertise and tools for pressure relief systems design, risk analysis, and instrumentation are required:

- Dynamic simulation of relieving vessels and flare piping networks to identify capacity constraints
- Risk tolerability criteria related to vessel overpressure hazards
- Risk assessment and reliability analysis to properly select and configure the HIPS

This paper provides a general framework for evaluating and maximizing available flare systems capacity, and investigates criteria and approaches for determining a tolerable risk event for flare systems.

HIPS, SIS, and SILS, What are they?

The ISA/ANSI Standard S84.01 96 defines a Safety Instrumented System (SIS) as a system composed of sensors, logic solvers, and final control elements for the purpose of taking the process to a safe state when predetermined conditions are violated. SISs act independent of the basic process control system (BPCS).

The term *high integrity protective instrumented system* is used in Section 2.2 of API RP 521 Guide to Pressure-Relieving and Depressuring Systems, as an alternative in some scenarios for preventing overpressure and over-temperature conditions. In usage, this has been truncated to High Integrity Protective System (HIPS) or in some cases High Integrity Pressure Protective System (HIPPS) to indicate it is specific to overpressure prevention.

A HIPS is a SIS that is designed to provide overpressure and over-temperature protection that is at least equivalent in reliability to a mechanical relief device. HIPS have traditionally been used for rapid depressurization of Hydrocrackers and Acetylene Hydrogenators in runaway conditions, to simultaneously reduce pressure and remove heat, where a safety valve is ineffective. More recently, HIPS have been employed to remove the heating supply to fractionation columns to avoid activation of the pressure relief device and causing a release to atmosphere or a flare system. In this use it is a secondary overpressure protective system for the purpose of optimizing the design of the flare header system and connected pressure devices.

The Safety Integrity Level (SIL) is the discrete integrity level (SIL 1, SIL 2, SIL 3) of the SIS defined in terms of Probability of Failure on Demand (PFD) as presented in Table 1.

Table 1: Safety Integrity Level

Safety Integrity Level	Probability of Failure on Demand Average Range (PFD_{avg})
1	10^{-1} to 10^{-2}
2	10^{-2} to 10^{-3}
3	10^{-3} to 10^{-4}

Flare System Analysis

Establish Global Overpressure Scenarios

The first step is to establish worst-case global overpressure scenarios. Typically, these are caused by general (plant-wide) failure of a utility system such as electric power or cooling water. Other typical potential causes are instrument air failure or fire. The global fire flaring load is often determined by applying a 2500 ft2 fire circle based on API RP 521 (3.19.2), but does not usually define the worst-case flaring load event.

When developing global scenarios, consideration of basic process control systems (BPCS) and safeguards is also necessary to establish a credible event. For example, credit can be given for some failure positions of control valves per API RP 521 (3.10.1). Credits or debits for other properly designed safeguarding systems may also be appropriate.

This review should conclude with an inventory of all the individual flare loads pertaining to each global scenario including relief devices, control valves, depressuring valves, etc. This will allow the establishment of a design flare loads base case.

Verify Relief Device Capacity

To complete the global scenario assessment requires flow capacity information for different relief device contingencies. Depending on plant age and quality of relief systems documentation, this information may be incomplete or lacking for existing facilities. In most cases, it becomes necessary to verify the relief loads based on material and energy balance information and valve mechanical data. Other aspects that need to be considered when verifying the flows include:

- Multi-component representation of stream compositions
- Device inlet and outlet piping configuration
- Relief device flow and opening characteristics for accurate representation of peak flow
- The presence of multiphase, supercritical, high-viscosity, and/or reacting flows

Construct Flare Networks Model

To cost-effectively analyze the flare system hydraulics requires constructing a network model of the flare collection system. This involves characterizing the geometric layout of the flare main header and sub-headers, including appropriate dimensional aspects. The individual design case flare loads are tied-into the headers at their respective locations.

Analyze Flare System Hydraulics

The flare network model is exercised to obtain a base-case flare system profile which establishes:

- Backpressure, flow reduction, pressure accumulation (%MAWP), and temperature accumulation (%MAWT) for protected equipment
- Sub-header, main header, and flare tip flow restrictions
- Exclusion zones for thermal radiation and noise restrictions

This base-case profile is used to identify sub-headers and individual relief devices that are deficient.

Many of these deficiencies are often associated with relief device stability caused by excessive inlet pressure loss or backpressure. Our experience and the literature indicate that 30 to 40 % of pressure relief valves in existence violate recommended guidelines for inlet pressure loss and backpressure [2]. Excessive pressure loss can lead to valve instability and possibly valve failure. As a result, many operating companies are faced with significant upgrade/mitigation costs. There are several simple means for dealing with such deficiencies, as reported by Melhem and Fisher [3] (see Appendix A for summary).

Typical flare system design and operating constraints are shown in Table 2. These design and operating constraints can differ depending on where the facility is located and who the operator/owner is.

At this point an evaluation of options to correct the deficiencies is undertaken, with the purpose of maximizing the use of the existing flare collection system. Options that are usually considered include:

- Automate shutdowns and/or isolation systems currently requiring operator intervention
- Maximum use of bellows/pilot relief valves
- Account for actual timing of loads (e.g., automated de-pressuring systems)
- Make reasonable header and relief piping size adjustments to correct deficiencies, if possible
- Model vessel dynamics and establish actual pressure and temperature accumulation based on flare pressure profiles when using (a) reduced set points less than MAWP, and where (b) the required flow rate is less than the actual relief device rated capacity.

These aspects need to be thoroughly investigated and evaluated before proceeding to consideration of HIPS. Flare systems mitigation can be costly. Careful analysis and use of accurate and detailed simulation tools will ensure continued safety and a cost-effective mitigation implementation where required. SuperChems™ Expert can be used to produce more accurate answers for flow dynamics and flare sub-header optimization. This is crucial for effective selection of mitigation options where necessary.

SuperChems™ Expert is the industry gold standard for the design and evaluation of emergency relief and flare systems networks. SuperChems™ Expert includes both steady state and dynamics dealing with single, multiphase, and reacting flows. In addition, SuperChems™ includes integrated Quantitative Risk Analysis (QRA) and consequence models for thermal radiation, dispersion, noise, and overpressure. SuperChems™ Expert is developed, supported, and marketed by ioMosaic Corporation. SuperChems™ for DIERS is marketed and endorsed by the American Institute of Chemical Engineers (AIChE) Design Institute for Emergency Relief Systems (DIERS). SuperChems™ is used by more than 350 users worldwide and is recognized by regulatory and government agencies both in the US and internationally.

Unique aspects of SuperChems™ Expert that ensure accurate and cost-effective flare systems analysis include:

1. *Flow dynamics*: time dependent flow dynamics can be represented easily in SuperChems™ including interlinked vessels, de-pressuring systems, etc.
2. *Advanced Flare Systems Analysis*: unlike other software tools, the flare systems modules in SuperChems™ enable the user to determine at what fraction of required relief capacity a particular device that is connected to the flare system will be flowing. The associated impact of flow reduction on the upstream vessel(s) is also automatically calculated in multiples of MAWP and MAWT. This information is critical for determining the adequacy of an existing flare system, what level of mitigation may be required, and if the system has excess capacity.
3. *Integrated QRA, Effluent Handling, and Consequence Models*: the SuperChems™ flare systems modules include the dynamics of effluent handling equipment like separators/knockout drums, detailed thermal radiation and noise estimates, as well as best in class and highly validated dispersion, fire, and explosion models. In addition, SuperChems™ contains sophisticated Quantitative Risk Analysis tools that enable complete evaluation of all important aspects of flare systems design and mitigation on the same platform. A high level of integration reduces errors because data does not have to be transported across different systems and enhances execution efficiency and speed.

HIPS Evaluation

Typically, HIPS are considered for de-bottlenecking existing flare collection systems in order to address one or more of the following conditions without having to significantly modify the existing flare structures or building new ones:

- Flare tip and/or sub-header connection Mach Number > 0.6
- Excessive relief device backpressure
- Excessive vessel accumulation/overpressure
- High flare thermal radiation levels on/off site
- High flare noise levels on/off site
- Adding atmospheric relief devices to the existing flare collection system

Select HIPS Candidates

HIPS are generally applied to vessels that require external heat input, such as a distillation column. HIPS can also be applied to reactor vessels where crash cooling or isolation of feed may be required to prevent a runaway reaction. Quickly isolating the source of heat eliminates emergency venting for certain global scenarios. For petroleum refineries, HIPPS are used on columns to eliminate power or cooling failure flare loads. The potential candidates are actually a result of the base design case global scenarios determination. Some potential candidates may be eliminated on the basis of a relatively small load that doesn't justify the cost of installing a HIPPS system.

Define HIPS Configurations

This activity focuses first on addressing the sub-header deficiencies. Using the base-case load information, a preliminary selection of HIPS equipment and identification of safety integrity levels (SILs) is established. This involves a risk-based analysis to determine the number of HIPS and the SILs required. This requires the establishment of a tolerable overpressure event risk criteria, which will be discussed later. These criteria are used to fix a tolerable event frequency target. This target is then utilized to evaluate different HIPS failure sequences to arrive at a possible design case.

Confirm HIPS Design Flare Loads

A HIPS failure sequence and resulting flare loads that meet the target event frequency is run through the network simulation model to obtain new values for backpressure, accumulation, flow rates, Mach number and radiation/noise profiles from the flare, where appropriate. Depending on the results, HIPS configuration will be refined by adjusting the number of HIPS and SILs, and the simulations repeated. Several iterations may be performed to arrive at a cost-effective and tolerable risk solution.

Verify Required SIL

Once the HIPS design configuration is finalized, the next task is to analyze the proposed HIPS design to verify that the specified components and arrangement will meet the safety integrity level (SIL) requirement. There are several methodologies for determining the SIL of a safety instrumented system (SIS) or HIPS for compliance with ANSI/ISA-S84.01-1996(1). The ISA supplement ISA-dTR84.0.02 provides guidance on the application of three techniques including fault tree analysis.

Table 2-A: Typical Flare System Hydraulics Design and Operating Constraints

Design Criteria	Value	Description
Maximum Flow Velocity	Mach ≤ 0.6	Maximum value for header and sub-headers design
Flow rate	Rated Capacity	Value for sub-headers and relief discharge piping design
	Required Capacity	Value for main header design
Backpressure	$\leq 0.1\ P_{set}$	Conventional relief valves
	$\leq 0.3\ P_{set}$	Balanced relief valves. Balanced relief valves may be accepted for backpressures up to 0.5 P_{set} with prior consultation with manufacturer and ioMosaic
	$\leq 0.5\ P_{set}$	Pilot operated valves. Pilot relief valves will be accepted for backpressures up to 0.7 P_{set} with prior consultation with manufacturer and ioMosaic

Table 2-B: Typical Flare System Thermal Radiation and Noise Design and Operating Constraints

Design Criteria	Value		Description
Radiation Intensity Solar radiation component should be added and can be as high as 317 Btu/h ft2 in some geographical locations like the middle east and south America	500 $BTU/h\ ft^2$	1.57 kW/m^2	Value at any location where personnel with appropriate clothing may be continuously exposed
	630 $BTU/h\ ft^2$	1.98 kW/m^2	Maximum value for pressured storage equipment
	1000 $BTU/h\ ft^2$	3.15 kW/m^2	Maximum value for atmospheric storage equipment
	1500 $BTU/h\ ft^2$	4.72 kW/m^2	Heat intensity in areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing. Maximum value for Process equipment.
	2000 $BTU/h\ ft^2$	6.30 kW/m^2	Heat intensity in areas where emergency actions up to 1 minute may be required by personnel without shielding but with appropriate clothing. Maximum value for Knock Out Drum.
	3000 $BTU/h\ ft^2$	9.45 kW/m^2	Heat intensity at any location to which people have access; exposure should be limited to a few seconds, sufficient for escape only.

Risk Concepts Applied to Flare Systems Analysis

Define Tolerability Criteria

A flare system which exerts excessive backpressure on relief devices poses a hazard to pressure vessels depending on the degree of overpressure. The risk tolerability of an overpressure condition in a vessel should be assigned based on:

- The consequences (effect) of the overpressure in terms of vessel integrity
- The frequency at which the severity of the overpressure can be tolerated

Effects of pressure accumulation on steel vessels designed to ASME VIII pressure vessel code are well documented and presented in Table 3. A set of risk criteria can be established using these overpressure effect characteristics.

In devising the criteria, one begins by deciding what level of overpressure is not acceptable and assigning a very low event frequency such as 1 in a million years. The probability of vessel failure becomes significant for any overpressure event that subjects a vessel to a pressure of >3 x MAWP. *No one should knowingly design for such an event*. Hence, accumulations > 3 x MAWP will not be considered. Thus, we set the frequency for the 165-300 percent accumulation event at 10-5/yr. However, this pressure range spans a level that is barely above hydrotest at one extreme to a level above the yield point at the other. While a frequency of 10-5/yr. seems right for the upper end of the range, it is quite conservative at the lower end.

Table 3: Effect of Pressure Accumulation in Carbon Steel Vessels

Accumulation	Effects	Remarks
<135	None expected	None
135-165	Potential for slight permanent deformation	This range of pressure corresponds to the tensile limit of the vessel and is both material and code dependent. The lower and upper limits correspond to ASME VII, Div.2 and ASM VIII, Div.1 (1998 edition and earlier) vessels fall in between these values. Therefore, a representative value for this range is 150%.
165-300	Permanent deformation, possible small leak	Valid for remote contingencies, as more frequent overpressuring could weaken the vessel by fatigue.
300-400	Same as above, but with a higher likelihood of a large leak or burst.	Dangerous overpressuring
400-500	Burst	Typical for healthy ASME VIII code vessels

A better risk-consequence characterization is obtained by further dividing the 165 to 300 range into two ranges as shown below in Table 4:

Table 4: Risk Consequence Characterization

Accumulations	Frequency
165-200	10^{-4}/yr
200-300	10^{-5}/yr

The selection of 200 percent accumulation as the break point is reasonable. The maximum allowable tensile stress (MATS) is used to determine the MAWP of a vessel of a given thickness. The ratio of the yield stress (YS) to the MATS is at least a factor of 2 for most carbon steels. So 200 % accumulation is near where the vessel just starts to yield. In addition, ASME VIII and NFPA 69 allow designing a vessel for containment of deflagrations with deformation using a stress that is 2/3 of ultimate tensile stress (TS). For most carbon steels the TS is > 3 times MATS. This is equivalent to designing for 2 times the MATS. Table 5 shows the resulting matrix for tolerable accumulation taking into account these various factors.

Table 5: Overpressure Event Risk Matrix

Accumulation	Frequency
<135	1 in 100 years
135-165	1 in 1000 years
165-200	1 in 10,000 years
200-300	1 in 100,000 years
>300	Not allowed

Select Target Event Frequency

The target frequency for an overpressure event is determined from the matrix shown in Table 4 using the calculated vessel accumulations from the base-case network simulation. The process begins with analysis of each sub-header and associated loads. The HIPS candidate with the worst accumulation is used to establish the target frequency. *Reducing flare loads in the sub-headers is often sufficient for achieving a satisfactory overall flare system design*.

Combined scenarios involving HIPS failures on any device connected to the flare may need to be examined to complete the design. For example, failures occurring within the total HIPS population are considered when evaluating the radiation or noise effects from a global scenario. Also, the tolerable frequency target may be more relaxed for the radiation event than overpressure.

Determine Safety Integrity Level

For each recommended HIPS, a design specification needs to be developed that details the actual configuration for the vessel being protected. The specified components and redundancy must be able to achieve the SIL requirement determined from the risk-based HIPS selection process. The application of fault tree analysis is an accepted method for determining the expected availability of a SIS or HIPS [4].

Refine and Improve Equivalent SIL based on Functional Test Interval

The application of fault tree analysis has been shown effective in establishing the relative frequency of potential incidents associated with base-case and alternative HIPS design configurations. The technique has the versatility to handle equipment and control failures along with human errors. Examples of the application of fault tree and reliability analysis for evaluation of safety interlock systems have been reported elsewhere.

Since ISA is a performance-based standard, it sets reliability performance requirements, rather than different integrity levels for an interlock based on configuration such as:

Type 3: Fully redundant components

Type 2: Partially redundant components

Type 1: No component redundancy

However, it may be possible to achieve a required SIL with lower reliability hardware through reduction of the test interval (i.e., more frequent testing). The following example demonstrates the level of analysis that can be applied. The analysis is performed on a Type 1 interlock consisting of sensors and final elements. The fault tree logic for the Type 1 level interlock employing a level switch is shown in Figure 1 for the configuration shown in Figure 2.

By including mission time in the system failure analysis, the expected unreliability of various instrumented system configurations can be estimated. The probability that a repairable device (without monitoring) fails to function (unreliability) during a test interval is approximately:

$$PFD_{avg} = \lambda t/2$$

Where: PFD_{avg} is the average probability of failure on demand over the test interval, λ^{d}□ is the component failure rate for dangerous outcome (failures/unit time), and t is the test time interval.

The PFD_{avg} of the system described by the Figure 1 fault tree is therefore:

$$PFD_{avg1} = 0.5(\lambda^d A\ t + \lambda^d B\ t + \lambda^d C\ t + \lambda^d D\ t)$$

Common cause failures, such as due to shared instrument taps or utility supply, may also need to be considered. Common cause (CC) failures are typically handled using a (β) factor, which is the percentage of the failure rate of one of the components with a redundant configuration, assuming each component has the same failure rate. Hence in a system with double redundancy of a component (Figure 3), 1oo2 voting, and a common cause failure, the PFD_{avg} relationship is:

$$PFD_{avg1} = 0.25\ (1-\beta)^2\ \lambda^d A\ \lambda^d B\ t^2 + 0.5\ (\beta)\ \lambda^d A\ t \quad \text{or}$$

$$= 0.25\ [(1-\beta)\ \lambda^d A\ ]^2\ t^2 + 0.5\ (\beta)\ \lambda^d A\ t \quad \text{for}\ \ \lambda^d A \equiv \lambda^d B$$

Since, the magnitude of PFD_{avg} is quite sensitive to the value selected for the (β) factor, some care is needed in assigning this value. The first choice is to configure the HIPS components to minimize common cause faults.

The PFD relationships of more complex configurations with common cause failure can be obtained from appropriately constructed fault trees.

Using appropriate component failure rates, the fractional dead times presented in Table 5 were calculated with incorporation of common cause failure.

As Table 6 illustrates, this provides the decision-maker with a good picture of the reliability trade-offs for a given mission (testing interval) duration.

Table 6: Unreliability of Level Interlock Systems With Consideration of Common Cause Failures [5]

Test Interval	Test Interval (Hours)	Unavailability Type 1 Design	Unavailability Type 2 Design	Unavailability Type 3 Design
1 shift	8	0.010%	0.007%	0.005%
1 day	24	0.029%	0.020%	0.016%
1 week	168	0.200%	0.140%	0.110%
1 month	720	0.870%	0.610%	0.490%
1 quarter	2,160	2.610%	1.840%	1.490%
6 months	4,320	5.220%	3.690%	3.030%
1 year	8,760	10.580%	7.540%	6.390%
18 month	12,960	15.660%	11.220%	9.780%
2 years	17,520	21.160%	15.270%	13.720%

This information can also be utilized for determining reliability (availability) for different SIS configurations (e.g., Type 1 - fully redundant). For example, these data were used to determine the interlock reliability (1- fractional dead time) for the three types of level interlock configurations as a function of functional testing interval (Table 7).

The reliability values account for common cause failures. Without considering CC failures, the Type 3 system would meet SIL 3 criteria with monthly and quarterly testing. Analyzing the sources of common cause unreliability and if possible reducing its impact is also worth investigation before making a final select of SIS configuration.

Table 7: Reliability of Different Level Interlock Configurations

Configuration Class	Redundancy	Test Interval	Reliability, %	SIL
Type 3	Fully	Monthly	99.5	2
		Quarterly	98.5	1
		Annually	93.6	1
Type 2	Final Element	Monthly	99.4	2
		Quarterly	98.2	1
		Annually	92.5	1
Type 1	None	Monthly	99.1	2
		Quarterly	97.4	1
		Annually	89.4	0

As seen, there is a trade-off between testing frequency, and the advantage gained by selecting the next higher SIL configuration. Combining these results with the ISA 84.01 SIL reliability requirements below enables the designer to take into account cost-benefit considerations between initial capital cost and ongoing maintenance cost.

Table 8: Combining Results with The ISA 84.01 SIL

Safety Integrity Level	Availability Range, %
1	90-99
2	99-99.9
3	99.9-99.99

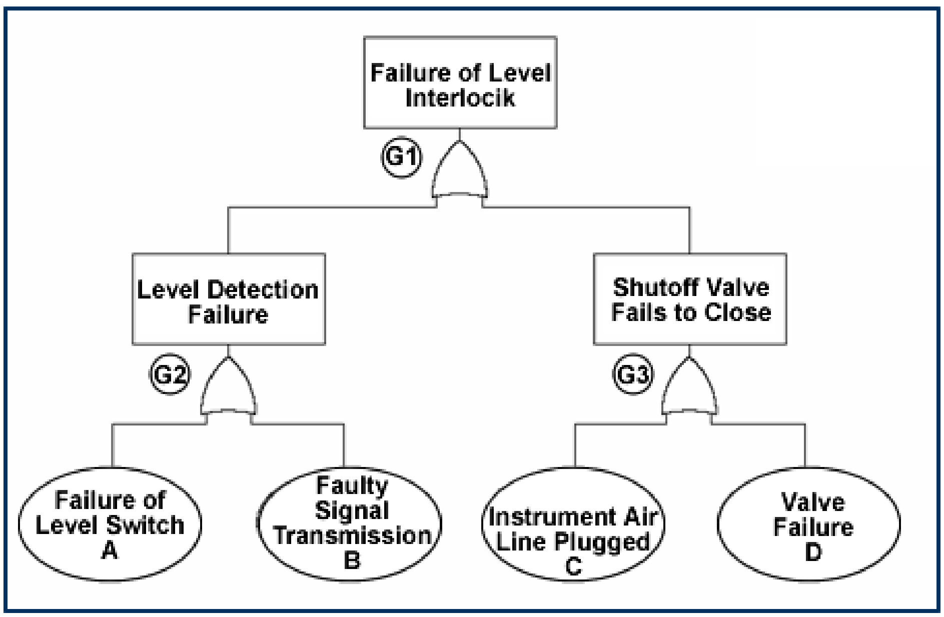
For example, a SIL 1 might be achieved using a Type 1 configuration with monthly function testing or a Type 2 configuration with annual testing. Using the assumptions presented in Table 5, the net present value (NPV) of the ongoing incremental (beyond annual testing) maintenance cost for monthly function testing is $24,000. In this case, if the incremental cost of a SIL 2 SIS is less than that sum, the decision becomes an obvious one.

Table 9: Cost Benefit Assumption

Cost	Benefits
Cost of Funds	7%
Labor Cost (fully loaded)	$40/hr.9
Person hours per test	6 hr
System Life	15 yrs

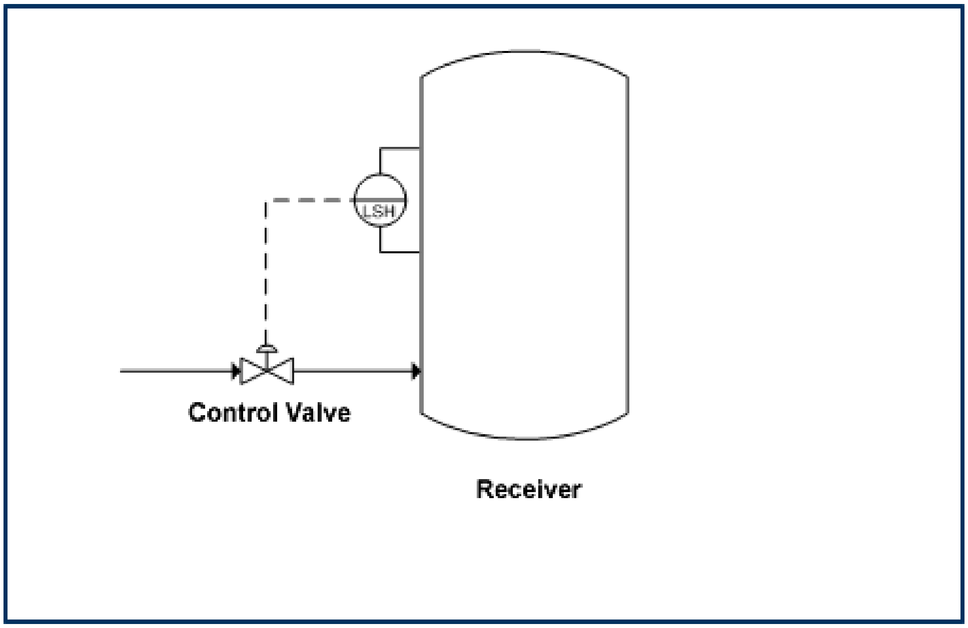
Other considerations, such as equipment availability, potential for spurious trips during testing, and uncertainty about future availability of maintenance labor, could also drive the decision towards installing the SIL 2 SIS over the system requiring more testing. The benefit of FTA is that it allows quantification/justification of the tradeoffs and eliminates guessing and bias. Sensor voting is often applied to reduce the frequency of spurious trips. The same methodology can be utilized to determine the reliability of SISs with sensor voting.

Figure 1: No Redundancy



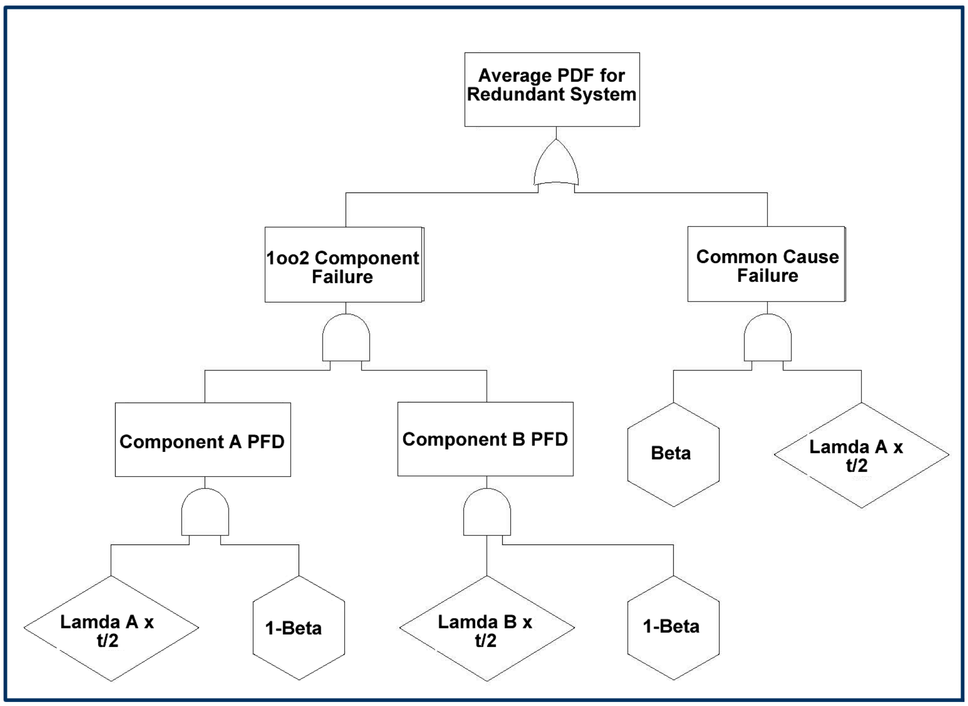
Source: ioMosaic Corporation

Figure 2: Receiver



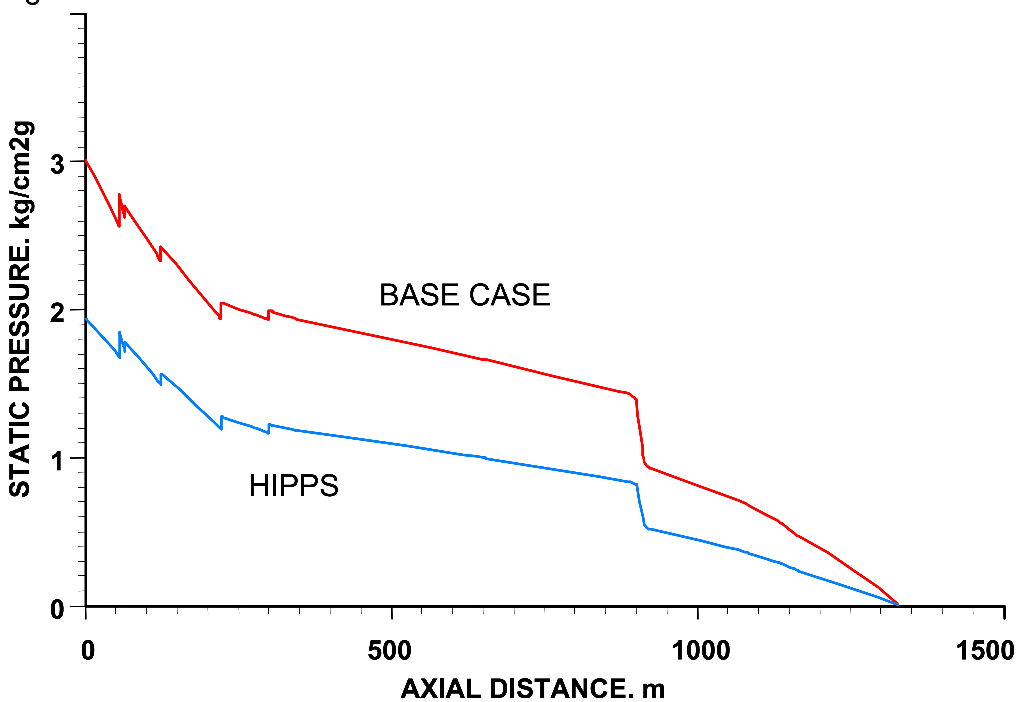
Source: ioMosaic Corporation

Figure 3: Average PDF for Redundant System



Source: ioMosaic Corporation

Figure 4: Main Header Pressure Profile



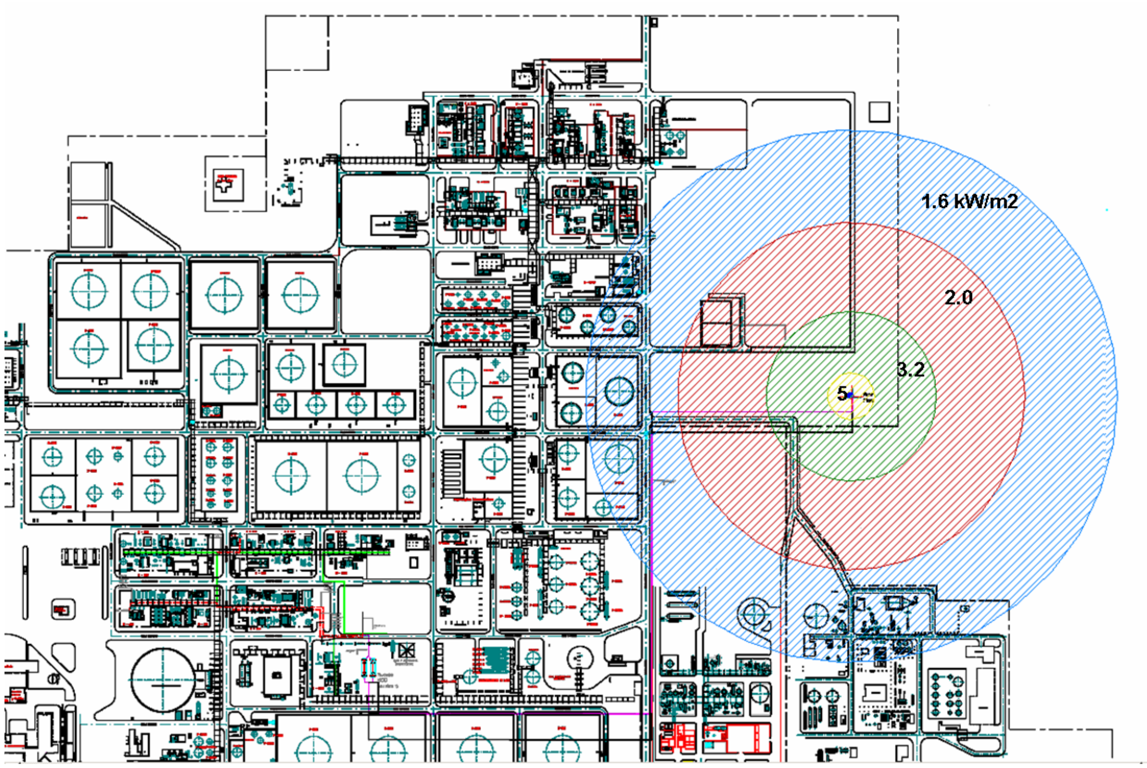
Source: ioMosaic Corporation

A Recent Case Study

The methodology outlined in this paper was recently used to optimize a flare system in an operating large refinery. The refinery needed to add more than twenty large relief loads from atmospheric vents on several existing columns to the flare system. Additional flare loads from a new planned unit expansion needed to be connected to the existing flare system as well. The design plans called for relocating the flare stack and for expanding the additional new main header piping to 48-inch diameter. The refinery did not want to modify the existing main flare header or any of the existing seven sub-headers. A total of 340 relief devices were connected to the main flare system.

After careful optimization of two of the seven sub-headers connected to the main flare header, the main flare header calculated actual flow capacity was 890,000 kg/hr vs. a requirement of 1,340,000 kg/hr. At a flow capacity of 890,000 kg/hr several large vessels would exhibit pressures up to 1.7 times the maximum allowable working pressure.

Figure 5: Flare System Thermal Radiation Hazard Zones at Ground Level



Source: ioMosaic Corporation

Twelve HIPPS systems with SIL levels of 1, 2, 2+2, and 3 were selected and optimized such that (a) all connected equipment comply with code requirements for pressure and temperature accumulation when ALL the HIPPS function on demand, (b) it is not possible for any simultaneous failure of one or more HIPPS to cause code violations at a frequency that exceeds the established target tolerability frequency, and (c) thermal radiation and noise criteria are met under both conditions a and b.

Profiles of pressure in the main header as well as the thermal radiation contours are shown in Figures 4 and 5 for the optimized flare system. Note the length of the main flare header. The HIPPS solution enabled the refinery to MAXIMIZE use of the existing flare structure and ensured continued safe operations with significant additional loads on the flare system. With HIPPS, a cost optimal risk reduction was achieved easily and quickly.

Conclusions

The use of many existing flare structures can be maximized using the risk-based approach outlined in this paper.

The use of advanced pressure relief dynamics tools such as SuperChems™ Expert can provide accurate estimates of flaring loads and flare systems performance. When coupled with proper risk analysis techniques, accurate flow dynamics provide an optimal cost-risk reduction benefit of where and how to use safety instrumented systems (HIPS). This will yield a safe and cost-effective design that meets code requirements for the best-case scenario (all systems working as designed) and that meets social and corporate risk tolerability criteria for worst-case scenarios (when one or more systems fail on demand).

Risk tolerability criteria need to account for the hazardous effects of accumulation on pressure vessels. Designs that result in a vessel accumulation > 300% should not be allowed or considered. Note that SIL levels can be enhanced using shorter testing intervals. Fault tree analysis is a flexible methodology for determining SIL for a HIPS that can easily accommodate different testing intervals and failure rates for components, and can incorporate common cause faults and voting.

Author

1. Georges A. Melhem, Ph.D.; melhem@ioMosaic.com (2006)

References

[1] Implicated in March 2005 explosion at BP's Texas City refinery

[2] Shelly, S. "Beware: Your pressure protection may be inadequate", Chemical Engineering, 106 (4), p. 58, April 1999

[3] Melhem, G. A. and H. G. Fisher, "Practical guidelines for dealing with excessive pressure drop in relief systems", Paper presented at the DIERS users group meeting, 2005

[4] ISA Technical Report ISA-TR84.0.02

[5] Reliability of Interlocking Systems, Process Safety Progress (Vol. 13, No.3)

Appendix A: Dealing with Excessive Pressure Loss

Typical causes of valve stability/chatter due to excessive inlet pressure loss:

1. Pressure relief valve is oversized for the installation because the flow is < 25 % of rated capacity or the valve is handling widely different rates.
2. Inlet piping has excessive length. $P_{inlet} = P_{vessel} - \Delta P_{loss} <= P_{blowdown}$
3. Inlet piping is undersized for PRV (Starving PRV)
4. Outlet piping has excessive length
5. Outlet piping is undersized for PRV
6. Upper adjusting ring too high

Some simple means that can be used to solve excessive inlet pressure loss leading to valve chatter:

1. Avoid turns, elbows and sharp area reductions in inlet and outlet lines
2. Use long radius elbows
3. Use multiple valves with staggered set pressures when the lowest required contingency rate is less than 25% of highest rate
4. Use larger inlet piping. Enlarged inlet pipe diameter is almost always required for:
    a. 4P6, 6R8, 6R10, and 8T10
    b. All safety valves used in series with rupture disks
    c. 1.5H3, 2J3, 3L4, and 6Q8 with shutoff valve and L/D=5
5. If you cannot enlarge the inlet piping
    a. Increase valve blowdown (for example, 5 % inlet loss can be tolerated if blowdown is set at 7 %)
    b. Install a smaller PRV or use a restricted lift valve
    c. Install a different type of PRV (for example, a pilot valve)
6. Restrict inlet pressure loss that can be tolerated to blowdown minus 2 %. Note that increasing blowdown allows more backpressure tolerance but also reduces the flow capacity of the valve and increases loss of vented product/material:
    a. If blowdown is 10 %, inlet pressure loss that can be tolerated is 8 %
    b. If blowdown is 5 %, inlet pressure loss that can be tolerated is 3 %
7. Adjust relief device blowdown and set points with care using a certified shop

Typical Inlet Line Considerations

1. Inlet line size must be at least equal to PRV inlet flange size.
2. Inlet piping should slope continuously upward from vessel to avoid traps.
3. Inlet piping should be heat traced if freezing or congealing of viscous liquids could occur.
4. A continual clean purge should be provided if coke/polymer formation or solids deposition could occur.

Typical Discharge Line Considerations

1. Enlarged outlet piping is almost always required for:
   a. 6R8 safety valves
   b. Conventional safety valves 3L4, 4P6, and 8T10 with a set pressure > 100 psig and discharge pipe length more than 10 ft
2. Discharge line diameter must be at least equal to PRV outlet flange size.
3. The maximum discharge velocity should not exceed 75% of sonic velocity.
4. For flammable releases to atmosphere, minimum velocity should be no less than 100 ft/sec.
5. Atmospheric risers should discharge at least 10 ft above platforms within 50 ft horizontally.
6. Radiant heat due to ignition of release should be considered.
7. No check valves, orifice plates or other restrictions permitted.
8. Atmospheric discharge risers should have drain hole.
9. Piping design must consider thermal expansion due to hot/cold release.
10. Auto-refrigeration and need for brittle fracture resistant materials.
11. Closed discharge piping should slope continuously downward to header to avoid liquid traps.