flotek.g 2017 – "Innovative Solutions in Flow Measurement and Control – Oil, Water, Gas"
August 28th - 30th, 2017, FCRI, Palakkad, Kerala, India

Smarter devices in pressure venting and process safety

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ABSTRACT

In Industrial plants, Pressure Vents are primarily used for burning off flammable gas released by traditional mechanical devices such as pressure relief valves during unplanned over-pressurizing of plant equipment, an alternate and effective way to deal such over-pressure scenario is by preventing such over-pressure scenarios.

Prevention of over-pressure scenario not only reduces carbon footprint by avoiding hydrocarbon emissions to the atmosphere thru flaring but also avoids a hazardous over-pressure event to plant equipments (e.g flare stack, flare header etc.), which can be optimally sized and designed for maximum working pressure and not for rare over-pressure scenarios, making projects economically viable.

HIPPS or "High Integrity Pressure Protection Systems" can be employed that prevent over-pressurization of a plant by shutting-off the source of the high pressure. HIPPS is a form of a Safety Instrumented System (SIS) which by definition, is a distinct, reliable system used to safeguard a process to prevent a catastrophic release of toxic, flammable, or explosive chemicals, which otherwise would be released to atmosphere thru a mechanical safety device such as pressure relieving device or rupture disc.

A typical HIPPS comprises of the following components:

- Initiator (e.g. pressure sensor), which observe process parameter.
- Logic solver (e.g. PLC), which receives and processes the input signal from the sensors and transmits the output to the final element.
- Final element system (ON/OFF Valve assembly) perform the emergency function (e.g. closure of valve) to bring the process to a safe state.

This paper would elaborate and discuss the criticality of the components, and redundant levels of the components in a HIPPS loop and the applications of HIPPS in pressure venting and safety of fluid handling arena.

KEY WORDS

HIPPS, Safety, SIS, Pressure vent, Redundancy

1.0 INTRODUCTION

Environmental emission is a major phenomenon, which not only affects the quality of air in its surroundings but also becomes sources of greenhouse gas emissions, resulting global warming. One of the major source of emission within the oil & gas and its associated industry is flaring.

Flaring is a result of unplanned or rather unexpected over-pressuring of plant equipment in industrial plants such as petroleum refineries, chemical plants, natural gas processing plants etc.

Flaring, an open-air burning of natural gas, which releases emissions into the atmosphere, affects humans, animals, plants and the environment. The problems associated with flaring would be as simple as affecting the quality of life – for example, make it difficult for people to sleep and could be as severe as causing cancer to vulnerable individuals.

Flaring would also happen in an upstream well-exploration site where unexpected excess pressure from well is flared to atmosphere in-order to protect the equipment.

2.0 OVER PRESSURE PROTECTION METHODS:

In applications where sudden surge in pressure could lead to loss of property, personnel and environment there has been a protective device, which would avoid such over-pressure scenarios. Two commonly used over-pressure protection device are pressure safety valve (PSV) and rupture/burst disc.

3.0 DISADVANTAGE OF PSV & RUPTURE DISC

Both these traditional mechanical devices are operated during over-pressure scenarios and the fluid that crosses these devices are mostly vented thru flares, increasing the carbon footprint and If the released fluid is an explosive material then releasing large quantities of it through relieving devices can increase the risk of fire or explosion.

4.0 NEW METHOD / SYSTEM

A different approach to overpressure protection is the use of an instrumented system. High Integrity Pressure Protection system popularly known as HIPPS, is an instrumented system as described in API 521, can be considered to protect the property, personnel and environment in the event of undesired over-pressure. HIPPS typically involve an arrangement of instruments, final control elements (e.g. valves, switches, etc.), and logic solvers configured in a manner designed to avoid overpressure incidents by removing the source of overpressure or by reducing the probability of an overpressure contingency to such a low level that it is no longer considered to be a credible case or HIPPS can be employed to isolate the overpressure source from other equipment.

With appropriate levels of redundancy, a HIPPS can be designed to achieve a level of reliability and safety availability that are equal to a mechanical relief device.

HIPPS also has the flexibility in accepting multiple causes (such as over-pressure scenario, external input, low-pressure scenario etc.) to bring the process to safe state where as a traditional mechanical device can only have single fixed cause (i.e. over-pressure) for its activation.

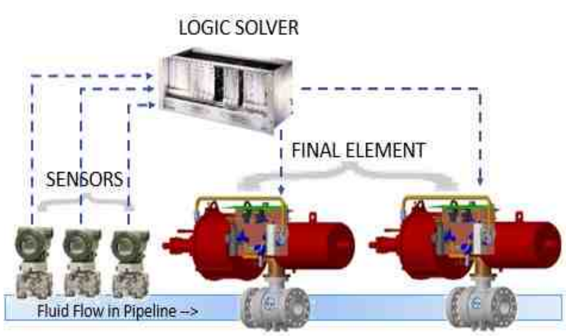
5.0 COMPONENTS OF HIPPS

The three major components of HIPPS include sensors, logic solvers and final element.

- SENSOR: Sensor would be selected based on the application, commonly used sensors are Pressure, Temperature, Level, and Flow. Sensor can also be equipped with interlocking manifold, which would help in safe isolation of any particular sensor from process during maintenance.
- LOGIC SOLVER: Would be PLC based system with appropriate redundancy level to use up to SIL-3 or would be solid-state based system with capability up to SIL-4.
- FINAL ELEMENT: ON/OFF actuated valve assembly with valve type as Ball, Butterfly or Gate and actuator type as pneumatic or self-contained hydraulic with suitable control system. As required by the process, Final element would be equipped with quick-closing control system in order to bring the process to safe state within stipulated time.

Figure 1 -

Overall architecture of Typical HIPPS



Type and Quantity of devices in each component (e.g. SENSORS) group shall be decided based on requirement as demanded by process, project and HAZOP (Hazard Operability) study.

6.0 CRITICALITY AND REDUNDANCY OF COMPONENTS

International standards such as IEC 61508 gives a systemic approach to choose component redundant level based on the Safe Failure Fraction (SFF). SFF is calculated based on the failure rate values of respective components from below formula,

Figure 2 - Formula to calculate SFF

$$SFF = \frac{\lambda^{SD} + \lambda^{SU} + \lambda^{DD}}{\lambda^{SD} + \lambda^{SU} + \lambda^{DD} + \lambda^{DU}} = 1 - \frac{\lambda^{DU}}{\lambda^{Total}}$$

In the above equation λ^{SD} or λ^{SU} Indicates Failures that don't affect Equipment Intended function and λ^{DD} or λ^{DU} Indicates Failures that affect Equipment Intended function, further described as below,

λ^{SD} – Safe Failure, that are Detected by specific testing methods with or without manual intervention.

λ^{SU} – Safe Failure, that are Undetected by specific testing methods with or without manual intervention.

λ^{DD} – Dangerous Failure, that are Detected by specific testing methods with or without manual intervention.

λ^{DU} – Dangerous Failure, that are Undetected by specific testing methods with or without manual intervention.

The various λ values are input from the respective Original Equipment Manufacturer (OEM).

Hardware Fault Tolerance (HFT) is widely used terminology within process safety application, which indicates the number of component failure that can be tolerated in process safety system without compromising safety function.

Choosing redundancy for desired Safety Integrity Level (SIL) is function of SFF and HFT as given in the below Table 1,

Table 1 - SFF Vs HFT
(Type-A Equipment)

Safe Failure Fraction	Hardware Fault Tolerance		
	0	1	2
< 60 %	SIL 1	SIL 2	SIL 3
60 % - < 90 %	SIL 2	SIL 3	SIL 4
90 % - < 99 %	SIL 3	SIL 4	SIL 4
≥ 99 %	SIL 3	SIL 4	SIL 4

Redundancy requirement varies based on the Equipment Type; Equipment Type shall be either Type-A or Type-B.

Type-A Equipment: Equipment that has well-defined failure modes, with well-known failure rates, and behavior of Equipment under fault conditions can be completely determined. Table 1 represents HFT guideline for Type-A Equipment.

Type-B Equipment: Equipment that do not have well-defined failure modes, failure rates are not well-known, and behavior of Equipment under fault conditions cannot be completely determined. Table 2 represents HFT guideline for Type-B Equipment.

Table 2 - SFF Vs HFT
(Type-B Equipment)

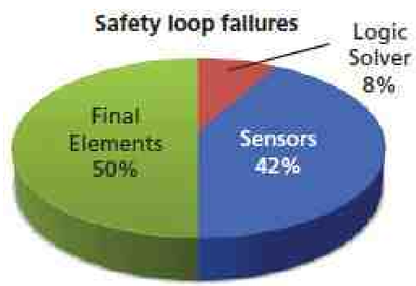
Safe Failure Fraction	Hardware Fault Tolerance		
	0	1	2
< 60 %	Not allowed	SIL 1	SIL 2
60 % - < 90 %	SIL 1	SIL 2	SIL 3
90 % - < 99 %	SIL 2	SIL 3	SIL 4
≥ 99 %	SIL 3	SIL 4	SIL 4

Choosing a SIL value for a safety function is based on the various parameters such as effect of identified process hazard and its frequency of occurrence, Risk reduction required etc.

Final elements (e.g. Actuated Ball Valves) are accorded the highest priority in a HIPPS loop as studies suggest that they account for 50% of safety loop failures historically and calculations suggest that their contribution is the highest when compared with the sensors and logic solver. Thus, selection and design of valves and actuator is of paramount importance in a safety loop.

Failure contribution of other components of HIPPS are as shown below.

Figure 3 – Analysis of Safety Loop Failures (Source: Oreda)



Adding diagnostic test features on the components, in order to take preventive measures and ensure availability of safety system, would have positive impact on the system SIL. After installing the HIPPS, various test at specified intervals shall be carried-out as recommended by SIS integrator in order to maintain the required SIL.

Logic solver, which is referred as Brain of HIPPS, processes signals from other components on real-time basis and helps making the HIPPS smarter with host of features such as scheduled maintenance thru diagnostic tests in final element in order to detect some of dangerous failures, generating alarms based on the sensor health etc.

7.0 APPLICATION OF HIPPS

Most discussed application of HIPPS are in reducing carbon foot-print by limiting or eliminating the need of flaring in process industry and in making the projects commercially viable by suitably downsizing the equipments without compromising the process plant safety. Below are some of the specific application of HIPPS,

- On processing plants, HIPPS can eliminate the need to upsize the flare system and can potentially replace it.
- At the wellhead or pressure source, a HIPPS system allows the downstream piping to be lower pressure rated.
- To reduce load on existing Flare systems due to increased throughput/addition of units/fuel upgrade etc.

8.0 ECONOMICAL BENEFITS IN HIPPS

Below cases, represents benefits on general basis, benefit for specific cases needs to be calculated by considering variabilities such as Line size, Line pressure-Temperature rating, Flare load, Cost of flare modification etc.

Case 1: Upstream Application.

When transporting fluid from upstream well to processing plant over large distance, say for 10 km thru a 12" pipeline, if the normal working pressure and expected surge pressure from well are 30 bar and 180 bar respectively, then sizing the 12" pipeline to withstand 30 bar pressure will save 1181 tonne of material as shown below,

Operating scenario,	**Normal working pressure**	**Surge pressure**
Pipeline fluid pressure, bar	**30**	**180**
	12" Sch. 160 (Thick : 33.3mm)	**12" Sch. SPL (Thick : 15.8mm)**
Pipe weight (Kg / metre)	238.69	120.59
Total distance, km	10	10
Total weight, Tonne	2387	1206

Installing HIPPS before start of the fluid transporting line would effectively isolate and safe guard the 10 km pipeline during the rare surge pressure from well. When the transporting line is isolated by HIPPS, other suitable means in upstream shall be used to harvest the well fluid safely.

Apart from cost saving thru direct material reduction, indirect cost such as cost of transportation and installation of such heavy materials etc. are also eliminated.

Case 2: Downstream (Refinery) Application.

When considering additional distillation unit in a refinery or while modifying process parameters in existing refinery, in order to improve the quality of products or to comply with new government regulations, there is always a probability for additional load to the existing flare system.

Installing HIPPS to control the process parameter such as Pressure in distillation unit will lessen the probability of Pressure Relief Valve (PRV) opening and this ensures less frequent load addition to flare system, meaning the operation of flare system is within safe limits in spite of process modification.

In above cases, in general, the direct cost advantage with respect to installing HIPPS on behalf of other options with traditional approach are observed to be in the ratio of 1 to 10 or better. For example, if a process modification in a petrochemical plant demands 200 crore investment in flare modification then minimizing load to flare by eliminating need for pressure venting with appropriate HIPPS solution would cost 20 crore or less without compromising the plant safety.

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