L&T Valves Limited

TAMIL NADU

SAFETY INTEGRITY LEVEL (SIL) VERIFICATION FOR HIGH INTEGRITY PRESSURE PROTECTION SYSTEM (HIPPS)

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Abbreviation	**Full Expression**
FIT	Failure rate In Time
HFT	Hardware Fault Tolerance
PFD	Probability of Failure on Demand
PFD_{avg}	Probability of Failure on Demand, Average
PST	Partial Stroke Testing
SFF	Safe Failure Fraction
SIF	Safety Instrumented Function
SIL	Safety Integrity Level
SIS	Safety Instrumented System

SAFETY INTEGRITY LEVEL (SIL) VERIFICATION STUDIES FOR HIPPS

1 BACKGROUND AND OVERVIEW

L&T Valves in addition to manufacturing valves also assembles systems and products such as High-Integrity Pressure Protection System (HIPPS) for safety applications.

HIPPS consist of pressure sensors, transmitters, logic solvers and valves used in applications for preventing over-pressurisation in the process industry. HIPPS need to be extremely reliable and safe as they shut off the high pressure source on demand. HIPPS typically need to meet SIL 3 or SIL 4 according to IEC 61508 / IEC 61511.

While the SIL rating for the individual components that make up the HIPPS are available, L&T requires the SIL level of the HIPPS loop to be evaluated under IEC (IEC 61511/61508) for each Safety Instrumented Function (SIF) executed by the loop.

The report contains the analysis and results of the verification process.

2 DESCRIPTION OF HIPPS AND ITS CONFIGURATION

HIPPS is an example of a Safety Instrumented System (SIS) applied to over pressure protection systems. The design, assembly, operation and maintenance are covered by IEC 61508/ 61511. The safety function of the HIPPS is to close the source of over-pressure within a predetermined time frame with at least the same reliability as a safety relief valve.

A HIPPS is considered as a barrier between a high-pressure and a low-pressure section of an installation and consists of several individual components functioning on demand. The HIPPS is a complete functional loop consisting of:

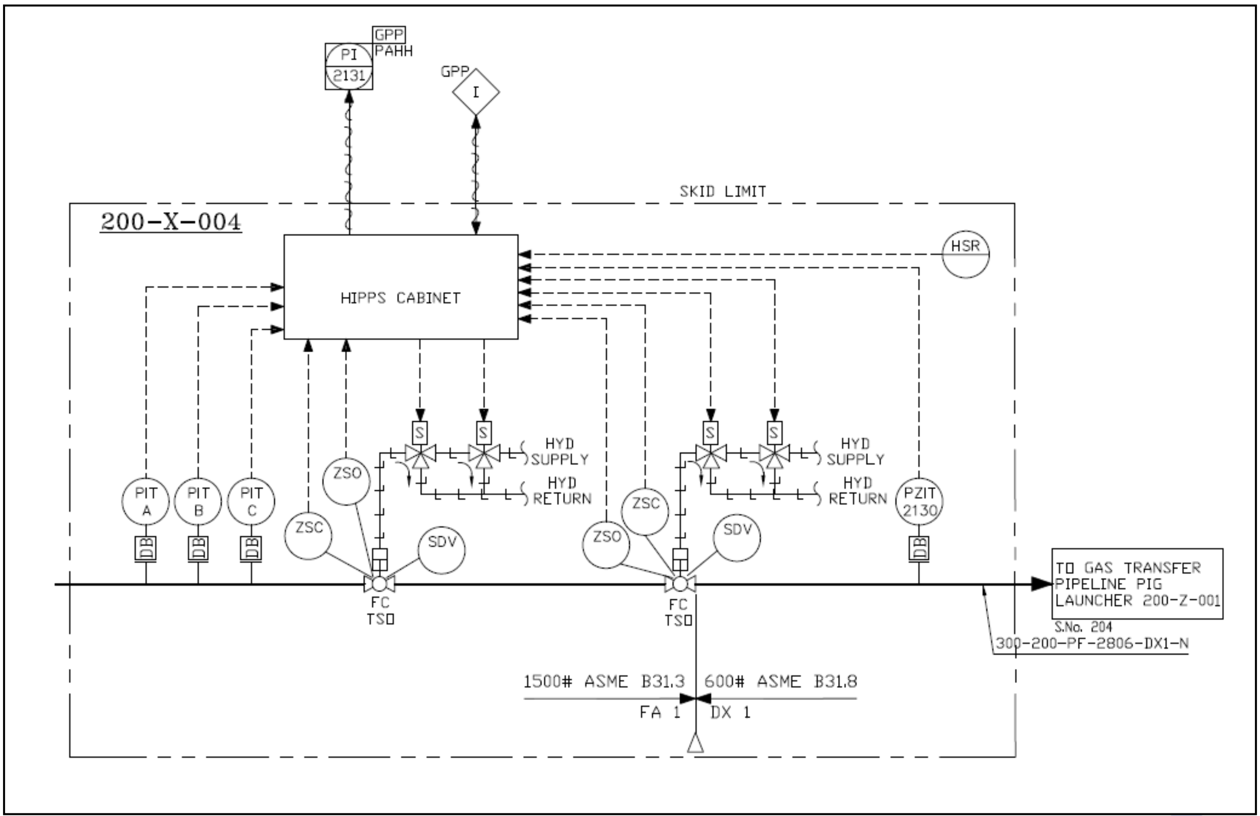
a) Sensors, (or initiators) that detect the high pressure/ low pressure scenario
b) A logic solver that processes the input from the sensors to an output to the final element
c) Final elements (valve, actuator and solenoid) that actually perform the corrective action in the field by bringing the process to a safe state.

The components of the HIPPS integrated by L&T Valves consist of Pressure Transmitter, Logic solver, Trunnion Mounted Ball Valve (TMBV), Hydraulic actuator with solenoid valve/ pilot valve

2.1 Details of the HIPPS Assembly

The HIPPS design configuration and architecture is given in Fig 1

Fig 1 P&ID of the HIPPS



The HIPPS consists of the following major components:

1. Shutdown valves of 12" size with hydraulic actuator and all required accessories
2. Pressure Transmitters (in 2oo3/1oo2 configuration) along with Interlocking manifold
3. Solid State Logic solver in HIPPS cabinet, to be installed at Gas Gathering Station (GGS) Instrument Equipment Room
4. Field mounted local control panel
5. Fiber Optic Link in HIPPS cabinet for connecting the HIPPS cabinet to the Fiber optic patch panel located in Gas Gathering Station (GGS) Instrument Equipment Room for monitoring and storage of all analysis data from Gas Processing Plant (GPP).

The control panel and fiber optic link are considered to be non-interfering components as their functions are non-safety related and do not impact the safety function of the HIPPS.

2.2 Operation logic of the HIPPS

The System is an integrated package located at upstream of the pig launcher of the Gas Gathering Station (GGS). HIPPS process trip inputs will be from the three pressure transmitters in 2oo3 configuration. If the pressure rises above the predefined set point, the HIPPS 2oo3 voting function (comparator module for 3 pressure transmitters) closes both the HIPPS TMBV valves.

In the overall Safety Instrumented System (SIS), it needs to be noted that it is constituted by combinations of components to execute a specific safety function (SIF). The characteristics of the HIPPS have been summarised in the table below

TABLE 1 CHARACTERISTICS OF HIPPS ASSEMBLY

S. No	Item	Description
1	Safety function of the HIPPS Assembly	The HIPPS will shut off the source of the high pressure before the design pressure of the system is exceeded, thus preventing loss of containment through rupture (explosion) of a line or vessel.
2	Typical Applications for which the assembly is used	General
3	Normal Operating period of the assembly	Suggested 1- 5 years
4	Type of Demand of the valve	Low Demand operation
5	Warranty period	18 months from installation (or) 24 months from procurement
6	Failure Modes of Final Element	Type A Random Failure as per IEC 61508 -2 7.4.4.1.2
7	Pressure transmitter	ABB 2600T (TUV certificate)
8	Sensor configuration	2oo3 (Normal Condition) 1oo2 (Downgraded Condition)
9	Logic Solver/ PLC	Solid state - HIMA ,Planar 4 (TUV)
10	Final element configuration	1oo2
11	Trunnion Mounted Ball Valve (TMBV)	L&T Valves TMBV (Metal seat, TSO) (TUV certificate)
12	Hydraulic actuator	Paladon HY Spring Return Hydraulic Scotch Yoke Actuator (SIRA Certificate)
13	Solenoid valve	Bifold-FP02 (EXIDA Certificate)
14	Pilot Valve	Bifold FP50
15	Applicable standards	IEC 61508 & IEC 61511

3 VERIFICATION PROCESS

The sub components that form the SIS loop have been certified individually for their SIL compatibility. The overall objective of the verification study was to calculate the average Probability of Dangerous Failure (PFD_{avg}) and the architectural constraints that dictate the achievable SIL rating for the SIS loop.

3.1 Input Data

The SIL Verification study has been undertaken for the given configuration. The manufacturers of the individual components have provided SIL class certificates for each equipment.

The following information provided by the company was used in the study.

TABLE 2 CERTIFICATES/REFERENCE DOCUMENTS USED FOR THE STUDY

Component	Make	Model	Certificate №.
Pressure Transmitter	ABB	2600T	SEBS-A. 164727/14, V1.0
Logic Solver	HIMA	PLANAR 4 –	U 98 06 19183 027
Trunnion Mounted Ball Valve	L&T Valves	Metal seat, TSO	8112375050-100-01
Actuator	Paladon systems	Spring Return HYS Hydraulic Scotch Yoke	Sira FSP 13007/01
Solenoid Valve	Bifold	FP02	BIF 1107001C001
Pilot Valve	Bifold	Bifold FP50	SM. FP50 Rev 10

Based on the certificates issued for the individual components, the quantitative analysis of the sub-components in the HIPPS assembly was performed. This analysis has revealed the overall SIL Rating for the entire Safety Instrumented System.

This report addresses the verification of the loop at the design stage based on the selection of components and configuration.

3.2 Definitions

The following definitions pertain to the study and are taken from IEC 61508-4 c IEC:2010

Failure Rate — the frequency with which an engineered system or component fails, expressed in failures per unit of time. It is denoted by the Greek letter λ (lambda)[1]. The lifetime of a population of a product consists of three periods: '**break-in'** or infant mortality period with a decreasing failure rate followed by a normal life

[1] reliability parameter (λ(*t*)) of an entity (single components or systems) such that λ(*t*).*dt* is the probability of failure of this entity within [*t*, *t*+*dt*] provided that it has not failed during [0, *t*]

period (also known as "useful life") with a low, relatively **constant** failure rate and concluding with an '**end-of-life'** or wear-out period that exhibits an increasing failure rate.

FIT — Failure In Time – (1x10-9 failures per hour)

Low demand mode — where the safety function is only performed on demand, in order to transfer the equipment under control into a specified safe state, and where the frequency of demand is no greater than one per year

MTTR — Mean Time To Restoration -- expected time to achieve restoration. MTTR encompasses the time to detect the failure (a); and, the time spent before starting the repair (b); and, the effective time to repair (c); and, the time before the component is put back into operation (d). The start time for (b) is the end of (a); the start time for (c) is the end of (b); the start time for (d) is the end of (c).

PFD_{avg} — average probability of dangerous failure on demand **–** mean unavailability (see IEC 60050-191) of an E/E/PE safety-related system to perform the specified safety function when a demand occurs from the equipment under control (EUC) or EUC control system

Proof Test — Periodic test performed to detect dangerous hidden failures in a safety-related system so that, if necessary, a repair can restore the system to an "as new" condition or as close as practical to this condition

PST — Partial Stroke Test is a technique used in a control system to allow the user to test a percentage of the possible failure modes of an element/ sub-system (e.g.: a shutdown valve) without the need to physically disable/ disconnect the element/ sub-system (e.g., close the valve). PST is used to assist in determining that the safety function will operate on demand. PST is not a replacement for the need to fully stroke valves as proof testing is still a mandatory requirement.

RRF — Risk Reduction Factor – the number of times that risk is reduced as a result of the application of a safeguard

SIL — Safety Integrity Level **–** discrete level (one out of a possible four), corresponding to a range of safety integrity values, where safety integrity level 4 has the highest level of safety integrity and safety integrity level 1 has the lowest

SFF — Safe Failure Fraction – summarizes the fraction of failures, which lead to a safe state and the fraction of failures which will be detected by diagnostic measures and lead to a defined safety action.

Type A device — A subsystem can regarded as type A when the components required to achieve the safety function meet all of the following conditions:

a) the failure modes of all constituent components are well defined; and

b) the behaviour of the subsystem under fault conditions can be completely determined; and

c) there is sufficient dependable failure data from field experience to show that the claimed rates of failure for detected and undetected dangerous failures are met.

Type B device A subsystem that does not qualify as Type A device is termed as a Type B device. Type B devices are complex components with potentially unknown failure, when one or more of the components required to perform a specified function is not Type A.

3.3 Assumptions

The following assumptions were considered during the calculations of the failure rate for the system.

1. Failure rates are assumed to be constant during the usable life of the sub-components (Break–in period failures or end of life scenarios are not taken into account)
2. Proof Tests are assumed to detect all of the faults in the system
3. A minimum proof test period of greater than 50% of the demand of the subsystem is used for calculation of PFD_{avg}
4. All components have been identified as Type A devices and operating under Low Demand mode (as per IEC 61508-4 3.5.16)
5. The total number of operational hours in a single year is assumed as 8760 hrs
6. The mean time to repair/ restoration (MTTR) for each component was assumed as 24 hours.
7. Restoration is assumed to be 100% effective to restore each component to fault-less state.
8. Non-interfering components, i.e. those components which do not impact the performance of the safety function of the system (Interaction-Free modules), are not included in the verification calculations. For example, the Communication modules 80100/1/2, Quadruple Fuse module 90100, Dual bypass module 90300, etc.

3.4 Approach adopted

The approach followed for the verification of the SIL rating for the HIPPS is given below

1) Estimation of the Average Probability of Failure on demand (PFD_{avg}) for the individual sub-systems (Initiating Device; Logic solver; Final Element) of HIPPS assembly

2) Assigning of SIL compatibility rating of the assembly under their respective configurations.

3) Selection of proof test interval to obtain the least average probability for dangerous failure (PFD_{avg}) for the HIPPS assembly.

The values of Failure rate in Time (FIT) used in the calculations were collated from the certificates issued for the individual components. In compliance with applicable portion in IEC 61508/61511 the calculations were carried out for each design configuration within the specified assembly.

4 RESULTS OF THE ANALYSIS

The process of verification was carried out and the results of the SIL compatibility study are discussed in the following sections.

A. FIT for valve Assembly No 1

Failure rate in Time (FIT) used in the above calculations were collected from the given certified sources. The values of failure rates have been taken from the certificates issued for the individual components in compliance with applicable portion in IEC 61508/61511 for each unit of equipment within the specified assembly and presented in Table 3.

TABLE 3 SUMMARY OF FIT FOR INDIVIDUAL COMPONENTS OF VALVE ASSEMBLY (W PARTIAL STROKE TESTING)

#	Component	Make, Model	Certificate ref.	Lambda values λ (1/h)				SFF
				λDD	λDU	λSD	λSU	%
1	Initiator (Pressure Transmitter)	ABB 2600T	SEBS-A. 164727/14, V1.0	4.64E-07	7.93E-08	2.51E-07	1.25E-07	91
2	Valve	L&T TMBV (Metal seat, TSO)	TUV Report No. 8112375050-100-01	8.74E-08	8.95E-08	1.81E-08	9.74E-10	54
3	Actuator	Paladon systems	Sira FSP 13007/01	0	4.95E-08	0	8.86E-08	64
4	Solenoid Valve	Bifold FP02	Exida BIF 1107001C001	1.43E-07	2.00E-09	0	3.36E-07	99
5	Pilot Valve	Bifold FP50	SM. FP50 Rev 10	2.04E-07	3.00E-09	0	3.39E-07	99

B. PFD_{avg} and Risk Reduction Factor

The values for average probability of dangerous failure (PFD_{avg}) and Risk Reduction Factor dictate the claimed SIL level for the sub-system. These indicate the actual amount of protection and risk reduction that the HIPPS can offer to the end user's process.

The average probability of dangerous failures (PFD_{avg}) have been calculated as per following cases of end use/application

1) **SIF 1**: If the pressure rises above the predefined set point, the HIPPS 2oo3 voting function (comparator module for 3 pressure transmitters) closes both the HIPPS valves. (Downgraded mode is also possible)

2) **ADDITIONAL FUNCTION**: If the pressure falls below the predefined set point (From downstream PT 1oo1 configuration), the HIPPS shall close both the HIPPS valves.

The case for downgraded condition of operation of the HIPPS was also considered. Downgraded condition refers to the change of the voting logic of the sensor element or initiating device from 2oo3 voting to 1oo2 under certain predefined circumstances. The conditions for switching to downgraded mode for the sensors are as follows:

1) Any one Pressure transmitter is isolated with Unique Key in Manifold block
2) Line monitoring fault for a HIPPS transmitter is detected
3) Failure of input analogue card

The achieved PFD_{avg} and Risk Reduction Factor (RRF) are reported in the table 4.

TABLE 4 SUMMARY OF SIL RATINGS FOR HIPPS ASSEMBLY

Safety Integrity Function	Application	Average Probability of Dangerous Failure, PFD_{avg}	Testing Interval Required, TI	Partial Stroke Test Interval	Compatible SIL	Risk Reduction Factor (RRF)
SIF 1	Fail to Close on Demand	2.94E-04	1 year	1 month	SIL 3	3.40E+03
SIF 1 (Downgraded)	Fail to Close on Demand	2.87E-04	1 year	1 month	SIL 3	3.49E+03
ADDITIONAL FUNCTION	Fail to Close on Demand	8.17E-04	1 year	1 month	SIL 3	1.24E+03

5 SUMMARY AND CONCLUSION

The current report contains the results of the verification of the SIL class of L&T's HIPPS SIS loop as per IEC requirements for subsystem.

The main results of the verification process are summarized below:

SIFs for the given conditions comply with SIL3 as per Architectural constraints and PFDavg

ANNEXURE A: PFDavg VALUES FOR HIPPS AND COMPONENTS

A. HIPPS Assembly

The PFD_{avg} calculated for various partial stroke test intervals and Proof test periods for the HIPPS assembly under the various design voting configurations are shown below

TABLE A.1 COMBINED HIPPS: - TYPICAL RESULT

SIF – Fail to Close on Demand	Voting Configuration	Make	Model	Proof test interval	PST Interval	PFD_{avg}
SIF 1 – 2oo3 PT for Overpressure Case						
Sensor	2oo3	ABB	2600T	5 years	-	1.85E-04
Logic Solver		HIMA	Planar 4	8 years	-	1.09E-04
Final Element	1oo2	TMBV + Paladon Assembly		1 year	1 month	1.66E-08
Total						**2.94E-04**
SIF 1 DOWNGRADED – 1oo2 PT for Overpressure Case						
Sensor	1oo2	ABB	2600T	5 years	-	1.78E-04
Logic Solver		HIMA	Planar 4	8 years	-	1.09E-04
Final Element	1oo2	TMBV + Paladon Assembly		1 year	1 month	1.66E-08
Total						**2.87E-04**

SIF – Fail to Close on Demand	Voting Configuration	Make	Model	Proof test interval	PST Interval	PFD$_{avg}$
ADDITIONAL FUNCTION – 1oo1 PT for Low pressure Case						
Sensor	1oo1	ABB	2600T	2 years	-	6.99E-04
Logic Solver		HIMA	Planar 4	8 years	-	1.09E-04
Final Element	1oo2	TMBV + Paladon Assembly		1 year	1 month	1.66E-08
Total						**8.17E-04**

Note: In Final Element, solenoid valve and pilot valve PST interval (1 year) is same as Proof Test interval .

B. Sensors

The PFD_{avg} values for the Sensors were calculated in accordance to the desired Voting configuration under both SIFs. The PFD_{avg} for the voting under the different operating conditions are given below,

TABLE A.2 PFD_{avg} FOR DIFFERENT PROOF TEST PERIODS FOR SENSOR (INITIATING DEVICE)

Application / Sensors	Proof Test Period / Voting Configuration	PFDavg 6 months	1 year	2 years	5 years	10 years	20 years
ABB 2600T	1oo1	1.78E-04	3.52E-04	6.99E-04	1.74E-03	3.48E-03	6.95E-03
	1oo2 (Downgraded)	1.77E-05	3.51E-05	7.03E-05	1.78E-04	3.62E-04	7.52E-04
	2oo3 (Normal Condition)	1.77E-05	3.54E-05	7.15E-05	1.85E-04	3.91E-04	8.67E-04

C. Final Element

The PFD_{avg} calculated for various partial stroke test intervals and Proof test periods for the Final element under 1oo2 voting condition are shown below,

TABLE A.3 PFD_{avg} FOR DIFFERENT PROOF TEST PERIODS AND PARTIAL STROKE TEST FREQUENCY FOR FINAL ELEMENT

Application / 1oo2 w/ PST	PST Interval \ Proof Test Period	PFDavg: 6 months	1 year	2 years	5 years	10 years	20 years
Metal Seat	1 month	6.79E-09	1.66E-08	4.94E-08	2.52E-07	9.37E-07	3.61E-06
	2 months	1.28E-08	2.55E-08	6.40E-08	2.84E-07	9.97E-07	3.73E-06
	3 months	2.07E-08	3.63E-08	8.05E-08	3.17E-07	1.06E-06	3.85E-06
	6 months	-	7.99E-08	1.41E-07	4.30E-07	1.26E-06	4.22E-06
	9 months	-	-	2.19E-07	5.59E-07	1.47E-06	4.61E-06
	12 months	-	-	3.14E-07	7.05E-07	1.71E-06	5.01E-06