SAFETY INSTRUMENTATION FOR PROCESS SYSTEM IN HYDROCARBON INDUSTRY

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Oil Industry Safety Directorate
Government of India
Ministry of Petroleum & Natural Gas
SAFETY INSTRUMENTATION
FOR
PROCESS SYSTEM
IN
HYDROCARBON INDUSTRY

Prepared by:
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These documents are intended only to supplement and not replace the existing statutory requirements.
FOREWORD

# 1 The Oil Industry in India is nearly 100 years old. Because of various collaboration agreements, a variety of international codes, standards and practices have been in vogue. Standardisation in design philosophies and operating and maintenance practices at a national level was hardly in existence. This, coupled with feedback from some serious accidents that occurred in the recent past in India and abroad, emphasized the need for the industry to review the existing state of art in designing, operating and maintaining oil and gas installations particularly using sophisticated instrumentation.

# 2 With this in view, the Ministry of Petroleum & Natural Gas, in 1986, constituted a Safety Council assisted by Oil Industry Safety Directorate (OISD), staffed from within the industry, in formulating and implementing a series of self regulatory measures aimed at removing obsolescence, standardising and upgrading the existing standards to ensure safe operations. Accordingly, OISD constituted a number of Functional Committees of experts nominated from the industry to draw up standards and guidelines on various subjects.

# 3 The present document on “Safety Instrumentation For Process System in Hydrocarbon Industry” is prepared by the Functional Committee on “Instrumentation”. In the revised standard of second edition, the marketing and pipeline installations have been excluded. This document is based on the accumulated knowledge and experience of Industry members and the various national and international codes and practices. It is hoped that provisions of this document when adopted, may go a long way to improve the safety and reduce accidents in oil and gas Industry. Users are cautioned that no standard can be a substitute for a responsible, qualified Instrumentation Engineer. Suggestions are invited from the users after it is put into practice to improve the document further.

# 4 This standard in no way supersedes the statutory regulations of CCE, Factory Inspectorate or any other statutory body which must be followed as applicable.

Suggestions for amendments, if any, to this standard should be addressed to:

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SAFETY INSTRUMENTATION FOR PROCESS SYSTEM
IN HYDROCARBON INDUSTRY

1.0 INTRODUCTION

Newer technologies, process integration, major expansions, requirements to meet improved quality products, yields & plant capacity optimisation and stringent environment considerations have made the process operations very complex and increasingly risk prone. Safety Instrumented System (SIS) takes the process & operation to safe state in case of operational upsets, process abnormality and emergency. This standard lists the safety instrumentation as minimum required for selected processes & operations for consideration of those associated with design, operation and maintenance of refineries, gas processing & petrochemical plants and associated pipeline installations.

Safety Instrumented System (SIS) is required for the process & operations where the mechanical integrity of the process equipment, control system and other protective devices are not adequate to mitigate the potential hazard. In this standard, reference has been taken from International Standards like IEC 61508, ANSI/ISA S 84.01 or equivalent to include the best engineering practices in SIS.

It is not intended that requirement of this standard should be applied rigidly to existing premises where for a variety of reasons, it may not be practicable to comply with. This standard shall, however, create awareness and help in selective implementation of the recommendations when major modifications/revamps are undertaken at existing installations.

2.0 SCOPE

The document provides guidelines for minimum requirement of the Safety Instrumented System (SIS) for critical process functions / equipment involved typically in the widely used processing route of various processes. The document covers areas including process operations in onshore production facilities, gas processing units, refineries and petrochemical process plants.

However, marketing and pipeline installations, cross country pipeline, entire offshore facilities, onshore transportation facilities for gas & crude from oil field or the well head have been excluded from the scope.

3.0 DEFINITIONS / BRIEF DESCRIPTION

3.1 Hazard: Potential Source of harm / accident
3.2 HAZOPS: Hazard and Operability Study is a systematic qualitative method to identify potential hazards and operability problems due to deviations in system parameters from normal design intent. At project stage, the appropriate time for HAZOP study is when P&IDs are frozen. However, for an existing installation in operation, HAZOP study should be done whenever changes from design case like procedural changes, modification or higher throughput occurs. Providing a better understanding of the plant, HAZOPS helps in predictive evaluation of events that have never occurred.

3.3 Risk: It is the combination of the likelihood of an accident with the severity of potential consequences. It is possible to make quantitative risk assessment to judge whether the risk involved in a situation is acceptable or not.

3.4 Tolerable risk: At some level, the risk is acceptable, in a given context based on the current values of society. Tolerability may be different for each risk posed by the equipment and its control system, because it depends not only on the level of risk but also on the benefits to be gained by taking the risk and the cost of reducing it.

3.5 Residual Risk: Risk that remains after protective measures have been taken.
3.6 **ALARP**: Risk reduced to a level that is “As low as reasonably practicable”.

3.7 **BASIC PROCESS CONTROL SYSTEM (BPCS)**: Basic process control system provides normal operation functions. It generally includes basic control and monitoring of process operation through operator supervision.

3.8 **PROCESS HAZARD ANALYSIS (PHA)**: Process Hazard Analysis (PHA) is a tool to systematically identify process hazards and associated risks in making decisions for improving safety and reducing the consequences of unwanted or unplanned releases of hazardous chemicals by minimising the likelihood of the occurrence and the consequences as mentioned in OISD-STD-206.

PHA is used to assess the adequacy of mitigation measures against potential hazards in the areas of mechanical integrity of the process equipment, control system and other secondary protections like gas detection, fire protection etc. Subsequently, analysis is carried out on layers of protection requirement.

3.9 **LAYERS OF PROTECTION**: Layers of protection are the systems or actions and devices that are capable of preventing a scenario from proceeding to undesired consequences. Examples of protection layers are i) inherently safe design features including basic control, ii) critical alarms & manual intervention, iii) safety instrumented system (SIS), iv) physical protection such as relief devices, v) Post release physical protection such as fire suppression system, vi) plant and community emergency response. Ideally such protection systems (i to vi) are independent from one another. Each identified protection layer (safeguard) is evaluated by layer of protection analysis (LOPA) for its effectiveness and independent character. Refer Fig1.

3.10 **SAFETY INSTRUMENTED SYSTEM (SIS)**: Safety Instrumented System (SIS) is composed of software & hardware which takes the process to a safe state when predetermined conditions, as set on control parameters like pressure, temperature, levels, flow etc, are violated. So, SIS protects against the possibility of a process excursion developing into an incident and limits the excursion potential. Please refer Fig 2 and Annexure-1 for details.

3.11 **SAFETY INTEGRITY LEVEL (SIL)**: Safety Integrity Level (SIL) is a measure of reliability / integrity of safety instrumented system when a process demand occurs. The level of reliability is defined in the scale of 1 to 4 as SIL-1, SIL-2, SIL-3 & SIL-4; wherein SIL-4 designates highest reliability level of safety instrumented system.

3.12 **FIRE, GAS & SMOKE DETECTION (FGSD) SYSTEM**:

A system that detects following at an early stage:
- Presence of flammable and toxic gases;
- Presence of a fire;
- Presence of smoke from smouldering or incipient fires.

FGSD system generates alarms, warnings and / or initiates shutdown functions and / or actuates fire fighting system. Also, based on pre-defined criticality on identified scenarios, it may be configured to initiate evacuation process, reports generation, historisation of data & events at predetermined level of concentrations. Associated electrical or electronics circuits connecting with the field devices of detection system require high availability and reliability in conformance to SIL level as per IEC 61508 or equivalent international standards. Initiating devices like gas/fire detectors should be in line with applicable standards such as NFPA-72, EN-54 or equivalent.

3.13 **HIGH LIQUID LEVEL**: Liquid level in a process system above the permissible operating level.

3.14 **HIGH TEMPERATURE**: Temperature in a process system in excess of the set operating limit.

3.15 **LEAK**: The accidental release of liquid and/or gaseous substances to atmosphere from a process system.

3.16 **LOW FLOW**: Flow in a process system less than the minimum set operating flow rate.
3.17 **LOW LIQUID LEVEL**: Liquid level in a process system below the lowest set operating level.

3.18 **LOW PRESSURE**: Pressure in a process system less than the minimum set operating pressure.

3.19 **SAFETY DEVICE**: An instrument of control or mechanism used for the safety of the system.

3.20 **SENSOR**: A device that measures the process condition.

3.21 **MACHINE SAFETY FEATURES**: These are in-built safety provisions or those additionally advised by the OEM (Original Equipment Manufacturer)/vendor for protection of the process equipment in emergencies. It includes alarms and trip signals required to be integrated with the trip logic system of the equipment and the process system. For example an automatically operated shutdown valve (SDV) used for the protection of process equipment is suitably configured for identified emergency scenarios.

3.22 **EMERGENCY SHUTDOWN SYSTEM (ESD)**: A system (confirming to a certain SIL level as per IEC 61508) of manual/automatic interventions depending on process criticality, when activated brings the equipment / facility to a safe and non-operating mode without following the predefined sequence/procedures. An Automatic Safety Shutdown System (ASSS) is a prevention safety layer, which takes automatic and independent action following predefined operating & safety logic to prevent a hazardous incidents from occurring and to protect personnel, plant and equipment. An auto or manual trip system required under SIS should cater minimum requirement as under:

1) PHA study based identification of critical parameters for system trip.
2) Independent Sensing element of each trip initiating parameter (preferably direct mounted).
3) Direct Type switch or Microprocessor based SMART Transmitters for Trip actuation.
4) Audio-visual alarms on trips.
5) Voting logic configuration for trip actuation on critical parameters to avert spurious shut downs.

3.23 **Shall**: indicates provisions that are mandatory in nature.

3.24 **Should**: indicates that provision is recommendatory as per good engineering practices.

3.25 **May**: indicates provisions that are optional.

4.0 **SAFETY INSTRUMENTATION FOR PROCESS EQUIPMENT & SYSTEMS**

4.1 General Philosophy

(i) In order to assess the adequacy of protection for a process function, PHA (HAZOP study) is done first. HAZOP tables list out Deviations, Causes, Consequences, Safeguards and Recommendations. The details so compiled include estimates of frequency for each cause and severity for each consequence. The HAZOP information is utilised for development of Layer of Protection Analysis (LOPA), as shown in the Fig. 1. LOPA is a simplified semi-quantitative technique of risk analysis. It helps to assess what independent protection layers (IPL) already exist or what are required for process safety. Please refer Annexure-2 for details on LOPA.

(ii) The LOPA team recommends use of an SIS, only if, other design changes for inherent (built-in) safety, cannot reduce the mitigated event likelihood to less than the target.

(iii) Wherever level, temperature and flow switches are mentioned, independent transmitters (for level, temperature and flow as applicable) shall be used for actuation of trip.

(iv) 2/3 voting logic for ESD systems should be implemented based on the SIL study.

(v) Alarm Management system should be in line with the best practices followed internationally, some of which are mentioned at item 6.6
4.2 CRITICAL PROCESS EQUIPMENT & PROCESS FUNCTIONS: SIS requirements for critical equipment and process functions have been covered which includes Separators, Main line pumps, Gas Hydrators, Distillation Columns, Process Heaters, Reactors, Process Gas Compressor, Storage Tanks, Fluidised Catalytic Cracking, hydrocracking, delayed coking etc., described as under:

4.2.1 SEPARATORS
Description: They serve to separate gas, oil and water in refineries, Gas Processing & Petrochemical plants. Separators for upstream (onshore) and for downstream processing have been described separately as under:

4.2.1.1 Separator for upstream (onshore)
Following safety instrumentation should be provided for oil hydrator (Refer Fig. 3)

(i) High pressure transmitter shall be provided to shut off inflow to the vessel.

(ii) High-pressure alarm.

(iii) Low-Low pressure switch to shut off inflow to the vessel.

(iv) High-High level trip to shut off inflow to the vessel in case the downstream component receiving the gas cannot handle liquid.

(v) Low-Low level trip to shut off the liquid outflow from the separator if the downstream system is not designed to handle gas breakthrough.

(vi) High-High Temperature trip on separators like heater-treater to shut off the source of heat.

(vii) Automatic power supply cut-off to the high voltage transformer used for electrostatic separation in case abnormal conditions develop requiring feed cut off and low level in the separator.

4.2.1.2 Separators for downstream critical services in Refineries/ Gas Processing & Petrochemical Plants
The following safety instrumentation shall be provided. (See Fig.4)

(i) High level alarm and High-High level interlock on separator (e.g. suction KOD of compressor etc.) to cut-off the compressor for preventing liquid ingress into it

(ii) Low level alarms for hydrocarbon (HC) level & water interphase level. In cases, where the downstream equipment is not equipped to handle gas breakthrough resulting from loss of liquid level, provision of Shut off valve should be made on the HC liquid outlet and water outlet and to be configured on Low-Low level.

(iii) Two independent level tapings & transmitters, in case of congealing fluid or dirty service like sour water.

4.2.2 GAS DEHYDRATORS
Description
Dehydrators using liquid desiccant are considered here. The desiccant considered may be suitable solvent like ethylene glycol.

Gas saturated with moisture but free of entrained liquid particles is brought into counter current contact with concentrated desiccant (solvent) in the contactor tower. After absorbing water vapour from moist gas, the desiccant passes out from the bottom of the contactor. After knocking off the entrained solvent, the dried gas exits from overhead and is sent to the pipeline. The bottom stream of wet solvent is sent for recovery of solvent and its reuse.

4.2.2.1 Following safety instrumentation shall be provided for gas dehydrators: (see Fig. 5):

(i) High level alarm and High-High level interlock on separator (e.g. suction KOD of compressor etc.) to cut-off the compressor for preventing liquid ingress into it

(ii) Low level alarms for hydrocarbon (HC) level & water interphase level. In cases, where the downstream equipment is not equipped to handle gas breakthrough resulting from loss of liquid level, provision of Shut off valve should be made on the HC liquid outlet and water outlet and to be configured on Low-Low level.

(iii) Two independent level tapings & transmitters, in case of congealing fluid or dirty service like sour water.
i) High pressure sensor on the glycol contactor to shut off inflow of gas.

ii) Low pressure sensor on the glycol contactor to shut off inflow of gas.

iii) High level sensor to trip the glycol pump and inflow of the gas to the contactor.

iv) Low level sensor to shut off the glycol outlet line.

v) Instrumentation System shall be installed for vessel depressurising and releasing excess pressure to flare in case of emergency.

vi) Shutdown valves on the Gas inlet and outlet line.

4.2.3 ELECTROSTATIC DESALTER

Description

In a Desalter, the crude is mixed with water and led into a vessel operating under pressure and having a electrostatic field. The water dissolves the undesirable soluble salts present in the crude and gets separated from the crude under the influence of electrostatic field.

The following Safety Instrumentation shall be provided:

(i) High- High level interphase alarm and actuation of interlock for power trip.

(ii) Low–Low interphase level alarm

(iii) Transformer trip on high current

(iv) High and low pressure alarm

(v) Additional features to be incorporated as per OEM’s recommendations

4.2.4 DISTILLATION COLUMN

Description

Distillation column is used to fractionate the hydrocarbon feed mixture into the desirable petroleum fractions as per requirement for primary crude distillation or in secondary units for fractionation in refineries, gas processing and petrochemical plants. Typically, the crude distillation column is used to fractionate the crude oil into various petroleum products. Hot crude oil from the furnace enters the flash zone of the column. Flashed vapour rises up and the liquid flows down. Various products are withdrawn as side streams. The overhead vapour is condensed and partially refluxed back for temperature control for top product (Naphtha) cut point requirements. Column pressure is controlled utilising the split range controller based on pressure set point. Column bottom level is controlled by level controller (LIC).

4.2.4.1 The following safety instrumentation shall be provided in a distillation column: (Refer Fig. 6)

(i) Column bottom level shall be monitored by two different smart level instruments with separate tappings.

(ii) Separate independent transmitter for safety interlock requirement, if any.

(iii) The column top temperature shall be monitored through minimum two temperature points -- one for control and another for indication with alarms on high & low temperature.

(iv) High temperature alarm for the column bottom.

(v) Pressure indications for fractionating column top and flash zone.

(vi) High and low level alarm for overhead reflux drum.

(vii) Low reflux flow alarm as leading indicator of an overhead upset

4.2.4.2 In the following cases, automatic shut down valve should be provided at the column bottom outlet for column isolation at low low bottom level to avoid gas passing to the downstream systems:

(i) Where column bottom operating temperature is above auto ignition temperature.

(ii) Where column would need immediate isolation in case of any incident of fire below the column.

(iii) Where downstream facility viz. Storage tank has not been designed to handle gas
released from the column bottom.

4.2.5 PROCESS HEATERS/FURNACES

4.2.6 Description
Process heaters are required to raise the temperature of various process fluids to achieve partial vapourisation of fractionation operation. The fluid enters the heater in convection section in more than one passes and after getting heated passes through the radiant section, before it enters the fractionator. The burners are normally combination type suitable for oil or/and gas firing. The furnaces are either natural/forced/balanced draft design. The balance draft furnaces are provided with FD and ID fan alongwith air pre-heater (APH) which will have stack dampers closed during normal operation.

4.2.6.1 SIS for Process Heaters
Following safety instrumentation shall be provided for safe operation of the heater in line with OISD-STD-111. Please refer Fig-7 & 8.

1) SIS for Feed Section in Process Heater
   (i) Low Feed flow alarms for each pass.
   (ii) High temperature alarm for each pass and at the heater outlet.
   (iii) Skin temperature measurements at 3 locations for each pass. High temperature alarm for each tag of tube skin temperature.
   (iv) Alarm of High-High flue gas temperature should be provided. Low total feed flow interlock to bring the heater to a safe minimum firing position by keeping only the pilot burners on.

   iv) For heavy, congealing type of service fluid, independent tappings for flow metering
   v) Heater shall trip in following cases:
      - Low-low feed flow on a pass coupled with High-High outlet temperature of the same pass.
      - Low pass flow in minimum two passes or low total flow for a multi pass furnace. In the case of catalytic process furnaces like Reformer employing a liquid hydrocarbon feed and recycle gas stream, the furnace shutdown should get actuated when recycle gas failure occurs.
      - High combined outlet temperature
      - High-High coil outlet temperature on each pass.
      - High furnace coil pressure

2) Coil purging:
Automatic injections of coil purging steam/ Nitrogen at the time of furnace trip may be considered in line with process requirement and accordingly, precautions/safeguards to be

3) Combustion Air Systems
   (i) Running of FD fan shall be verified in the circuit by Motor contactor closure and discharge pressure low-low pressure switch. This will ensure positive protection against mal-operation of guide vane.
   (ii) Low air flow alarm and low air flow combined with motor contactor to warn mal-operation of FD fan.
   (iii) Heater trip on low combustion air pressure as
well as its low flow with AND gate.

(iv) Air storage tank to ensure opening of drop out door. In case of air failure provision for mechanically opening shall be provided.

(v) Provision should be made to check up operation of drop out door in running condition, wherever dropout door have been provided. This is referred as crack open test.

(vi) Positive protection for mal operation of ID fan shall be provided by motor contact closure and pressure switch.

(vii) Tripping/stopping of ID/FD fan shall have provision to automatically open the stack damper.

(viii) Heater trip due to high arch pressure shall be preceded by high pressure alarm. This very high pressure (PHH) trip shall be sensed preferably by three directly mounted pressure transmitters and voting logic of two out of three shall be used for furnace tripping.

(ix) In the event of fuel oil and fuel gas cut off to the heater, the following simultaneous actions are needed:-
   (a) Stack Damper to Open
   (b) ID Fan to trip
   (c) FD Fan to trip
   (x) Hydrocarbon Gas detector shall be provided at the FD fan suction hood

(x) For variable speed or fixed speed drives of FD fan, speed of fan and motor contact should be used for heater trip interlock.

4) SIS for Burner System

(i) Low pressure alarm and Low-Low pressure alarm for pilot gas should be incorporated in the safety interlock system of the furnace.

(ii) A separate shut off valve shall be provided on the pilot gas header. It will close only in case of low-low fuel gas header pressure in pilot gas line and will not close in case of furnace trip due to other process interlocks.

(iii) Main FO/FG headers shall be provided with shut off valves operated by low fuel pressure and other reasons of furnace trip.

(iv) Shut down valve operated by manual push button to trip the furnace by cutting-off fuel supply to main burners.

(v) Pressure transmitters shall be directly mounted on the FO/FG headers for safety.

(vi) For dual firing the safety interlock should take care that no interruption in furnace operation takes place during change over of fuel.

(vii) Pilot flame detection should be provided in the safety interlock wherever remote burner lighting system is existing so that main fuel cannot be admitted without establishment of pilot flame.

(viii) There shall be two sets push button emergency trip, one located in the control room and another near the furnace.
(ix) Arrangement for positive isolation of fuel gas supply line to heater is necessary. Block-&-Bleed to flare/ safe venting should be provided.

(x) FO firing cut off interlock shall be provided to actuate at low-low differential pressure of atomising steam and fuel oil

(xi) SIL based system as per IEC 61508 for furnace safety instrumentation or Burner Management System is recommended.

4.2.7 HDS REACTOR (HYDRO DESULPHURISATION)
Description
Hydro de-sulphurisation of Petroleum products like naphtha, kero, diesel etc is carried out in presence of catalyst in the HDS Reactor. The high sulphur petroleum feed alongwith hydrogen is heated in a furnace to the required temp. Outlet stream from furnace at controlled temperature is fed to the reactor for Desulphurisation reaction. The sulphur present in the Petroleum products reacts with H2 to form H2S. The reaction products go to the separator where the H2S rich gas is separated from the liquid product.

4.2.7.1 HDS Reactor
The following safety instrumentation shall be provided for HDS unit.
Please refer Fig: 9.

(i) Reactor thermocouple assembly consisting of number of thermocouples of different lengths to measure and record reactor bed temperature at different heights. Hydrogen quench should be provided in between the beds for controlling bed temperature.

(ii) Reactor inlet and outlet temperature high temperature alarms using separate sensors for recorders and alarms.

(iii) Reactor inlet temperature control to be incorporated in the furnace outlet temperature control scheme.

(iv) Safety interlock shall be provided for low hydrogen flow, low feed, high reactor temperature.

(v) Feed pump and heater shall trip on low recycle gas flow to the reactor.

4.2.8 HYDROCRACKER UNIT:
Description:
Hydrocracking process is catalytic operation performed at relatively high hydrogen pressure and elevated temperature to convert a heavy oil fraction into products of lowers molecular weight. It is a flexible process to produce widely different fuels from same or different feedstocks. Generally, hydrocrackers use fixed beds of catalyst with downflow of reactants. During the process with severity increasing, the first reaction leads to saturation of any olefinic matter present in feedstock. Next follow the treating steps involving reactions of desulphurisation, de-nitrogenation and de-oxygenation, wherein only limited cracking takes place. Finally, on further increase in severity, hydrocracking reaction is initiated, which proceeds at various rates, with the formation of intermediate products (e.g. saturation of aromatics), which are subsequently cracked into lighter products. In the Single-stage hydrocracking process the treating step combines with cracking reaction to occur in one reactor. However, Two-Stage or Series Flow hydrocrackers are employed for high/ full conversion
by an additional reactor. Please refer Fig. 10.

**4.2.8.1** SIS in Hydrocracker unit shall be in line with the process licensor’s design guidelines and taking into consideration the following safety instrumentation:

(i) Automatic depressurization through the dump valve actuated at high-high temperature with any two of the temperature indications provided on the top bed of the reactor. Please refer Fig: 11.

(ii) Reactor thermocouple assembly consisting of number of thermocouples of different lengths to measure and record reactor bed temperature at different heights. Hydrogen quench should be ensured in between the beds for controlling bed temperature. High temperature alarms for the beds shall be provided.

(iii) Reactor inlet and outlet temperature high alarms.

(iv) Reactor inlet temperature control incorporated in the furnace outlet temperature control scheme.

(v) Safety interlock shall be provided for low hydrogen flow, low feed, high reactor temperature.

(vi) Feed pump and heater shall trip on low recycle gas flow to the reactor

**4.2.9 PROCESS GAS COMPRESSORS**

**Description**

Process gas compressors are used in the petroleum processing and gas pipeline systems to increase the pressure of gas for specific use and handling & transportation. The safety interlocks shall be in line with OEM’s recommendations and follow minimum provisions as under:

**4.2.9.1** The compressors shall be provided with the following instrumentation. Please refer Fig.12. Additional instrumentation shall be provided as per manufacturer’s recommendations.

(i) Low–Low suction and High-High discharge pressure shall be configured to trip the compressor.

(ii) Gas detection and fire detection devices shall be provided if the compressor is located inside enclosed buildings totally covered on all the sides. The protection shall also include turbine enclosures.

(iii) Devices to monitor and trip in case of excessive vibration, speed, low lube oil pressure, seal oil low differential pressure, high bearing temperature and high discharge temperature, low governor oil pr etc. in line with manufacturers recommendations.

(iv) High-High level on the suction knockout drum shall trip the compressor.

Note: Compressor trip shall mean shutting down the drive unit.

**4.2.10 FLUIDISED CATALYTIC CRACKING (FCC) UNIT - REACTOR/ REGENERATOR**

**Description**

Lighter products are obtained from Vacuum Gas Oil (VGO) by Catalytic cracking in FCCU. The catalyst is heated to a temperature of about 650 degree C and is then allowed to flow with the feed in the riser pipe of the reactor. Carbon particles are deposited on the catalyst when the feed cracks into lighter ends like Fuel Gas, LPG, Naphtha, diesel and heavy oil. The carbonized catalyst known as spent catalyst is then taken into the regenerator for regeneration. In the regenerator
controlled air is blown through the hot catalyst to convert the carbon into carbon monoxide, thereby releasing equilibrium catalyst for use in the next cycle.

FCC Reactor contains hydrocarbon vapour and regenerator contains hot air. Air should not enter the reactor and hydrocarbon vapour should not find entry into the regenerator. Regenerator is kept at higher pressure (by 0.5 Kg/CM²) compared to the reactor. Additionally, static head due to spent catalyst level in the reactor aids the transfer of spent catalyst from reactor to regenerator. During normal operation spent catalyst slide valve operation is dependent on the level in the reactor through its level controller (LRC). The reactor is maintained at a temp around 490°C by the transfer of hot regenerated catalyst from regenerator. During normal operation regenerator catalyst slide valve opening is controlled by reactor temperature controller (TRC). Please refer Fig. 13.

4.2.10.1 Following safety instrumentation shall be provided in FCC

(i) The spent catalyst slide valve (SCSV) shall be automatically shut off in the event of low differential pressure across the SCSV.

(ii) The regenerated catalyst slide valve (RCSV) shall be automatically shut off in the event of low differential pressure across the RCSV.

(iii) Reactor high temperature alarm shall be provided.

(iv) Emergency feed by pass provision to divert feed from the reactor.

(v) Hand jack provision for all slide valves for manual operation. In addition, local electrical / hydraulic / pneumatic operation shall also be provided.

(vi) Steam Low flow alarm and emergency cut in for steam and bypassing feed to reactor may be considered.

(vii) Regenerator dilute phase high temperature alarm should be provided.

(viii) Plant shutdown shall be provided on low air flow to regenerator

4.2.11 FLARE GAS SYSTEM

Description
Gas to be flared is routed through a knock out (K.O.) drum. From the K.O. drum the liquid is pumped back to Recovery System and the gas goes to flare stack through a water seal drum. Flare flame failure alarm may be considered. T.V. monitoring of the flame may be considered.

4.2.11.1 Following safety instrumentation shall be provided. Please refer Fig. 14.

(i) K.O.D. liquid level High and Low alarms for auto start / stop of the pump.

(ii) Low water level in the seal pot alarm

(iii) Pilot FG header Pressure low alarm

(iv) Gas detector near the flare KOD

(v) H2S detector near the H2S KOD

4.2.12 STORAGE TANKS

Following safety instrumentation shall be provided in line with OISD-STD-108:

(i) Tanks shall be provided with at least two numbers of level instruments working on different principles and one level indicator shall be Radar gauge type for at least class A Storage tanks. One of the above shall be used for High-High and Low level alarms.

(ii) Automatic isolation of tank receipt line based on High-High Level sensing device should be considered for tanks receiving at high flow rates (unloading from ship/ pipeline receipt etc.).

(iii) Low-low level switch from the primary level instrument to stop transfer pump (optional)
(iv) High temperature alarm should be provided wherever required.

### 4.2.13 AIR COMPRESSORS

**Description**

Air compressors are used in hydrocarbon industry for supplying air to pneumatic instruments and as well as for process requirements. The compressors considered here are reciprocating type.

Following safety instrumentation shall be provided for Air Compressor - Reciprocating:

(i) Cooling water low flow trip.
(ii) Discharge temp high trip.
(iii) Frame oil low pressure trip.
(iv) Discharge pressure high trip.
(v) Automatic loading/unloading system to be considered wherever possible.
(vi) Additional instrumentation be provided as per manufacturer’s recommendations.

### 4.2.14 TURBINES

**Description**

Turbines are steam/gas driven drive units used in hydrocarbon industry for driving compressors, blowers and alternators in the process units and captive thermal power station. Stipulations of OISD-STD-121 should be followed for Steam turbines’ operations, inspection and maintenance practices.

Following safety instrumentation shall be provided for Turbines - in line with manufacturer’s recommendation:

(i) Lube Oil pressure low trip.
(ii) Governor oil to pressure low trip.
(iii) Turbine exhaust pressure high trip.
(iv) Over speed trip.
(v) Axial displacement trip.
(vi) Vibration high trip.
(vii) Emergency trip.
(viii) Condensate level high alarm.
(ix) Exhaust hood high temperature alarm.
(x) Bearing temperature high trip.
(xi) FG pressure low trip.
(xii) Exhaust temp.(average of 3 thermocouples in exhaust) high trip.
(xiii) Lube oil temp. high trip.
(xiv) K.O drum level high trip.
(xv) Lube oil tank level alarms & trip.

#### 4.2.14.1 SIS Specific features for Gas Turbines

(i) Flame failure trip.
(ii) Gas detection in turbine enclosure.
(iii) L.O. Pr low.
(iv) Exhaust Pr high.
(v) Exhaust temp high trip.
(vi) Lube Oil tank level alarms and trip.

### 4.2.15 LPG - PRESSURE STORAGE AND BULK LOADING

**Description**

LPG is received from the plant through pipelines. It is stored under pressure at atmospheric temperatures in spheres or bullets or mounded storage. The LPG is pumped to a loading gantry from where it is loaded through loading arms into truck tankers or rail tankers.

When LPG is received through road or rail tankers, it is transferred by unloading pumps into the bullets or spheres.

Following safety instrumentation shall be provided for LPG Sphere. Please refer Fig. 15:

(i) Fire detection and protection system

In line with OISD-STD-144 and OISD-STD-150 as applicable, LPG storage, LPG pumps, compressor house etc. shall be protected through automatic fire detection and/or protection (Fixed) system based on smoke/heat detection.
through thermal fuses/ quartz bulbs/ EP detectors. Sensors shall be installed at all critical locations e.g. near ROV.

On detecting LPG concentration beyond the set limit, following auto actions shall be initiated:

i) Closure of remote operated valves in the affected area.

ii) Activation of tone generator in paging or a siren in the particular area.

iii) Tripping of LPG pumps and compressors.

iv) Activation of water deluge valve and sprinkler.

Emergency push buttons shall be provided in the control panel and at a safe place in the field to initiate the above actions manually.

ROVS shall be provided with open/close indications on the control panel.

(ii) Gas Detection Systems

Gas detectors shall be provided at all locations where possibility of build up of LPG vapour exists, which might lead to a fire.

The locations are:

- i) LPG Pump and compressor house.
- ii) LPG Truck and rail loading gantries
- iii) LPG Sampling Point.
- iv) Near ROVS.

Gas detectors shall have two levels of alarms. Suggested values are 20% LEL and 40% LEL.

(iii) Level gauging devices

#1 LPG spheres shall be provided with two independent indicators as a minimum.

(iv) Level switches

A separate high level switch shall be provided for alarm in the control room.

A water seal pot shall be provided on the low pressure side of the DP type level transmitter if use, the seal pot and the connecting pipe shall be of the same rating as that of the sphere. Alternatively, the low pressure leg of the D. P. transmitter shall be heat traced. The D. P. transmitter shall be provided with level elevation or suppression kit.

4.2.16 COKING CHAMBERS IN DELAYED COKING

Description

The Delayed Coking process for upgrading the heavy ends, is a semi-batch operation wherein a severe form of thermal cracking is allowed to occur at high temperatures (about 500 Deg C) for an extended period of time in the coke chamber. The process module contains a fired heater, two coking chambers (Drums or reactors) and a fractionation tower. The coke gets deposited on the chamber and cracked vapour goes from the top to fractionation section. After a definite cycle, the reactor is changed over, deposited hot coke is steam stripped and quenched with water. After water draining, bottom cover of the drum is opened (de-headed) in preparation for decking. The coke bed is fractured/cut into smaller pieces using high pressure water jet and dumped through the bottom opening. The batch operation in coking presents typical hazards attributed to most of the serious accidents. The operation activities include drum switching, coke drum head removal and coke cutting by hydro-blasting.
Following safety instrumentation shall be provided for Coking Chambers. Please refer Fig: 16

1) Coke Drum Switching:
(i) Interlocks for automated or remotely activated valve switching systems.
(ii) Interlocks for valves that are manually operated to avoid unanticipated valve movement.
(iii) Indicator lights at valve and valve control panel to help for intended operator action.

2) Coke Drum Head Removal:
Equipment upgrades by automating should be provided for both top and bottom head removal operations for keeping workers away from hazard prone areas during head removal.

3) Coke Cutting by Hydro-Blasting:
(i) During coke cutting, when the cutting/drilling tools need to be brought out for the tool change etc., the coke cutting water pump discharge shall automatically get routed to storage tank.
(ii) Provide interlocks to shut-off and prevent restart of cutting water pump whenever the cutting head level is raised above a pre-determined point within the coke drum. Provide a redundant level transmitter (voting 1 of 2) as additional protection layer against the hazard due to cutting head under pressure.
(iii) Coke cutting water pump should trip for following conditions:
   (a) Low discharge pressure.
   (b) If isolation valve on water line at other chamber is in open position.
   (c) If the cutting tool is out of chamber and discharge does not get routed to storage.

4) Temperature indication and high temperature alarm at vapour outlet (after HGO quench). Skin thermocouple at top/ middle/ bottom of the chamber.

4.2.17 SULPHUR RECOVERY UNIT (SRU):
The acid gas rich in H2S (>90%), generated from the Hydrotreating units is processed in SRU to recover the sulphur. One third of the acid gas is converted to SO2 in the reaction furnace at a temperature of 1200 deg C. The SO2 formed will react with the H2S to form sulphur. The reaction takes place in the presence of catalyst. Please refer Fig. 17.

In view of the toxic nature of the gas being handled, the following safety instrumentation shall be considered for implementation with the process licensor:

a. The feed to the unit shall be cut off and the furnaces shall trip in following conditions:
   i) high pressure inside reaction furnace
   ii) low combustion air flow/ pressure
   iii) when the off-gas incinerator trips

b. Any other protection for safe operation of the system in line with the process licensor

5.0 SAFETY INSTRUMENTED SYSTEMS IN PETROCHEMICALS

5.1 CRYOGENIC STORAGE:
Liquefied Natural Gas (LNG) turns to liquid state at (-161 ºC) under atmospheric pressure. As liquefaction reduces volume by 600 times, LNG is stored and transported in liquid form. Ethylene produced from Cracker unit is stored at (-104 ºC) at atmospheric pressure. The cryogenic storage tanks consist of double walls and are designed as per API 620. Please refer Fig 18.
Considering hazardous nature of the fluid handled, the storage facility requires provision of following safety instrumentation as minimum:

i) Interlocking for Vacuum breaker isolation valves.
ii) Level transmitter for low-low level trip of pump.
iii) Pressure transmitter for low-low pressure trip of the pump.
iv) ESD to shut off all inlet valves in feed line in case of high-high level and high- high pressure in the tank. ESD to be located in Main Control Room and at site (outside the periphery of tank)
v) Any other protection for safe operation of the system in line with OEM

5.2 EXPANDER – COMPRESSOR SYSTEM:

Following safety interlocks as minimum with required instrumentation, as given in Table 1, shall be incorporated for safe operation of the system in line with OEM. Refer Table-1 and Fig. 19.

Table 1: Details on trip requirements for Expander-Compressor

<table>
<thead>
<tr>
<th>TRIP PARAMETERS</th>
<th>Initiating cause for Tripping of (Driver side) Expander turbine</th>
<th>Initiating cause for Tripping of (Load side) Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing temperature</td>
<td>High-High</td>
<td>High-High</td>
</tr>
<tr>
<td>Bearing temperature</td>
<td>Low-Low</td>
<td></td>
</tr>
<tr>
<td>Shaft Vibration</td>
<td>High-High</td>
<td>High-High</td>
</tr>
<tr>
<td>Shaft Speed</td>
<td>High-High</td>
<td></td>
</tr>
<tr>
<td>Lube oil Del Pr</td>
<td>Low-Low</td>
<td>Low-Low</td>
</tr>
<tr>
<td>Seal gas Del Pr</td>
<td>Low-Low</td>
<td>Low-Low</td>
</tr>
<tr>
<td>Thrust Diff Pr</td>
<td>High-High</td>
<td>High-High</td>
</tr>
<tr>
<td>Inlet (Suction)Pr</td>
<td>Low-Low</td>
<td>Low-Low</td>
</tr>
<tr>
<td>Discharge Pressure</td>
<td></td>
<td>High-High &amp; Low-Low</td>
</tr>
<tr>
<td>Discharge Temperature</td>
<td>Low-Low</td>
<td>High-High</td>
</tr>
<tr>
<td>Suction KOD level</td>
<td>High-High</td>
<td></td>
</tr>
<tr>
<td>Expander suction/discharge</td>
<td>Causes expander to trip when SDV closes</td>
<td></td>
</tr>
<tr>
<td>switch actuation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDV limit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge Flow</td>
<td>Low-Low</td>
<td></td>
</tr>
<tr>
<td>Power-failure</td>
<td>Power fail contact taken from electrical sub station and given to instrument system for tripping expander-compressor</td>
<td></td>
</tr>
<tr>
<td>Trip</td>
<td>High shaft speed</td>
<td>---</td>
</tr>
</tbody>
</table>

5.3 GAS CRACKER UNIT: Pyrolysis Furnace

Pyrolysis or steam cracking is the primary process utilized to manufacture olefins. This gas-phase reaction takes place in metal alloy tubes within a fired furnace. An industrial Pyrolysis furnace is a complicated piece of equipment that functions as both a reactor and high-pressure steam generator. The Pyrolysis reactions proceeds in tubular coils made of Cr/Ni alloys. These coils are hung vertically in a firebox. Burners are arranged on the walls and on the floor of the firebox for indirect firing. This section is called the radiant section because the radiant heat is recovered. At the end of the Pyrolysis, the reaction needs to be quenched rapidly to avoid further decomposition of desired olefins. This is achieved by indirect cooling using a...
quench exchanger or direct cooling by injecting quench oil into the gas effluent. The heat carried by the flue gas is recovered at the convection section of the furnace. This section consists of a series of “tube banks” where the heat is recovered for superheating steam, preheating the hydrocarbon feed, boiler feed water and dilution steam.

5.3.1 Following safety instrumentation shall be provided for Pyrolysis furnace (Refer fig 20).

1) On occurrence of any of following abnormalities:
   i) Hydrocarbon feed low low flow
   ii) Steam drum water low low level.
   iii) High pressure superheated steam coil outlet high high Temperature
   iv) Bypass MOV to decoke drum
   v) Manual push button of partial shut down in field as well as in control room.

   partial shutdown of pyrolysis furnace will take effect, wherein
   - ID fan remains in line
   - Hydrocarbon feed flow valve shuts off.
   - Fuel gas valve shuts off to floor burners
   - Fuel gas valve shuts off to few wall burners
   - Dilution steam flow valves are reset

2) On occurrence of any of following abnormalities:
   i) Main dilution steam low low flow
   ii) Water quench tower overhead high high temperature.
   iii) Fuel gas low low supply pressure
   iv) Furnace arch high high draft
   v) Manual push button of complete shut down in field as well as in control room.

   complete shutdown of pyrolysis furnace will take effect, wherein
   - Main fuel gas supply valve cuts off
   - ID fan also stops
   - Closure of furnace draft damper

6.0 RECOMMENDED PRACTICES & INNOVATIONS FOR IMPROVEMENT

Long industry experience on operating complex processes, lesson learnt from major incidents in the past and proven guidelines from process licensors and OEMs, provide us with set of best practices to follow for enhanced safety. A few of them are listed as under:

6.1 Application of diagnostic provisions for Predictive/Maintenance/ Failure Alerts e.g. to detect chokage in impulse line, use of smart positioners for online checking of critical safety instrumentation/interlocks wherein demand overrides the Partial Stroke Test. For example for dump valve in Hydrocracker.

6.2 Frequent periodic testing to ensure availability of SIS and its components on demand

6.3 Recommendations by the Process Licensor's and International standards as applicable should be used as guidelines viz. IEC 61511 -1,2,3 which pertains to the trips and alarms and emergency shutdowns required for the protection of the equipment and loss to assets.

6.4 Required SIL level should to be ensured for SIS components in critical process functions, in line with IEC 61508 guidelines.

6.5 To defend against common mode failure, it is appropriate to monitor dissimilar but related alarm conditions in the same equipment/ circuit. For example, monitor both, low cooling water flow high water outlet temperature.

6.6 ALARM MANAGEMENT

Alarm system is an important constituent of Abnormal Situation Management in any process plant. The purpose of an alarm system is to direct the operator’s attention towards plant conditions requiring timely assessment or action. Each alarm should alert, inform and guide the operator. It should have a defined response relevant to the process. Adequate time should be allowed for the operator to carry out his defined response. Alarms are configured to alert the operator whenever the process parameters undergo change beyond their permissible operating limits. Based on the extent of change in parameter and severity of related consequence, the alarms’ priority need be assigned to enable the operator taking corrective actions.
Too many alarms overload the operator. Nuisance alarms create distraction in handling emergencies by the operator. For efficient use of alarm system especially in emergency handling, average alarm rate performance needs to be continually improved through alarm rationalisation, review of control strategies and by addressing the worst performing alarms first in priority. In addition, alarm system should be supported by ongoing maintenance practice, alarm system design practices, routine monitoring as well as by investigating performance of alarm system following major upset in conditions.

The aim has to be continual reduction in nuisance alarms. This involves activities like assessment of Base Case performance by collecting alarm history, followed by analysis to identify reconfiguring requirement and comparing the current rate of occurrence periodically with the EEMUA guidelines as benchmark (Refer Table-2). Such reviews with measurement of the frequency of alarms provide trend chart on alarm system performance. The team that needs to work on it should comprise of a facilitator, area operators, area process engineer, area production supervisor, and area instrumentation engineer. For Alarm rationalisation, the principle should be "no alarm if no action required". Operators should have standard operating practices for each alarm detailing a unique predefined follow up action – either from control room or in the field or both. It is preferable to configure alarms with the non-controlling loops or open loops.

Detailed periodic review of alarm summary should be undertaken to identify the redundant / nuisance alarms.

For quick understanding by the operator about the priority level of an alarm, use of different colour codes and beeps may be considered to assign priority 1, 2, 3 and 4.

**Table 2: Typical Best Practices Bench Marks: **EEMUA 191**

<table>
<thead>
<tr>
<th>Plant Alarms</th>
<th>Target maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of Alarms during normal operations of manageable steady state</td>
<td>1 over 10 minutes or less or @ 5 per hour (120 per day)</td>
</tr>
<tr>
<td>Alarms after plant upset i.e. during flood state</td>
<td>10 in 10 minutes or less</td>
</tr>
<tr>
<td>Peak Alarm hourly rate</td>
<td>15 per hour or less</td>
</tr>
<tr>
<td>Peak Alarm Minute rate</td>
<td>2 per minute or less</td>
</tr>
<tr>
<td>Average number of standing alarms</td>
<td>10 or less</td>
</tr>
<tr>
<td>Average number of shelved alarms</td>
<td>30 or less</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Priority-wise Alarm Activity Distribution</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical Alarms</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>High priority</td>
<td>~ 5%</td>
</tr>
<tr>
<td>Medium Priority</td>
<td>~ 15%</td>
</tr>
<tr>
<td>Low Priority</td>
<td>~ 80%</td>
</tr>
</tbody>
</table>

**EEMUA** (Engineering Equipment & Materials Users Association) is an established industry Association with an international reputation in engineering, technology and the management of capital assets, typically chemical process plants, refineries, power stations and upstream oil/gas facilities. EEMUA Publication 191 - first published in 1999 and revised in 2007, is recognised world over as a reference and guide to the design, management and procurement of alarm systems.

The terminologies used in the table -2 above, are defined as under:

i) **Manageable steady state** - the maximum rate at which a single operator can effectively address alarms.

ii) **Flood state** – the rate at which a single operator is overwhelmed by alarm activations.
iii) **Average Process Alarm Rate** - the average rate at which a single operator can be expected to perform as required.

iv) **Peak Alarm Hourly Rate** - the target peak hourly rate for the most active hour within the evaluated time period.

v) **Peak Alarm Minute Rate** – the target peak minute rate for the most active minute within the evaluated time period.

vi) **Priority-wise Alarm Activity Distribution** – the suggested approximate distribution of alarm activity.

vii) **Alarms within ten minutes of a major upset** – the maximum rate in the 10 minute period following a major upset.

viii) **Standing Alarms**: An alarm that has annunciated and never cleared. It is a leading indicator of operational performance and management attention.

ix) **Shelved Alarms**: An alarm that has been temporarily suppressed (taken out of service) while being corrected or fixed. It should be shelved with assessment from competent authority. It is a leading indicator of maintenance performance and management attention.

8.0 REFERENCES:

i) **IEC 61508**: A generic standard by International Electro-technical Committee on “Functional Safety of electrical/ electronic/programmable-electronic safety related systems”. It is intended to be a basic functional safety standard applicable to all kinds of industry.

ii) **IEC 61511**: Standard by International Electro-technical Committee on “Safety Instrumented system for process industry sector”. It is intended to provide guidelines for determination of required safety integrity levels.

iii) **Recommended Practices for Analysis, Design, Installation and Testing of Basic Surface Safety Systems for Offshore Production Platforms (API-RP-14 C)**.

iv) **EEMUA 191**: Provides guidelines for the design, management, and procurement of alarm systems.

v) **ANSI/ISA S84.01**: Application of Safety Instrumented systems for process industries adopted by American National Standards Institute (ANSI).
## Process Control and Safety Instrumented System – a Comparison

<table>
<thead>
<tr>
<th>Features</th>
<th>Process Control</th>
<th>Safety Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control type</td>
<td>Active, complex, optimising</td>
<td>Passive, simple, direct acting</td>
</tr>
<tr>
<td>Tasks</td>
<td>Many variables, expanding, experimental</td>
<td>Limited, strictly defined</td>
</tr>
<tr>
<td>Modes of control</td>
<td>Auto/manual, supervisory</td>
<td>Automatic, no manual intervention, no external command levels</td>
</tr>
<tr>
<td>Communications</td>
<td>Open systems, Field bus etc</td>
<td>Limited, specialised, difficult with bus networks</td>
</tr>
<tr>
<td>Changes</td>
<td>Easy to make, password protected, configurable, parameter changes</td>
<td>Strictly controlled, password protected, verified and documented, parameter changes strictly controlled</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>Limited</td>
<td>Intensive proof-testing</td>
</tr>
<tr>
<td>Redundancy</td>
<td>Used for high availability for continuous use</td>
<td>Used for high reliability</td>
</tr>
<tr>
<td>Documentation</td>
<td>For convenience</td>
<td>Essential for validation of each function</td>
</tr>
<tr>
<td>Testing</td>
<td>Nominal loop testing</td>
<td>Failure modes testing</td>
</tr>
</tbody>
</table>
Details on LOPA (Layer of Protection Analysis)

In order to assess the adequacy of protection for a process function, Hazop study as a method of Process Hazard Analysis (PHA) is done first. HAZOP tables list out Deviations, Causes, Consequences, Safeguards and Recommendations. The details so compiled include estimates of frequency for each cause and severity for each consequence. The HAZOP information is utilised for development of Layer of Protection Analysis (LOPA), as shown in the Fig.1. LOPA is a simplified semi-quantitative technique of risk analysis. It helps to assess what independent protection layers (IPL) already exist or what are required for process safety.

The LOPA team recommends use of an SIS only if other design changes for inherent (built-in) safety, cannot reduce the Mitigated event likelihood to less than the target. While LOPA does not suggest which safeguards to add or which design to choose, it does assist in deciding between alternatives.

1) **First LOP** is the primary protection catered by a safe and effective basic process control system (BPCS), e.g. controllers, control valves and operator supervision. It is a preventive measure protection.

2) **Second LOP** is also in-built in the Process control system in the form of alarms combined with operator’s intervention to bring the process to safe state in case of upset. It is a preventive measure applied for protection in all major installations. Where control system is not designated as safety related, the protective system for a process has to be separate and independent from control system as the third LOP.

3) **Third LOP** is the Safety Instrumented System (SIS) which is independent of the process control system. Having separate sensors, valves and logic system, its only role is Safety. Based on available experience and technological know-how with the process designer, SIS is configured to protect the process & equipment against envisaged adverse process conditions. Adequacy of SIS is verified through PHA. SIS remains dormant or passive until demand arises.

4) **Fourth LOP** is the secondary protection configured to minimise consequence of a process upsets like overpressure causing equipment rupture, loss of containment causing large uncontrolled spills or release leading to explosion/fire/toxic environment. For example relief valves or rupture discs designed to prevent overpressures can provide the secondary protection. Similarly, it may exist in the form a dyke or other passive barriers to contain a fire or channel of energy of an explosion and minimise the consequence or spread of damage. System for Pressure Relief & Disposal and system for Oily Water Sewer (OWS) should be designed in line with OISD STD-106 and OISD-STD-109 respectively and also in compliance to the layout stipulations of OISD-STD-118.

5) **Fifth LOP** is Post release physical protection such as fire suppression system, it generally includes early warning system such as release detection, fire detection and fire protection system provided in the location. These systems shall be designed in line with OISD STD 116 for refineries and gas processing plants, OISD STD 117 for marketing terminals & depots and pipe line stations and OISD STD 189 for upstream locations.

6) **Sixth LOP**, also the final layer, is the emergency response plan (ERP) for both onsite & offsite. It generally includes evacuation plan, fire fighting, rescue operation etc. This LOP responds to minimise consequence in terms of the ongoing damage, injury or loss of life. Accordingly, each installation/group of installation handling hazardous material needs to have risk mitigation plan or disaster management plan (DMP) in place.

**Notes:**

i) As Layers of Protections together mitigate the risk severity to ALARP (as low as reasonably practical) limits, LOPA is an essential step to follow after PHA (HAZOP study). LOPA uses risk tolerance criterion of $1 \times 10^{-6}$ per year for an event with consequence of 2 to 10 fatalities for the risk that is broadly acceptable.

ii) OISD-STD-152 mainly deals with SIS requirement (i.e. 3rd LOP) and also covers safety related instrumentation of the 2nd LOP.

iii) In order to assess the requirement of Safety Instrumented Functions for protection of the process facility, it is recommended to perform Process Hazard Analysis (covering HAZOP, Risk Analysis and SIL studies) for any proposed (new) facility or modifications/change in the existing process facility, so that SIS can be suitably designed / upgraded.
SIL Determination – An Overview

There are several methods to determine SIL level for a Safety Instrumented Function (SIF). These include ALARP, Risk Matrix, Risk Graph, Layers of Protection Analysis (LOPA), etc. LOPA is very helpful to establish SIL targets.

1) **SIL**, also termed as SIL rating, helps in defining the extent of process safety performance expected from SIS to bring the process to safe state, when the specific process control (BPCS) provided fails to cope with the upset conditions. Based on the SIL rating, each specific process function is optimized for risk protection by selecting components rated appropriately in line with IEC 61508. SIL is the discrete level (1 out of a possible 4) for specifying safety integrity requirements of the safety functions to be allocated to the electrical/electronic/programmable electronic safety related systems. SIL 4 stands for the highest level of safety integrity and SIL 1 the lowest. SIL concept helps the safety system designers and developers in making systems “acceptably safe” for their intended use in the safety function with an understanding of the risks and defined safety requirements for the risks needing reduction. Main objective of SIL is to provide a consistent, auditable result of performance of SIS present in the process facilities. SIL should be assessed and determined in terms of both hazards and consequences associated with specific installation. Accordingly, it should be considered essential to assign and verify SIL level of various SIS present.

2) **SIL & related Measures for low demand mode operation**

<table>
<thead>
<tr>
<th>SIL</th>
<th>Availability</th>
<th><em>PFD (avg)</em></th>
<th>*MTBF = (1/PFD) = equivalent <em>RRF</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>&gt;99.99%</td>
<td>10-5 to &lt;10-4</td>
<td>100000 to 10000</td>
</tr>
<tr>
<td>3</td>
<td>99.9%</td>
<td>10-4 to &lt;10-3</td>
<td>10000 to 1000</td>
</tr>
<tr>
<td>2</td>
<td>99 – 99.9%</td>
<td>10-3 to &lt;10-2</td>
<td>1000 to 100</td>
</tr>
<tr>
<td>1</td>
<td>90-99%</td>
<td>10-2 to &lt;10-1</td>
<td>100 to 10</td>
</tr>
</tbody>
</table>

* MTBF = Mean Time between failures,  RRF = Risk Reduction Factor  
* PFD = Probability of Failure on Demand

3) **Steps involved in Assignment of SIL Rating of a Safety Function:**

- **Step 1:** A detailed Hazard & Risk Analysis of the process system shall be undertaken by a multi-disciplinary team to enlist all foreseeable Hazards, their probability of occurrence and impact on plant, manpower, society and environment (operational, corrosion related, accidents and natural calamities). For non-availability of requisite data, subjective probability shall be assigned based on collective experience of the members.

- **Step 2:** A comprehensive Layer of Protection Analysis (LOPA) shall be conducted to specify the protection layers for reduction of above Hazards. LOPA helps to establish whether the hazards involved need reduction by application of SIS as LOP.

- **Step 3:** Safety Integrity Functions (SIFs) shall be defined for each identified SIS LOP.

- **Step 4:** Then, for each SIF, the SIL rating shall be defined based on the desired level of risk reduction. A sample exercise of SIF with SIL assignment is reproduced to conceptualise the SIS architecture.
### SIL Rating for SIF Listing – a sample matrix

<table>
<thead>
<tr>
<th>SIF ID</th>
<th>SIF Description</th>
<th>Hazard</th>
<th>Inputs</th>
<th>Outputs</th>
<th>SIL</th>
<th>Reason</th>
<th>Risk Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Pump high discharge Pressure demands emergency shutdown of the facility through activating ESD</td>
<td>Potential for rupture of main line due high pressure</td>
<td>P,T</td>
<td></td>
<td>2</td>
<td>Potential fatal impact</td>
<td>1000 times</td>
</tr>
</tbody>
</table>

**Note:** This simplified matrix is intended to illustrate in broad sense the methodology for SIL assessment and does not provide a model solution. A case specific assessment will be required for each process safety function.

- **Step 5:** The SIS conceptualised at step-4, shall then be Safety certified by TUV, FM or equivalent.
- **Step 6:** During commissioning and thereafter once every five years, the SIS shall be functionally validated. OISD-STD- 153 provides the minimum re-calibration intervals for SIS instruments.
- **Step 7:** Whenever, any retrofitting to the plant is done, new processes are added, major repairs are done, a major modification to the plant or in operation philosophy is done, a detailed review should be done by following above procedure from steps from 1 to 7.
- **Step 8:** During design of SIS, useful design life of the system shall be evaluated. Due consideration to be taken for de-rating the reliability due to ageing as well as availability constraints of maintenance spares. The entire SIS shall be replaced upon completion of the design life. During replacement, the above procedure shall be followed.
- **Step 9:** If is decided to extend the operation of the SIS beyond the design life, approval shall be obtained from the head of the plant and documented. Upon completion of the extension period, the replacement shall be ensured as per procedure step 9. (There has to be rare instance where from Engineering Estimation, Maintenance Data and other evidences, it is decided to extend the operation of the SIS)

**Reference:** IEC 61511 is an application specific adaptation of IEC 61508 for the Process Industry sector. This standard is used in the petrochemical and hazardous chemical industries.
Figure 1 Relationship between HAZOP and LOPA Information

HAZOP Information
- Deviation
- Cause
- Cause Frequency
- Consequence
- Consequence Severity
- Safeguard
- Recommendation

LOPA Information
- Impact Event
- Event Severity
  - Minor
  - Serious
  - Extensive
- Initiating Cause
- Cause Likelihood
- Process Design IPL & PFD
- BPCS IPL & PFD
- Alarms, Procedures IPL & PFD
- SIS IPL & PFD
- Additional Mitigation IPL & PFD

Mitigated Event Likelihood

Add IPLs or redesign the process

Mitigated Likelihood less than target?

NO

YES

Continue with next Consequence Cause pair

Totalize Mitigated Event Likelihoods for whole process

BPCS — Basic Process Control System
IPL — Independent Protection Layer
PFD — Probability of Failure on Demand
SIS — Safety Instrumented System
Fig 2: Instrumentation in typical process plant
NOTE: SDV in the fuel gas line shall be required in case of heater treater.

FIG. 3

SAFETY INSTRUMENTATION FOR SEPARATOR
FIG. 4

SAFETY INSTRUMENTATION FOR SEPARATOR
FIG: 6

SAFETY INSTRUMENTATION FOR CRUDE COLUMN
FIG 8

SAFETY INSTRUMENTATION FOR COMBUSTION AIR SYSTEM
Two Stage Hydrocracking

FIG 10: HYDROCRACKING
FIG: 11: DUMP VALVES IN HYDROCRACKER UNIT
SAFETY INSTRUMENTATION FOR FLUIDIZED CATALYTIC CRACKER
SAFETY INSTRUMENTATION FOR FLARE GAS SYSTEM
FIG. 15

SAFETY INSTRUMENTATION FOR L.P.G SPHERE
FIG. 16

SAFETY INSTRUMENTATION FOR COKE CHAMBER
FIG:18 Cryogenic Storage

Note: SIS - EDS 1 HH will activate EDSV 3 and LL will trip pump 4. ESD 2 will activate ESDV 3.
FIG; 19  EXPANDER-COMPRESSOR
LEGENDS: SD 1 – Partial shutdown; SD 2 – Complete shutdown

**FIG 20: GAS CRACKER FURNACE**