ISA Delhi Section

PNID – 2012

....Fueling Technology

An event by

ISA DELHI SECTION

VENUE
HOTEL TAJ PALACE,
S P Marg, New Delhi

DATE
5th Oct 2012,
Friday

PROGRAMME OUT LINE

5th October-2012	Time From	Time to
Registration	***8:30 AM***	***9:15 AM***
Inauguration Session		
Arrival of Chief Guest & other dignitaries	09:15 AM	
Welcome of Dignitaries with Bouquet	09:20 AM	
Lamp Lighting	09:25 AM	
Welcome address by ISA-D President	09:30 AM	
Address By Shri Satish Puri Director General-DGMS	09:40 AM	
Address By Shri Anil Wali, MD FITT, IIT DELHI	09:50AM	
Address by Chief Guest, Shri A K Purwaha, C&MD EIL	10:00 AM	
Key Note Address By Shri R K Ghosh, Director Refinery, IOCL	10:15 AM	
Release of Souvenir by Chief Guest	10:30 AM	
Vote of Thanks by Convener-ISA(D) PNID-2012	10:50 AM	
Inauguration of Exhibition by Chief Guest and Dignitaries	11:00 AM	
Networking Tea Break	**11:00 AM**	**11:15 AM**
Session-1 - "Safety & Security"	**11:15 AM**	**1:00 PM**
High Integrity Pressure Protection System (HIPPS)	Mr. Elango Pushpalingam	M/s Mokveld Valves BV
Leak Detection System	Mr. GS Baveja	M/s Nextgen
Safety and Availability- A Case Study	Mr. D. Singhal	M/s Haldor Topsoe
	Ms. Prema Suresh	M/s Technip - Mumbai
Networking Lunch Break	**1:00 PM**	**1:45 PM**
Session-2" Wireless Technology"	**1:45 PM**	**3:45 PM**
Wireless Technology	Mr. Hemal Desai	M/s E&H
Wireless HART Standards	Mr. Unnikrishnan.R	M/s P&F
Wireless Technology improves Plant Efficiency	Mr. Harish Mane Mr. Vinayak Kore	M/s Honeywell
Wireless Solutions for upstream Oil & Gas production	Mr. Mike Ilgen	M/s Emerson Process
Tea Break	**3:45 PM**	**4:00 PM**
Session-3 -"Surge Protection Solution"	**4:00 PM**	**5:30 PM**
Surge Protection System	Mr. Ashish Manchanda	M/s Phoenix Contact
Surge Protection- A case study	Mr. Nakul Gupta Mr. Jiten Chaudhari	M/s Bechtel
Surge and Transient Protection System	Mr. Abhijit Majumdar	M/s DEHN INDIA
Session-4-	**5:30 PM**	**6:30 PM**
Presentation By Dr Mrs. Vijay Malik – Head (PCD), BIS **Followed by** "Panel Discussion on **Statutory Requirements"**		
Honours and Awards	**6:30 PM**	**7:00 PM**
Networking Dinner	**7:00 PM Onwards**	

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Regd. Office : Engineers India Bhavan, 1, Bhikaiji Cama Place, New Delhi-110066

A. K. PURWAHA
CHAIRMAN & MANAGING DIRECTOR

I am happy to note that International Society of Automation (ISA) - Delhi section is organizing Petroleum and Natural Gas Industries Domain (PNID-2012) conference and exhibition on 05th October 2012 with a vision to take automation in Petroleum and Natural Gas Sector to global heights.

The Oil & Gas Sector, an important energy provider to nation, faces challenges from ever increasing demand for high productivity, improved plant efficiency, increased safety and security. Instrumentation, Controls & Automation is the key to achieving these objectives.

To further augment the productivity levels, it's imperative to connect the plant floor with the enterprise level to collaborate real time plant information. Plant Intelligence solutions for connecting and integrating the disparate systems that work in isolation is also emerging as imminent need of the industry. Latest technological advancements without compromising on operational safety have to be adopted to face the complex process challenges.

I believe that this symposium will provide platform to technology developers, end users and other stakeholders of the industry to engage and deliberate the challenges facing the industry and discuss its role in developing a world-class Petroleum and Natural Gas sector in the country.

I wish the symposium all the success.

(AK Purwaha)

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Rajkumar Ghosh
Director (Refineries) &
Director-in-charge (Assam Oil Division)

CHIEF PATRON & KEYNOTE SPEAKER

I am glad to be the Chief Patron of Petroleum and Natural gas Industries domain (PNID-2012) conference and exhibition organized by International Society of Automation (ISA) - Delhi section on 05th October 2012.

The Oil and Gas Sector, which is the most critical Energy sector, continuously faces challenges from ever-increasing demand for high productivity, improved plant efficiency, increased reliability and security. This industry also demands Plant Intelligence solutions that help connect and integrate the disparate systems that work in isolation. To enhance the production operations it's necessary to connect the plant floor with the enterprise level that will give real time plant information.

Huge investments are still required to ensure the industry has enough production capacity to meet future demand. Automation expenditures by the upstream oil and gas sector, which includes exploration, production, and pipelines, are expected to grow at a compounded annual growth rate (CAGR) of nearly 7% over the next 5 years.

I am sure this symposium will provide a platform to share the latest trends in instrumentation and automation for End users, consultants, professionals, EPCs & suppliers and enhance knowledge base to meet the challenges of today and future.

I wish the symposium a grand success.

(Rajkumar Ghosh)
Chief Patron
ISA-PNID 2012

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Dr. (Mrs.) Vijay Malik
Scientist F & Head
(Petroleum & Coal Dept), BIS

I am glad to be the part of Petroleum and Natural gas Industries domain (PNID-2012) conference and exhibition organized by International Society of Automation (ISA) - Delhi section on 05th October 2012.

Importance of standardization in expanding global market, technological innovation and access to information and knowledge has long been understood and standards at international levels have been formulated to minimize the barriers in International Trade, to the extent feasible. Our country has made significant contribution in the field of standardization at national and international level through our National Standards body, namely, Bureau of Indian Standards (BIS).

One of the core activities of BIS is the development of the National Standards which is spread over 14 Divisions, out of which Petroleum, Coal and related Products Division (PCDC) covers oil and gas sector covering complete range of petroleum products. The standards help transforming the markets by removing inefficient products and encourage efficient services. Indian Standards in the field of petroleum products are being regularly updated to encourage use of latest instrumentation techniques in monitoring the quality of petroleum products.

I hope this symposium will provide a platform to share the latest trends in instrumentation and automation for End users, consultants, professionals, EPCs and suppliers and enhance knowledge base to meet the challenges of today and in future.

I wish the symposium for their success.

Regards,

Dr. (Mrs) Vijay Malik

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Satish Puri
Director-General of Mines Safety,
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Tel: 0326-2221042 (R)

M E S S A G E

I am glad to be the Guest of Honor for Petroleum and Natural Gas Industries domain (PNID-2012) conference and exhibition organized by International Society of Automation (ISA) - Delhi Section on 05th October 2012.

The purpose of this forum is to enable learning from peers and industry experts and their experiences in the field of Petroleum and Natural Gas sector automation, so as to promote sustainable development of Petroleum and Natural Gas sector automation solutions.

The Symposium intends to engage automation experts from Petroleum and Natural Gas and Petrochemical industries (e.g. offshore well head and process platforms, onshore wellhead and pipeline industries, Gas processing plants, Oil Refineries and Petrochemicals), Automation Providers/ Manufacturers, System Integrators, Consultants, R&D Organizations, Academicians and others for an invigorating exchange of knowledge.

I hope this symposium will provide a platform to share the latest trends in instrumentation and automation for stake holders and enhance knowledge base to meet the challenges of today and in future.

I sincerely hope that this Conference will benefit the industry at large.

28/9/12

(Satish Puri)

MESSAGE

As the President of ISA Delhi Section, it is indeed a great pleasure to present to our members and distinguished delegates, yet another edition of PNID-2012. Our team at ISA(D) has been concentrating on efforts at knowledge sharing, to bring high quality technological contents to our esteemed members. Organising this next edition of PNID is an indication of our continuing efforts to focus on the technologies central to Automation in the Petroleum & Natural Gas industry segment.

On behalf of the Executive Committee, I would like to thank all our senior advisers, paper presenters, supporters, HPTC (High Power technical committee) members and sponsors for making this event a grand success.

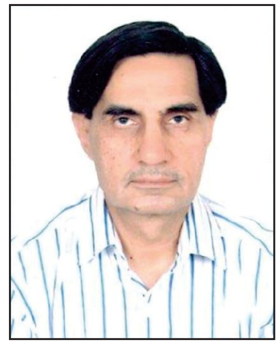
I also take this opportunity to compliment and congratulate the Souvenir team of ISA Delhi Section for putting together a compendium of technical information with excellent content and great design. I do appreciate the guidance provided by our senior members in advising our Souvenir team. I also put on record the efforts of Sh Manish Kumar and Sh Radhey Shyam Tiwari in braining this print on time.

In the days to come, I sincerely wish that with the continuing support of our active members, there will be a wide variety of knowledge sharing and learning activities contributing to the collective wealth of our accumulated knowledge.

I do congratulate the entire organising team and in particular, the program convener Sh S.K Dhawan for putting together such a wonderful program under the banner of ISA Delhi Section.

With best wishes,

Prasenjit Pal
(Hon President - ISA Delhi Section)



MESSAGE

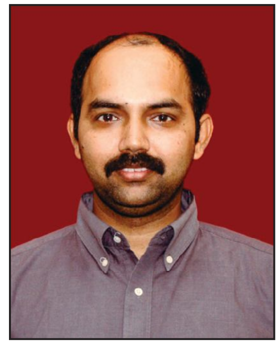
I am happy that International Society of Automation (ISA) - Delhi section is organizing the Petroleum and Natural gas Industries domain (PNID-2012) conference and exhibition on 05th October 2012 highlighting importance of Instrumentation & Automation industry in Petroleum Oil & Gas sector and chosen me again as a Convenor for the PNID-2012.

This Oil & Gas Sector is an important energy provider industry and demands Plant Intelligence solutions that help connect and integrate the disparate systems that work in isolation. To enhance the production operations it's necessary to connect the plant floor with the enterprise level that will give real time plant information with adoption of latest safety and security standards.

I believe that the engagement and involvement of various stake holders including technology providers and developers would certainly help in achieving the roadmap for implementing strategies for automation so essential for a world-class Petroleum and Natural Gas utility.

I convey my best wishes for the great success of the event.

SK DHAWAN
CONVENOR-PNID-2012



MESSAGE

I am glad to be the Technical Co-ordinator of Petroleum and Natural gas Industries domain (PNID-2012) conference and exhibition organized by International Society of Automation (ISA) - Delhi section on 05th October 2012.

Instrumentation & control systems have always kept pace with the technical and scientific evolutions - from pneumatically controlled system to fully automated state-of-the art Distributed control Systems and microprocessor based field instruments having analog and digital communication with SMART & Foundation Fieldbus technology which are in place for more than a decade. Wireless technology being picked up in the industry is really regarded as the paradigm shift in the world of automation and process industry.

Technology being on the cutting edge with continuous development, I am sure this meet will provide more insight to improve awareness instrumentation and automation technology and generate lot of inspiration and confidence to review and evaluate the future roadmap of technologies in the plant control and monitoring applications with active participation and invaluable knowledge sharing between end-users, suppliers and consultants.

Regards,

S. Mahesh Kumar
Technical Co-Ordinator
ISA-PNID 2012

ISA (D) - PNID-2012

PNID is an initiative taken by ISA-Delhi section to provide a common platform to all stakeholders of the Petroleum and Natural Gas Automation community including users, Petroleum and Natural Gas equipment suppliers, Automation system suppliers, system integrators, consultants, R&D establishments, academicians, independent experts and students for sharing of their knowledge and experiences. The purpose of this forum is to enable learning from peers and industry experts and their experiences in the field of Petroleum and Natural Gas sector automation, so as to promote sustainable development of Petroleum and Natural Gas sector automation solutions.

The vision of the ISA (D) - PNID:

"Take the automation in the Indian Petroleum and Natural Gas sector to global heights and acquire numero-uno position."

The mission of the ISA (D) – PNID:

"Engage all stake holders of Petroleum and Natural Gas sector in adopting the latest instrumentation and automation standards, there-by achieving safe, reliable, efficient and environment friendly Petroleum and Natural Gas availability in country."

To realize the above vision and to execute the mission, various long term and short term activities being carried out by ISA(D) - PNID are :

- Enable knowledge sharing among Petroleum and Natural Gas sector automation fraternity including utilities, consultants, equipment manufacturers, suppliers and academicians.

- Facilitate through integrated automation, the realization of a world class Petroleum and Natural Gas plants in India with green, clean and lean visualization, there-by establishing global benchmarks in Petroleum and Natural Gas generation in terms of reliable & quality, at a competitive cost.

- Provide an opportunity for Indian Petroleum and Natural Gas sector automation experts to get an exposure to the global developments in automation and there by providing an opportunity to seek & implement latest state-of-the-art global solutions best adapted for India Specific conditions.

- Provide an interface for the automation fraternity with the policy makers and regulators

We believe that the engagement and involvement of various stake holders including technology providers and developers would certainly help in achieving the roadmap for implementing strategies for level-4 automation so essential for a world-class Petroleum and Natural Gas utility.

2012-2013 ISA Delhi Section Leaders

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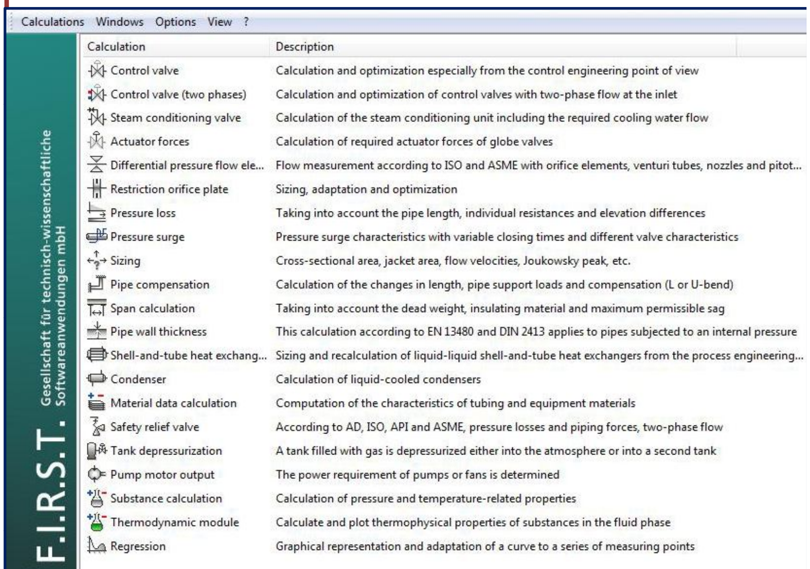
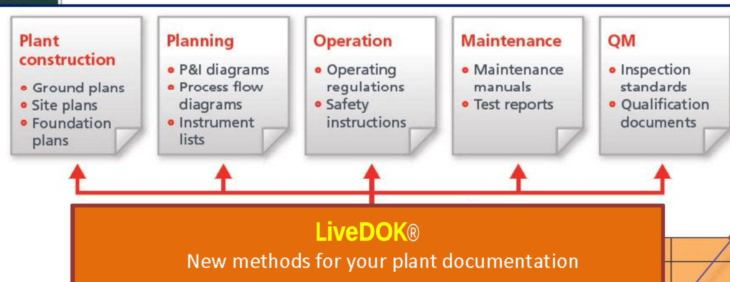
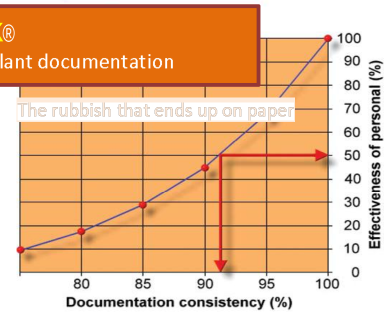

Calculations Windows Options View ?

Calculation	Description
Control valve	Calculation and optimization especially from the control engineering point of view
Control valve (two phases)	Calculation and optimization of control valves with two-phase flow at the inlet
Steam conditioning valve	Calculation of the steam conditioning unit including the required cooling water flow
Actuator forces	Calculation of required actuator forces of globe valves
Differential pressure flow ele...	Flow measurement according to ISO and ASME with orifice elements, venturi tubes, nozzles and pitot...
Restriction orifice plate	Sizing, adaptation and optimization
Pressure loss	Taking into account the pipe length, individual resistances and elevation differences
Pressure surge	Pressure surge characteristics with variable closing times and different valve characteristics
Sizing	Cross-sectional area, jacket area, flow velocities, Joukowsky peak, etc.
Pipe compensation	Calculation of the changes in length, pipe support loads and compensation (L or U-bend)
Span calculation	Taking into account the dead weight, insulating material and maximum permissible sag
Pipe wall thickness	This calculation according to EN 13480 and DIN 2413 applies to pipes subjected to an internal pressure
Shell-and-tube heat exchang...	Sizing and recalculation of liquid-liquid shell-and-tube heat exchangers from the process engineering...
Condenser	Calculation of liquid-cooled condensers
Material data calculation	Computation of the characteristics of tubing and equipment materials
Safety relief valve	According to AD, ISO, API and ASME, pressure losses and piping forces, two-phase flow
Tank depressurization	A tank filled with gas is depressurized either into the atmosphere or into a second tank
Pump motor output	The power requirement of pumps or fans is determined
Substance calculation	Calculation of pressure and temperature-related properties
Thermodynamic module	Calculate and plot thermophysical properties of substances in the fluid phase
Regression	Graphical representation and adaptation of a curve to a series of measuring points





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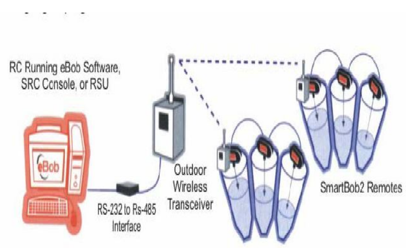
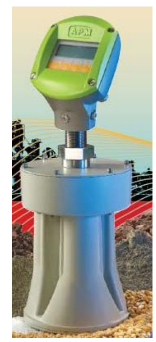


SILO / BIN INVENTORY SYSTEM



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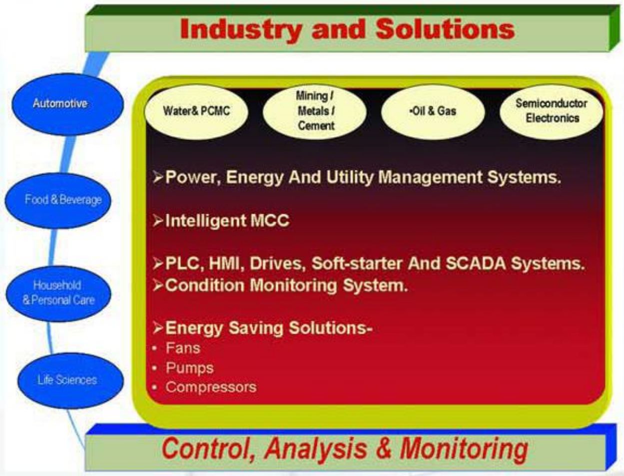

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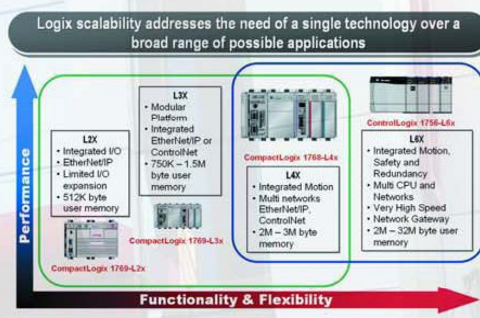

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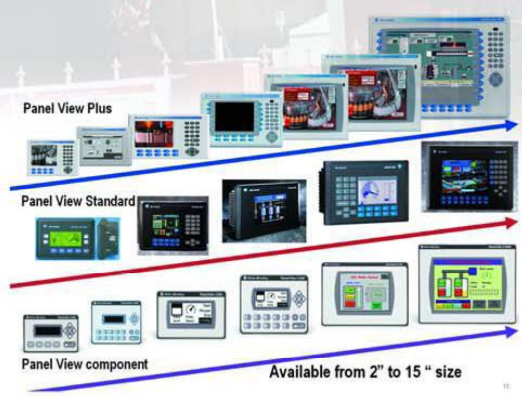

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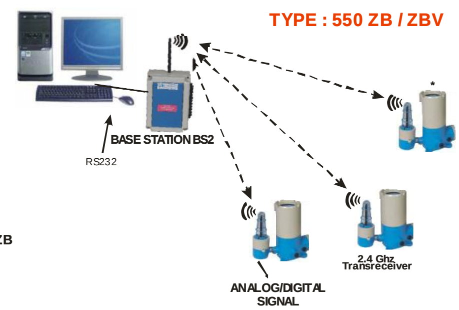

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Technical Papers

Modifications in the Latest Revision of the IEC 61508 and the Consequences for Final Elements like Valves/Actuator Combinations.

Presenter : Elango Pushpalingam - TÜV FS Eng. ID 2212/10
Mokveld Valves BV – The Netherlands

In 2010 a new revision of the IEC 61508 was formally published. The previous version dated back to 1998 and since then it is used in the Oil and Gas industry for over-pressure protection systems. This presentation will focus on the modifications in the IEC 61508 related to the final elements and as example an application in the Oil and Gas industry is used.

It should be clear that this presentation does not cover all modifications / additions or revisions in the standard, for instance specifically on the development of ASIC's a vast work was done by the committee.

Before the IEC 61508 was written in the Oil and Gas business over-pressure protection of for instance a gas well flowing into a separator would be governed by a prescriptive standard like the API. This standard describes in detail how to design such an installation, including pipe diameters based on flow data, wall thicknesses, but also the safety system to protect the lower pressure part.

Basically the API would prescribe to install an emergency shut-down valve which would close upon high pressure down-stream of the control valve. In addition to this, a full flow flare system would be installed. This of course had limits while real big platforms off-shore might not have the possibility to burn such big quantities of gas without danger to the platform itself. In some case separate platform to accommodate the flare only would be required.

Therefore instrumented safety shut-down systems were designed, actually the API recognises this in the standard as well. But for these Instrumented systems no standards were available. The clients simply added redundant sensors and redundant final elements instead of a full flow relief valve. In general a small relief capacity remains which may then evacuate leakage of the safety shut-down valves. So these systems still relied on redundancy and actually required 3 valves in series, specifically when fast acting valves were required like in HIPPS systems.

Then in the late 90's people would start to think about how reliable these systems were and the IEC 61508 was being written.

If applied in huge steps this standard would say about HIPPS:

- In case the high pressure can severely damage the vessel and then cause injury or death to people in the vicinity of the separator.
- In case the pressure rise is rapid.

Then we assume, for the sake of this example, that a SIL3 over-pressure protection is required.

Based on the 1998 version we would then, if we forget all the other important requirements and focus on the hardware fault tolerance only, be able to apply a single final element in case the Safe Failure Fraction is higher than 90%, referring to IEC61508 table 2 architectural constraints on type A safety-related subsystems. The Safe Failure Fraction is the fraction of the safe and dangerous detected failures to all failures.

This means in case we have many safe failures and many detected failures we can reduce the number of final elements.

Over the past years this was usually done by means of a quite loose definition of a safe failure and electronic devices were added to detect dangerous failures. All this to increase the Safe Failure Fraction.

The standard is quite clear that the dangerous detected failures should be detected by what was called diagnostics. This is a term which mainly comes from the electronic foundation of the standard. In electronic systems it is quite easy to continuously measure and monitor and based on that decide if the system is still safe and still properly performing it's safety mission.

Therefore actually the result of the Safe Failure Fraction and it's implication on the hardware fault tolerance would be that now instead of having a total of three final elements in series we would end up with only one final element. Usually the sensors would still be in a 2oo3 situation while these are not type A equipment.

In 2003 the IEC 61511 was published. This standard is mainly for end-users and integrators and not for the manufacturers of elements. However this standard shows a more conservative table for the application of the number of final elements. There is actually a specific table for final elements and sensors (IEC61511 paragraph 11.4.4 table 6). This table requires a 1 out of 3 (1oo3) configuration for a SIL3 protection level. Only in case prior use can be justified this may be reduced to 1oo2.

The 2010 release of the IEC 61508 has more emphasis on the hardware fault tolerance reduction in general and more specific in the case of additional diagnostics. A paragraph is added indicating that the hardware fault tolerance shall be defined without applying diagnostics (ref. IEC 61508 para 7.4.4.1.1).

The standard also defines more in detail at what intervals diagnostic tests shall be performed. Actually several paragraphs are covering different cases, like high demand mode / low demand mode, but also the hardware fault tolerance of the element. The longest possible interval of the different paragraphs requires a diagnostic test shorter than the Mean Time To Repair of the system in case of failure, this would normally be 8 to 24 hours. The shortest interval actually would be within the process time.

For a final element often it is assumed that diagnostics can be performed by means of partial stroking devices mounted to the final element. These are devices moving the final element approximately 10% and then verify if the actuator is still capable to move the valve. While a partial stroking device usually performs the diagnostic test only once per 3 months these devices cannot be considered diagnostics within the limits of the standard.

In addition to the further definition of the diagnostics also the definition of a safe failure is much more stringent in the new revision. A safe failure is where the system goes to the safe state without a demand. This new definition is actually so clear that it can only be applied for the integrated combination of valve plus actuator which will have only one safe failure. This is the failure of the seal at the actuator, a failure of this seal would evacuate the air or hydraulic pressure and as such the springs can close the valve.

Naturally you could also think of dynamic forces that move the closing member after a stem breakage or an unbalanced valve that moves to the safe position after stem breakage, however these forces are rarely big enough to perform full closure and would make the safe failure dependent of the flow velocity. An unexpected change in the position of the final element because the solenoid would spuriously trip would be a safe failure of the solenoid and not the final element itself. A leak in the tubing or couplings would close the valve and such spurious trip would also not be attributed to the final element.

To be even more specific so-called no effect and no part failures are described as well now and may not be accounted for in the SFF calculation. These changes in the definitions have of course a serious impact to the Safe Failure Fraction of the final element.

Based on the different definitions it could even be argued that the Safe Failure Fraction is not even applicable for a mechanical component like a final element but only to systems having electronics like the sensors or the voting logic.

So even if we would argue that also for a final element a Safe Failure Fraction can be determined these more stringent definitions will significantly reduce the Safe Failure Fraction of the final element. A SFF of 90% or more would be hard to claim following the 2010 standard. In fact it will be significantly lower than 60%.

In Short conclusion:

1) HFT shall be determined by calculation of the SFF where diagnostics are not used to increase the DD

failures and to reduce the HFT.

2) The diagnostic test interval used in PFD calculation shall be at best not longer than the MTTR, hence very frequent testing is required to credit diagnostics.

3) No part and no effect failures shall not be used in the SFF calculations, SFF are basically only spurious trip failures, reducing the SFF for final element (FE) to below 60%.

For FE elements the partial stroking have become increasingly popular as feature to reduce the full stroke proof test interval. Also there are documented cases where the 'diagnostic capabilities' of partial stroking devices are credited to increase the SFF and by that reduce the HFT. However as indicated these devices cannot be considered to perform diagnostics.

While in the definition of the standard it is indicated that the target of a proof test should be to reach 100% coverage of the proof test it seems to be contradictory to the standard to mount a device that is specifically designed to perform only a partial test.

The standard does indicate that staggered tests or imperfect proof tests may be performed, however a specific justification shall be written for the assumptions that are made. The results of the tests should be documented and archived. In case the result of a proof test, or any partial proof test, is negative a shut-down should be performed. Therefore the partial stroke testing devices and the data coming from the devices are to be considered safety related.

What is also new in the IEC 61508 are the different routes to assure a proper hardware fault tolerance is applied for each application or actually SIL level. A difference is made between the use of the Safe Failure Fraction or the use of dependable failure data.

Route 1 uses the same table as in the 1998 revision and therefore uses the safe failure fraction as a basis for the required hardware fault tolerance. If we would argue that the safe failure fraction is mainly for E/E/PE safety related system where the standard is mainly written for than actually this route would not be applicable to final elements at all.

The new route 2 in the standard is based on the prior use / proven in use as it appeared in 2003 in the IEC 61511. In applications requiring a protection level SIL3 or SIL2 in the high demand mode a hardware fault tolerance of 1 and thus a 1oo2 configuration.

Proven in use is quite clearly defined in the standard. The term "proven in use" itself is quite clear, although it should be understood as "proven in your specific application". For a final element this would mean that it shall be verified that statistical data is available for the same application. The same type of process data, for instance is it fluid from a well head as the previous example or does it concern clean gas suitable for the consumer market, but also the size and rating or the material selection shall be considered.

All aspects of the applications and safety mission shall be verified, for instance It shall also be considered if the final element has sufficient statistical data for the required response time. In general it can be said that safety shut-down valves move in 1-2 seconds per inch, which means for a 12 inch minimal 12 seconds. Therefore in applications below this response time, which is the lower limit, the statistical data of the final element shall be verified. It shall be demonstrated that that specific combination of valve and actuator have sufficient experience in response time below 1 second per inch or below 12 seconds.

Basically this already applied for route 1 while also in route 1 dependable failure data are required. In all safety systems designed in accordance with the IEC 61508 sufficient confidence level shall exist that the equipment is suitable for the application.

As a conclusion it can be said that in the early days of gas treatment plants the "old" prescriptive standards would require redundant final elements. But that due to the revised definitions of safe failures and diagnostics and the addition of a new route to verify the required hardware fault tolerance the IEC 61508 also requires redundant final elements on higher SIL applications.

In addition to this it can be concluded that the use of partial stroking devices on these final elements is not recommended while the standard sets a target for a 100% proof test.

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Mr. GS Baveja
Business Development Advisor
M/s Next Gen Oil & gas Ltd.

SAFETY & AVAILABILTY – VOTING SCHEMES COMPARISON

Prema Suresh – Technip KT India Ltd. & Dharmender Singhal – Haldor Topsoe India Pvt Ltd.

INTRODUCTION

Safety is of paramount concern for any industrial processes such as refineries, oil and gas,petrochemical plants, power plants and so on. In spite of application of wide variety of safe guarding measures, many accidents in the process industries still happen today.

Some reasons for employing various safe guarding measures are protection of personnel and environment from harm, conformance to laws and regulations, increase productivity and reduce damage to equipments and so on and so forth.

The above objectives are fulfilled by the use of safeguarding systems that offer both safety and process availability. Regrettably process availability is of almost no interest in IEC 61508 and IEC 61511. Focussing only on SIL and not on preventing nuisance trips is not a good design as industry data shows that incidents are much more likely during start-up and process shutdowns.

Any well designed safety system balance both safety and availability by considering appropriate voting and high diagnostic coverage in its architecture.

Voting in the form of redundancy is used for safety and fault tolerance of the safety Instrumented system. Many a times the line between redundancy for safety and redundancy for availability (reliability) gets blurred and then the confusion starts.

There are many ways in which we can provide redundancy and voting when we build a SIF loop or a control system. Unfortunately with so many systems that are designed with various levels of redundancies and are often promoted based on their claimed ability to continue operation in case of detection of one or more failures, it is intuitively not obvious which system is more suitable for a particular application.

Here is an attempt to compare frequently applied voting schemes for Oil & Gas industries Safety systems e.g. 1oo2D, 2oo3D and 2oo4D, in terms of safety availability (PFD), architectural comparisons (fault tolerance), and nuisance trips (PFS).

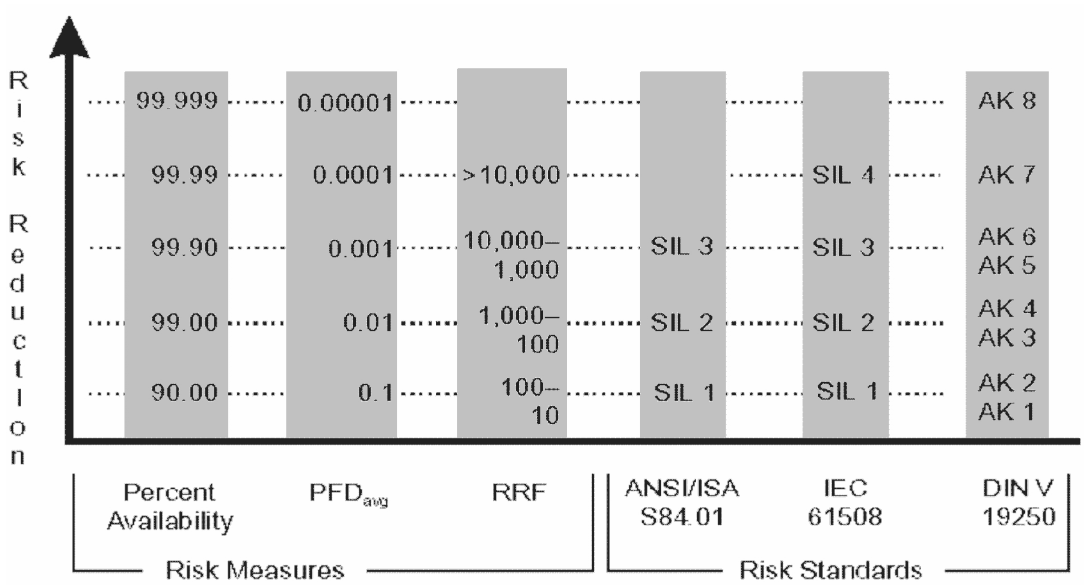
PFD calculations take into account probability of random failures, common cause failures and systematic failures. The probability of random hardware failures can be assessed from the reliability data provided by the manufacturers and are likely to only affect a single channel at a time in a multi channel system. However systematic and common cause faults could affect all the channels of a system in exactly the same way.

It will be clear from the sections below that the common cause failures contributes substantially to the PFD and PFS values and it depends on system design of various vendors that utilise these voting schemes. If common cause failures are ignored, then the conclusions could be different. It is our endeavour that the conclusions are completely independent to any commercially available vendor products or their opinions.

SAFETY INTEGRITY LEVEL (SIL):

A SIL can be considered as a statistical representation of the availability of safety function at the time of process demand. SIL are categories of Probability of Failure on Demand (PFD) for a particular safety instrumented function. These categories ranges from one to three, as defined by ISA 84.01, or one to four as defined by IEC 61508 and IEC 61511. The PFD ranges and associated Risk Reduction Factor (RRF) ranges that correspond to each SIL are shown in figure 1.

Figure 1: Safety Integrity levels and corresponding PFD & RRF (Low demand mode of operation)



FAILURE MODES:

Failure modes must be considered in systems designed for safety protection applications. Two failure modes are important: safe and dangerous.

Safe failure mode: System may initiate a nuisance trip and shut down the equipment (under control), or process plant when nothing is actually wrong. ISA 84.01 defines "safe state" as states (s) in which the equipment under control, or process, shall attain after proper operation of the SIS. There is a probability that a normally energised SIS will fail with its outputs de-energised. This is called probability of failing safely (PFS).

Dangerous failure modes are defined as failures that prevent the SIS from responding to a potentially dangerous condition known as a "demand." In this condition safety system fail to respond to an actual shut down demand (a potential dangerous condition). There is a probability that a normally energised SIS will fail with its outputs energised. This is called probability of failure on demand (PFD).

Note: For the sake of computations, the failure rates of a hypothetical single safety controller are used for all voting schemes throughout this paper and listed below.

λ_{DU}(Dangerous undetected) = 22 FITS, λ_{SD}(Safe detected) = 1872 FITS, λ_{SU}(Safe undetected) = 93 FITS, λ_{DD}(Dangerous detected) = 1034 FITS

Mission Time (T) = 8760 hrs (1 year) , Mean Repair Time (MRT) = 8 hrs (Typically 1 Shift) and Time required to restart the process after shutdown (RS) = 16 hrs (2 shifts).

FAULT TOLERANCE:

Fault-tolerance or graceful degradation is the property that enables a system to continue operating properly in the event of the failure of (one or more faults within) some of its components. Fault tolerance is normally expressed by the specific voting scheme. For example, in 1oo2 voting only one component is required to fulfill the intended safety function.

DIAGNOSTICS:

One important feature of any safety system is its ability to detect a failure and to manage the failures. This feature can be used to reduce the repair times and to control operation of several fault tolerant architectures. The measure of this ability is known as diagnostic coverage factor, which is calculated by adding failure rates of detected failures and dividing by the total failure rates. Detected failures are expected to be repaired within few hours; dangerous undetected failures are called covert failures and detected only by a periodic offline proof test. Diagnostic can only raise the level of detection of faults; it cannot increase the life span of component.

DIFFERENT VOTING SCHEMES (with typical industry examples):

ANSI/ISA 84.01 defines NooM voting as : System made up of M independent channels, which are so connected that at least "n" of the "m" channels to be in agreement before the SIS can take action.

In Oil & Gas industries following voting principles are widely used/ discussed

1-out-of-2D (1oo2 D) voting

2-out-of-3D (2oo3 D) voting

2-out-of-4D (2oo4 D) voting

(Note: The extension "D" implies for diagnostic coverage as explained in previous section).

a) 1-out-of-2D (1oo2 D) Voting

This architecture consists of two channels connected in parallel. During normal operation, both channels need to agree to execute shutdown. Therefore during healthy conditions, this acts as 2oo2 system with a few false trips. In addition diagnostics information signals are shared between two channels and this information is used to control the diagnostic switches of both channels (refer figure 2). If the diagnostic tests in either channel detect a fault then the output voting is adapted so that the overall output state then follows that given by other channel. If the diagnostics test finds faults in both channels and a discrepancy that cannot be allocated to either channel, then the output goes to safe state. Here the diagnostics of both the channels shall be independent of each other. Thus there is an advantage of 1oo2D system in terms of safety at the same time avoiding spurious trips.

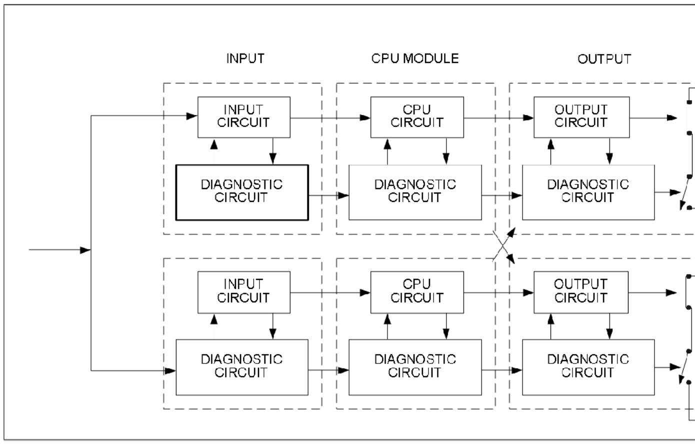


Figure-2:
1oo2D Voting Schematic

The Voting truth table which defines the different ways of failures to fail to function, nuisance trips and safe operating is shown in the Table 1.

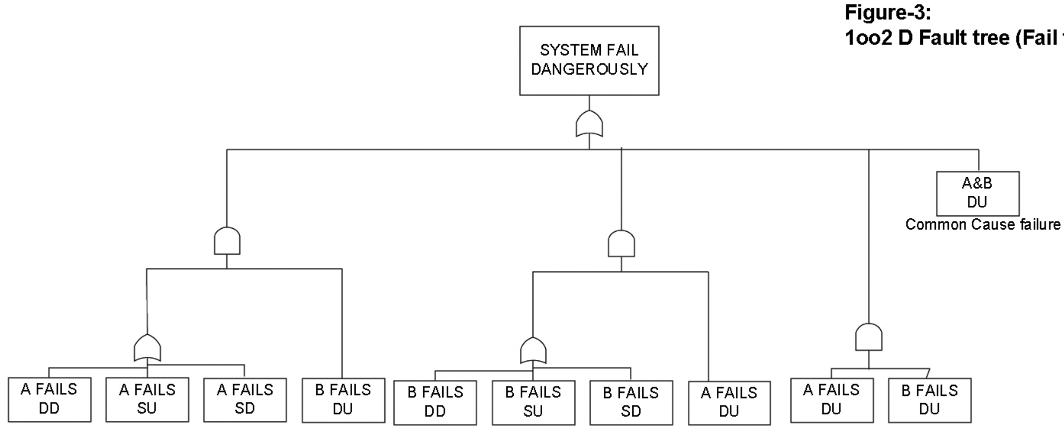
Table-1 : 1oo2 D Truth Table

S. No.	Voting	Channel-1	Channel-2	Channel-3	Channel-4	System Status
1	**1oo2D**	DU	DU	not press.	not press.	Fail to function
2	**1oo2D**	S or DD	DU	not press.	not press.	Fail to function
3	**1oo2D**	DU	S or DD	not press.	not press.	Fail to function
4	**1oo2D**	SD or DD	Healthy	not press.	not press.	Safe Operating
5	**1oo2D**	Healthy	SD or DD	not press.	not press.	Safe Operating
6	**1oo2D**	SU or DU	Healthy	not press.	not press.	Safe Operating
7	**1oo2D**	Healthy	SU or DU	not press.	not press.	Safe Operating
8	**1oo2D**	S or DD	S or DD	not press.	not press.	Trip

Note: Diagnostic testing will report the faults and would change any output states or change the output voting.

From the voting truth table, PFD Fault tree for 1oo2D and the equations for PFD shall be derived and is illustrated in figure 3.

Figure-3:
1oo2 D Fault tree (Fail to function)



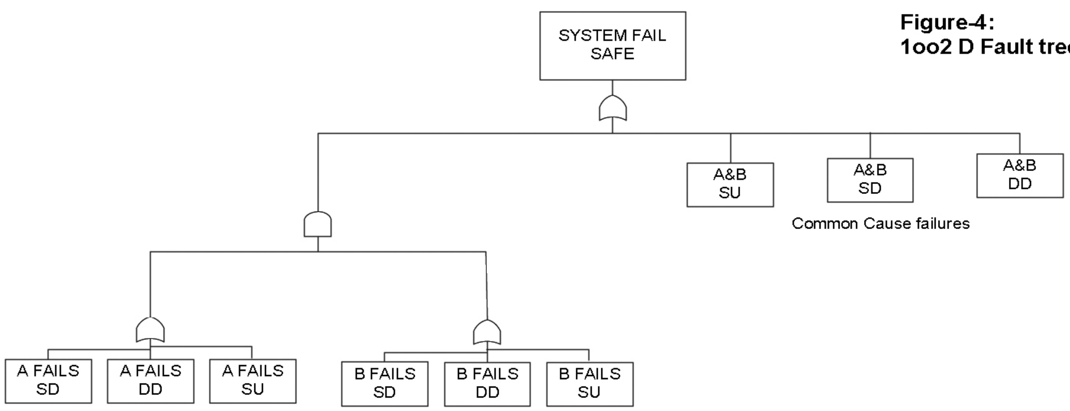
$$PFD_{1oo2D} = (\lambda_{DU} \times T)^2 + 2 \times (\lambda_{DU} \times T) \times (\lambda_{SD} \times MRT + \lambda_{DD} \times MRT + \lambda_{SU} \times T) + (\beta \times \lambda_{DU} \times T)$$

$$PFD_{1oo2D\ avg} = \frac{(\lambda_{DU} \times T)^2}{3} + (\lambda_{SD} \times MRT \times \lambda_{DU} \times T) + (\lambda_{DD} \times MRT \times \lambda_{DU} \times T) + \frac{2 \times (\lambda_{SU} \times \lambda_{DU} \times T^2)}{3} + \frac{\beta \times \lambda_{DU} \times T}{2}$$

Note : Equation for **PFD_{avg}** are derived by integrating PFD between 0 to T and dividing it by mission time value (T)

Fault Tree diagram for probability of safe failures and simplified equation derived from the fault tree (after ignoring the failure rates whose contributions are negligible) is shown in figure 4

Figure-4:
1oo2 D Fault tree (Nuisance Trip)



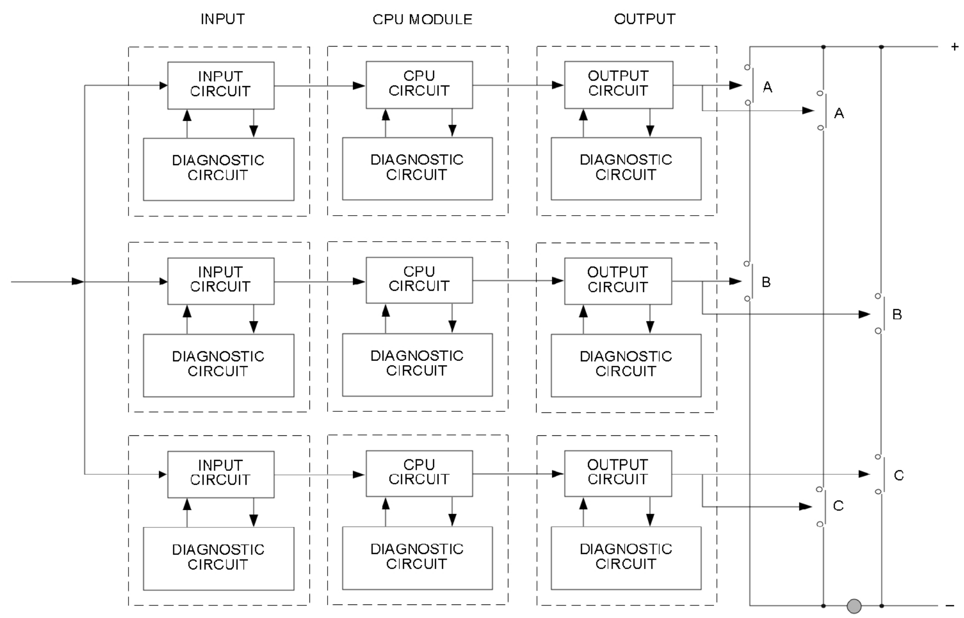
$$PFS_{1oo2D} = (\lambda_{SD} \times MRT + \lambda_{DD} \times MRT + \lambda_{SU} \times T)^2 + RS \times \beta \times (\lambda_{SU} + \lambda_{SD} + \lambda_{DD})$$

b) 2-out-of-3D Voting (2oo3 D, also called TMR or triple modular redundant)

This architecture consists of three channels connected in parallel with a majority voting arrangement for the output signals, such that the output state is changed if two channels give a similar result. Whatever two or more channel says, that's what the system does.(Figure 5)

It is assumed that diagnostic testing would report the faults found and would not change any output states or change the output voting. Other architectures for majority voting's are 3oo5 (used in nuclear industry), 7oo10 (used in aerospace) 1oo4, 1ooN (used in highly toxic processes where safety is the only concern).

Figure-5:
2oo3D Voting Schematic



The Voting truth table which defines the 2oo3D is shown in the Table 2 and the corresponding fault tree and the PFD equations are shown in Figure 6

Table-2 : 2oo3 D Truth Table

S. No.	Voting	Channel-1	Channel-2	Channel-3	Channel-4	System Status
1	2oo3D	DU or DD	DU or DD	Healthy	not press.	Fail to function
2	2oo3D	Healthy	DU or DD	DU or DD	not press.	Fail to function
3	2oo3D	DU or DD	Healthy	DU or DD	not press.	Fail to function
4	2oo3D	SD or SU	SD or SU	Healthy	not press.	Trip
5	2oo3D	Healthy	SD or SU	SD or SU	not press.	Trip
6	2oo3D	SD or SU	Healthy	SD or SU	not press.	Trip
7	2oo3D	S or D	Healthy	Healthy	not press.	Safe Operating
8	2oo3D	Healthy	S or D	Healthy	not press.	Safe Operating
9	2oo3D	Healthy	Healthy	S or D	not press.	Safe Operating
10	2oo3D	S	D	Healthy	not press.	Safe Operating (Time restriction)
11	2oo3D	D	S	Healthy	not press.	Safe Operating (Time restriction)

Note : Diagnostic testing will only report the faults and would not change any output states or change the output voting.