The 2013 World Congress on
Advances in Structural Engineering and Mechanics (ASEM13)
Jeju, Korea, September 8-12, 2013

Subsea System Reliability and Risk Management

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ABSTRACT

This study was to present the required reliability and risk based design methods and relating to standards to be asked during subsea system engineering tasks. The detail methods of reliability and risk analysis for subsea system engineering were explained as well as their limits with review results of API Recommended Practice 17N and BP Subsea Reliability Strategy. The study provided an example for reliability and risk assessment for high integrity pressure protection system (HIPPS) installed to detect abnormal high pressure surge on offshore production manifolds. A systematic approach to assign the acceptable safety level of HIPPSs was proposed based on the LOPA (Layer of Protection Analysis) and the quantitative method summarized in IEC 61508 part 5 annex C.

1. INTRODUCTION

Subsea system is installed to delivery subsea multiphase products (e.g. oil, gas, water and solids) from subsea production reservoir to surface facilities or customers safely. A typical subsea system is illustrated in Figure 1. A subsea system has following technical characteristics to be considered during design, manufacture, installation and operation phases.

- High reliability system
- High level integrity system
- Unmanned operation system
- Sever damage to environment, people, asset (If an accident occur)

A few standards and guidelines are available to design, manufacture, installation and operation. API RP 17N(Recommend Practice for Subsea Production System Reliability and Technical Risk Management) and BP Subsea Reliability Strategy give basic systematic approaches to design, manufacture, installation and operation of subsea systems based on reliability and risk management. BP Subsea Reliability Strategy gives a technical fundamental to prepare API RP 17N. Both BP Subsea Reliability

Strategy and API 17N present a required reliability and risk management techniques for subsea systems from conceptual design phase to operation.

The purpose of the study is to present the required reliability and risk based design methods and relating to standards to be asked during subsea system engineering tasks based on BP Subsea Reliability Strategy and API RP 17N. In addition, the study provided an example for reliability and risk assessment for subsea high integrity pressure protection system (HIPPS) installed to detect abnormal high pressure surge on offshore production manifolds. A systematic approach to assign the acceptable safety level of HIPPSs was proposed based on the LOPA (Layer of Protection Analysis) and the quantitative method summarized in IEC 61508 part 5 annex C.

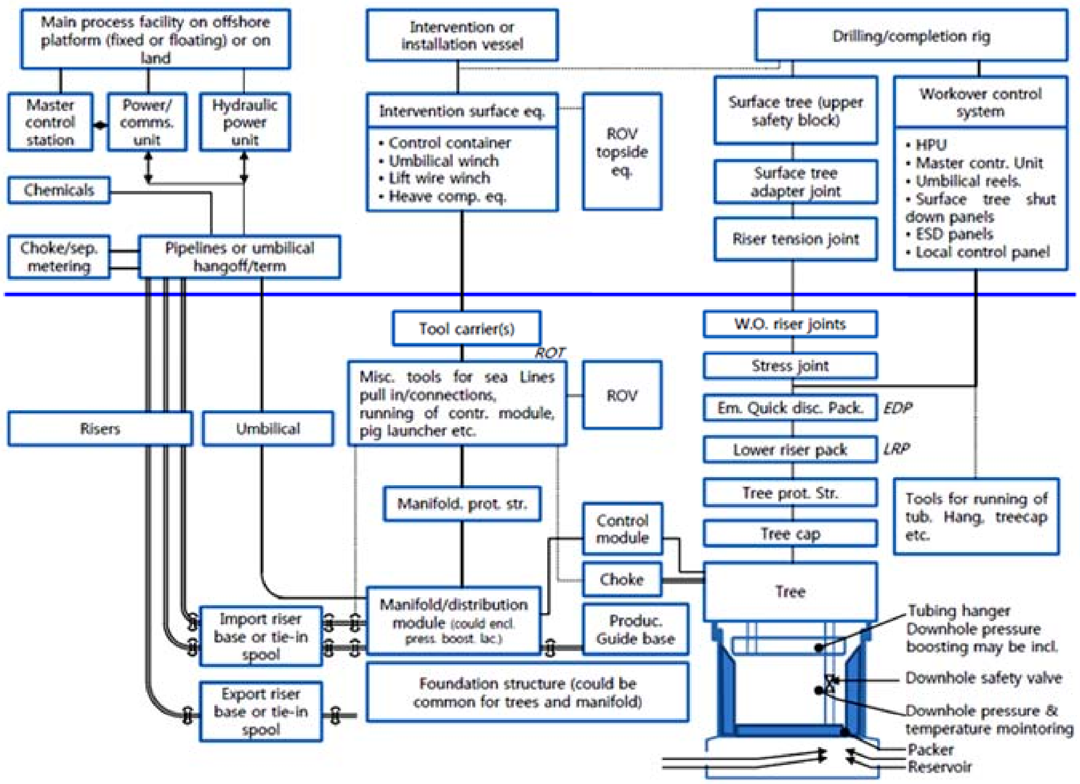

Fig. 1 Subsea system configuration diagram presented in ISO 13628 part 1

2. BP SUBSEA RELIABILITY STRATEGY AND API RP 17N

The BP Subsea Reliability Strategy recommend 13 re-liability processes to design, manufacture, installation and operation for subsea systems as followings:

1 : Definition of reliability requirements
2 : Risk and reliability analysis in design
3 : Reliability assurance

4 : Reliability verification, validation and Benchmarking
5 : Project risk management
6 : Reliability and qualification testing
7 : Performance tracking and analysis
8 : Supply chain Management
9 : Management of change
10: Reliability improvement and risk reduction
11: Organizational learning and knowledge management
12: Education and training in reliability
13: Reliability research and development

The above mentioned 13 reliability processes are linked with the overall project life cycle, from conceptual design to operation as shown in Figure 2.

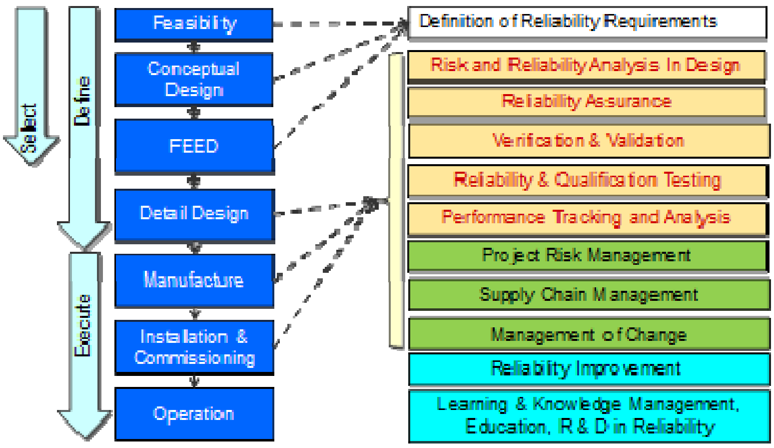

Fig. 2 Basic frame of BP Subsea Reliability Strategy

API RP 17N has a close relationship with BP Sub-sea Reliability Strategy as following.

Key Reliability Processes:
1. Definition of reliability
2. Design to achieve reliability
3. Reliability assurance
4. Verification and validation
5. Risk and Reliability Analysis
6. Reliability performance tracking
7. Reliability & Qualification testing
8. Project risk management
9. Supply chain management
10. Management of change
11. Organizational learning
12. Education and training
13. Research and Development

[BP Subsea Strategy]

Life cycle Phases addressed:
1. Feasibility and Concept Design
2. Front End Engineering Design
3. Detail Design
4. Manufacture
5. Installation and Commissioning
6. Operation
Other Issues addressed
Long term investments in reliability
Organizational issues

[API RP 17N]

The following section gives an example of a subsea system, HIPPS, how to design based on BP Sub-sea Reliability Strategy and API RP 17N.

3. SYSTEM DESCRIPTION OF HIPPS

A HIPPS is a typical subsea system installed to keep system safety against abnormal pressure rising, which is a completely independent of other emergency shutdown system or control system in off-shore production facilities. The high pressure protective function is designed to protect all pipe work and equipment from the well shut in pressure including all wellhead tower topsides pipe work, pig launching equipment, production gas export pipelines and the downstream systems.

A various requirements and verification procedures based on reliability analysis techniques should be considered during design, installation, and operation of HIPPSs as follows as a minimum:

- Redundancy with high reliability
- Speed of response
- SIL validation with IEC 61508 and 61511
- SIL verification/Reliability verification
- Safety requirement specification
- All inspection and testing services including the vendor’s factory acceptance test, system integration tests, site acceptance test
- Protective coating
- Recommended spares for start-up
- Proof test interval
- etc.

The safety requirement can be reviewed with qualitative risk assessments such as HAZID or HAZOP. The reliability requirement is usually ex-pressed as SIL through the SIL assignment and verification analysis. The various procedures can be considered to determine safety and reliability requirements for HIPPSs.

It is expected that the increasing demand for HIPPS application to offshore industry and its importance. However there are a few references avail-able for determination of the credible risk reduction performance which shall be assigned to HIPPS.

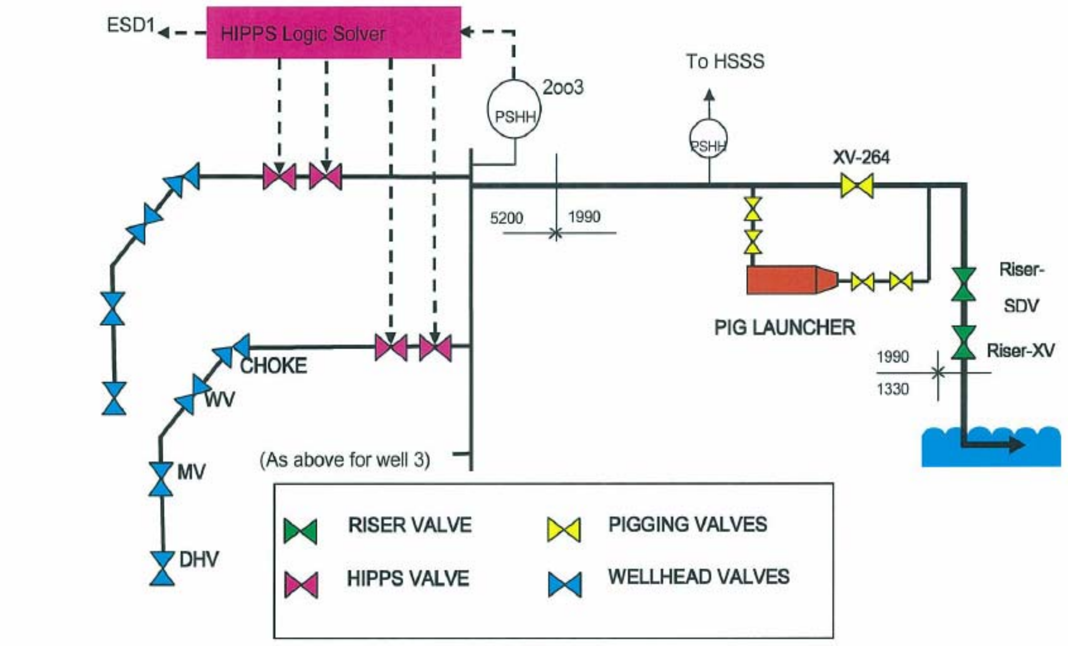

Fig. 3 HIPPS pilot model diagram

The basic function of the system is to detect high pressure on the production manifold and to reliably and quickly isolate the source of the high pressure through closure of HIPPS valves on the flow line and to initiate emergency shutdown (ESD) signal to shutdown the wing and master valves on the well-heads.
The typical HIPPS consists of the following major subsystems.

- Programmable logic solver
- Logic Solver communications module
- Pressure Transmitters with redundancy
- Hydraulic control module
- Electro-hydraulic pilot operated solenoid valves for HIPPS shutdown valve
- Redundant configuration of HIPPS shutdown valves

The schematic diagram of HIPPS pilot model for the study is shown in Fig. 3. The wellhead is provided with a surface valve block, a master valve and a wing valve. A choke valve drops the pressure to the required operating pressure. In case of abnormal high pressure occurrence, pressure transmitters detect the overpressure and initiate the closure of HIPPS valves installed in series. The action of the HIPPS prevent further pressure rise.

4. RISK ASSESSMENT BASED ON LOPA

LOPA is a simplified risk assessment to determine if there are sufficient IPLs (Independent Protection Layers) against an accident scenario. The results of LOPA can be used for the decision-making for numerical criteria and the number of IPL credits although LOPA does not suggest which IPLs to add or which design to choose. LOPA has a number of steps and the steps are summarized in Table 1.

Table 1. LOPA Procedures

Step 1:	Identification of the consequence to screen the scenarios
Step 2:	Select an accident scenario
Step 3:	Identification of the initiating event of the scenario and determination of the initiating event frequency
Step 4:	Identification of the IPLs and estimation of the PFD of each IPL
Step 5:	Estimation of the risk of the scenario by mathematically combing the consequence, initiating event, and IPL data
Step 6:	Risk evaluation

The frequency for risk estimation is calculated as follow:

$$f_i^C = f_i^I \times \prod_{j=1}^{J} PFD_{ij}$$

f_i^C:	Frequency for consequence C for initiating event *i*
f_i^I:	Initiating event frequency for initiating event *i*
PFD_{ij}:	Probability of failure on demand of the *j*th IPL

5. ANALYSIS EXAMPLE FOR PILOT MODEL

5.1 *Preparation of Input Data & Information*

As explained in Section 4, the first step of LOPA is to identify a scenario and its initiating events. The possible identified scenarios and initiating events of the HIPPS are following:

Scenario: Overpressure wellhead piping, subsea production flow line and topsides.

Initiating event:
1. Topside process shutdown initiation
2. Spurious closure of riser shutdown valve

The required information and the quantitative data for the initiating event of topside process shutdown initiation reviewed and added for the LOPA are summarized in Table 2. The tolerable frequency for the study is assumed as 5.0E-6 [1/year].

Table 2. Input summary for the initiating event of topside process shutdown.

		Frequency/ Probability/ PFD
Initiating event	Topside process Shutdown (PSD)	10 [1/year]
Enabling condition	Normal operation	1
IPL	#1: WHT occupancy	0.02
	#2: Single PSD → Close WV	0.1
	#3: Operator shift pattern	0.5
	#4: Probability of ignition	1
	#5: Pressure alarm initiation → Close WV/MV	0.0417
Tolerable frequency	5.0E-6 [1/year]	

5.2 Example of PFD$_{avg}$ Calculation for IPL

The PFD$_{avg}$ of the IPL 5 in the study is calculated based on the Fault Tree Analysis (FTA). The failure data to estimate the PFD$_{avg}$ of the IPL 5 to close the wing valve and/or master valves based on FTA model are summarized in Table 3. The PFD_{avg} of the IPL 5 is calculated as 4.17E-2.

Table 3. Failure data for estimation of PFD_{avg} of IPL 5.

Basic event	PFD
PSHH fails	5.65E-3
Communication failure	0.1
Pressure transmitter fails (HIPPS)	9.8E-5
Logic solver fails (HIPPS)	1.6E-5
Wing valve (WV) fails	2.05E-5
Master valve (MV) fails	2.05E-5
Pilot valve fails	5.65E-3
CCF WV/MV	1.43E-3
CCF pilot valve	2.83E-3

5.3 Unmitigated Event Frequency

As explained in section 5.2, the unmitigated event frequency for the topside process shutdown initiating event is calculated as follows:

Unmitigated event frequency for topside process shutdown initiating event
= Frequency of initiating event × Probability of enabling condition × (PFD of IPL 1) × (PFD of IPL 2) × (PFD of IPL 3) × (PFD of IPL 4) × (PFD of IPL 5) = 4.17E-4

The unmitigated event frequency for topside process shutdown should be added to the value for another initiating event, spurious closure of riser SDV to get the total unmitigated event frequency for personnel risk.

Sum unmitigated event frequency =
Unmitigated event frequency for topside process shutdown + Unmitigated event frequency for spurious closure of SDV = 4.17E-4 + 3.3E-3 = 3.72E-3

Finally, the risk reduction factor given to the HIPPS is determined as the ratio of the total unmitigated event frequency to the tolerable frequency.

Risk Reduction Factor =
Total unmitigated event frequency / Tolerable frequency = 3.72E-3 / 5.0E-6 = 743

The required SIL is obtained as follow:

Target SIL = 1 / Risk Reduction Factor = 1 / 743 = 1.35E-3 (SIL 2)
The SIL target figure assigned to the HIPPS is estimated as 1.35E-3 which is SIL 2.

6. CONCLUSIONS

The reliability and risk based subsea systems development be getting important with increasing in deepsea developments. There is an only high level guidance for subsea system design, manufacture, installation and operation. The existing reliability and risk management standards and techniques already used in surface facilities can be applied to subsea system development. However, the modified and conservative reliability and risk management models should be developed with the consideration of operation characteristics of subsea systems.

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