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Recent Developments in the Risk Management of Offshore Production Systems

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Abstract

The development of offshore oil and gas fields involves important investments and operational expenditures to design, build and operate production facilities. In the context of deep offshore, several risks on the level of production have to be taken into account at the design phase. Various phenomena, such as gas hydrate plugs or wax deposit (named "flow failures"), which are related to the physical nature of the fluid and to the flowing conditions, can indeed lead to important reduction of production. Furthermore, the design of the system is mainly decided at a moment where information on the nature of fluids or the reservoir itself is incomplete, and when the prediction of those phenomena is hard to realize. A rational design of the production system should then take into account uncertainties present at the moment of the decisions, through an appropriate risk management of phenomena potentially leading to loss of production. This paper gives an outline of a methodology developed by IFP to manage risk related to the production performance of offshore oil and gas production systems. This original methodology allows to take into account risk caused by equipment failures as well as "flow failures" due to undesired physical phenomena resulting from the conditions of production. The approach is based on an explicit integration of production uncertainties relating to a lack of knowledge on the reservoir, into the mathematical models describing the undesired physical phenomena. Dedicated tools lead to an evaluation of the consequences of the occurrence of such "flow failures" on the availability and production availability of the production system. The approach may finally provide a global performance evaluation and a technical and economical optimization of the production system.

Keywords: Risk management, production availability, offshore.

1. Introduction

A current trend in the development of the oil and gas industry is the search for new reserves in deepwater. In a few decades, the offshore industry has moved from depths of a hundred meters to more than two thousand meters water depth. This evolution has been allowed by the improvement of the technology, associated to the discovery of important oilfields. Nowadays, the industry is aiming at drilling and production by three thousand meters with sub-sea pipelines of more than a hundred kilometers long. Following this trend, the investment in drilling in ultra-deep-water has been multiplied by thirty in fifteen years. This evolution involves however specific technical challenges related to ensuring the production. The low temperature of the sea can cause physical phenomena such as paraffinic solid deposits in the lines or obstruction of the lines by creation of hydrate plugs. Furthermore, the development of offshore oil and gas fields involve important investments and operational expenditures to design, build and operate production facilities. The design of the system is mainly decided at a moment where information on the nature of fluids or the reservoir itself is incomplete. A rational design of the production system should then take into account uncertainties present at the moment of the decisions, through an appropriate risk management of phenomena potentially leading to loss of production.

2. Risks involved

Various phenomena, related to equipment failures or to the physical nature of the fluid itself and to the flowing conditions, such as gas hydrate plugs or wax deposit (named "flow failures"), can indeed lead to important reduction of production. As previously explained, they have to be explicitly taken into account.

2.1. Hydrate plugging

In hydrocarbon production, solid particles can form under specific thermodynamic (high pressures, low temperatures) conditions that are encountered in deep offshore (Sloan, 1998). These particles are made of water and gas and can aggregate and plug the production lines. This can happen especially during the system shut-down phases (in case of maintenance or repair operation for instance) because the fluid temperature then quickly decreases. Hydrate plugging can be prevented by adequate insulation or by circulating inert oil (called dead-oil) with no dissolved gas, to remove the production fluid, or by chemical injection. These events are very important since they can fully stop the production. Moreover, removal of hydrate plugs (for instance by depressurization) is very complicated, time-consuming and may possibly be dangerous. Indeed field experience has shown that hydrate plugs can happen on important pipeline length and cause important production losses as well as important intervention costs. Hydrate plugging is then one of the major risks to take into account in the analysis of deep offshore production systems.

2.2. Wax deposits

Paraffinic crude oils exhibit a tendency to create solid deposits along the walls of the flow lines (Burger et al., 1981). Such deposits are made of paraffinic components called wax. They appear when the temperature of the pipeline wall is lower than the temperature of the fluid. The wax deposit build-up is a slow continuous process that can progressively reduce the effective hydraulic diameter and eventually plug the lines. In order to deal with this problem, specific devices called "pigs" are sent into the pipe to clean the inner wall. The wax deposit is then retrieved when the pig is extracted at the end of the lines. This phenomenon can lead to two kinds of risks, namely a reduction of the production or a risk of blocking the pig itself in the line.

2.3. Equipment failures

Many equipments are placed both on the sea-bottom and on the platform. Such equipments can be hydraulic or electric control equipment, sensors, or actuators. Their failures have of course to be taken into account in the analysis, especially if they are located under the water, where interventions are complicated and cost and time consuming. According to the nature of the equipment failures, repair or replacement can need the mobilization of remotely operated vehicles (ROV) which are small robots, or of dedicated vessels, which may not be immediately available onsite.

3. Methodology

When studying this problem, one quickly reaches the conclusion that it is necessary to evaluate all aspects of the situation in a coupled way. Indeed, equipment failure can cause shut-down situations, which themselves will modify the flowing conditions and therefore cause flow failures. IFP has then developed a methodology of simulation of the life of the production system (Dejean et al., 2005). This methodology covers several steps :

1. identification of the risks
2. representation of the dynamics of the system
3. simulation of the system dynamics
4. integration of the flow failures in the approach
5. uncertainty modeling
6. analysis of the results

3.1. Identification of the risks

Of course, the identification of the risks to take into account is the first step of the approach. As examples, hydrate plugging and wax deposits are important phenomena that need to be taken into account into an analysis. In different cases, other physical phenomena (corrosion, slugging for example) could also be analyzed. A relevant modeling should include failures of the main equipments, which are represented on the Fig. 1.

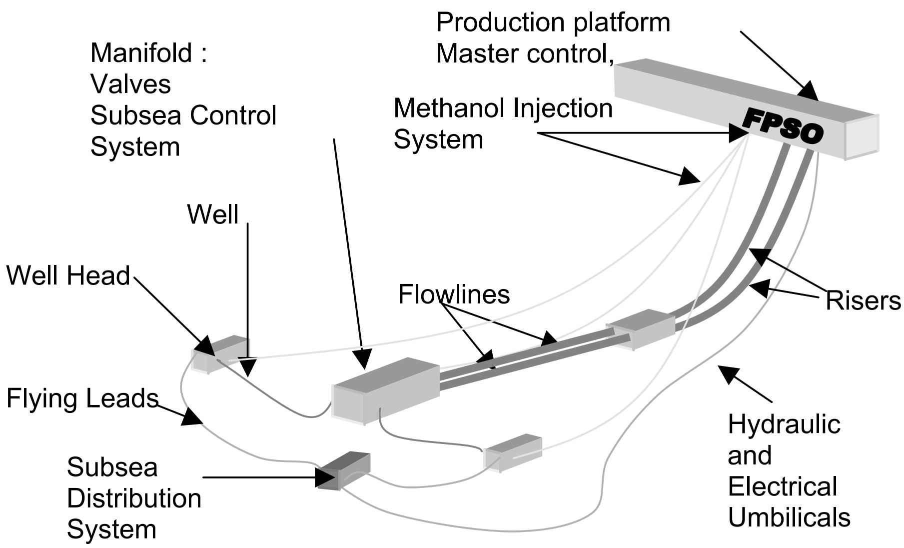

Figure 1. Representative offshore production system

3.2. Representation of the dynamics of the system

In order to simulate correctly the life of the system, it is necessary to represent its dynamics. More precisely, one needs to examine and describe the situation that the production system will encounter, when several events (such as failures) occur. Such an analysis may often be represented using so-called event-trees. An example of event-tree is given on Fig. 2., where a maintenance operation (by an ROV) of a sub-sea equipment is described. In order to derive quantitative values, one needs also to define numerical data such as delays of mobilization, of repair, probability of repair.

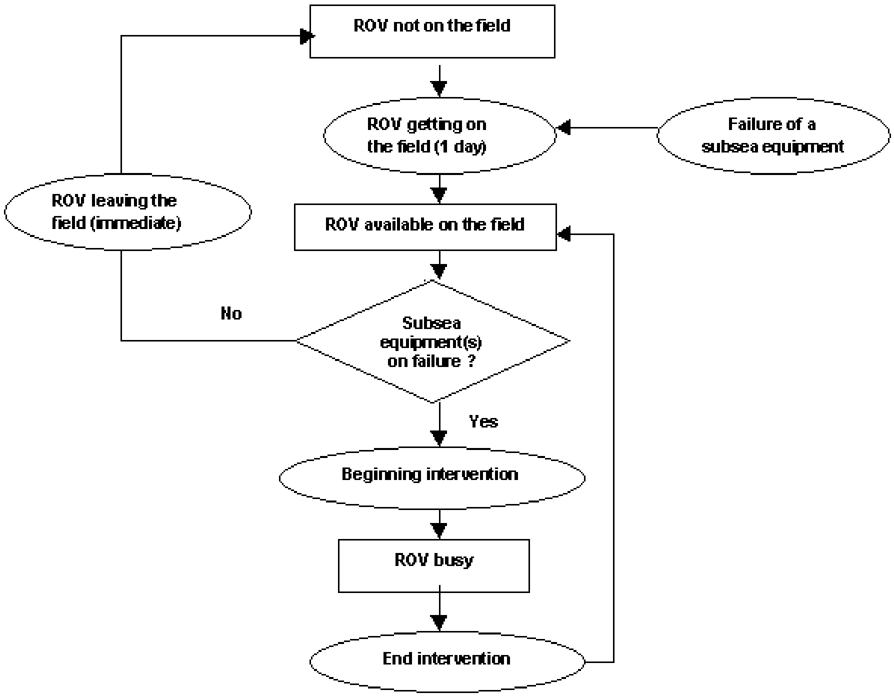

Figure 2. Event-tree for ROV intervention

3.3. Simulation of the system dynamics

In order to simulate the system dynamics and evaluate the system performance in terms of reliability, availability, maintainability and safety, one has to describe the rules that define the change of states of the system. These rules may be derived from the events trees where delays and probability of success of the actions are detailed. Afterwards, one needs to use a stochastic simulator to evaluate the system performance, in terms of deferred production, production availability (the ratio of the total effective production to the maximum theoretical production).

This may be done within the general mathematical framework of dependability. Dependability provides tools to model complex production systems and compute statistics such as availability or production availability. The most important problem for these tools is to take into account the dependencies that exist between some physical parameters (such as pressure, temperature, flow rate, etc.) of the production process and the nominal or dysfunctional behavior of some components of the production system. In our case, we have decided to use hybrid stochastic Petri nets, which provide powerful modeling tools. Petri nets (Petri, 1962) are widely known and were firstly introduced in the field of dependability for oil and gas applications in the nineties (Signoret, 1995).

Stochastic Petri nets provide advantages over other classical techniques such as Markov chains, thanks to their ability to model precisely complex systems, and especially systems with dependencies (which cannot be modeled by Markov chains). Their modeling power also resides in their graphic representation, which enables to easily model complex systems by describing the system dynamics with simple elements. These are the main reasons for the use of stochastic Petri nets in this work. Calculations were made with the commercial software MOCA-RP V12.10 that allows all necessary facilities (Dassault Data Services, 2005).

3.4. Integration of the flow failures in the approach

Integrating the events related to the "flow failures" in the modeling of the system presents several difficulties, because the physical behavior of the system may only be described by complex thermodynamics and multiphase hydrodynamics models. However, since Petri nets models require numerous Monte-Carlo simulations, one possibility that is being explored is to replace the complex models by Response Surface Models (RSM). The RSM mathematical framework helps deriving simplified models based on interpolation of complex models. In order to obtain an effective approach, experimental design techniques shall be used to limit the simulation time (Manceau et al., 2001). RSM modeling has been proven to solve this problem (Averbuch et al., 2005), and is being integrated at the moment in dependability modeling in a current international project. As an example, a given RSM will define for a given shutdown duration if a hydrate plug will form at a defined location, as a function of pressure, temperature and fluid composition. A key factor for the use of RSM is the fact that the flow failures are in limited numbers (since for instance, the locations of hydrate plugs are generally known in advance). During the simulation of the system dynamics by the stochastic Petri nets, for any shutdown situation, the stochastic simulator will then call the RSM to determine if an hydrate plug will form. Such an event would then be treated by the Petri nets exactly as an equipment failure.

3.5. Uncertainty modeling

The principle of stochastic Petri nets is to use extensive Monte-Carlo simulations by running numerous histories (up to millions), each of these histories representing a random evaluation of all stochastic variables. This approach is widely used for dependability evaluations, where a lot of variables are assumed to be stochastic (time to failure and time to repair of equipments, mobilization durations for instance). This facility may also be used to model uncertainties on other variables. In our case, uncertainties on flow parameters and on reservoir characteristics may be treated in the same way. This involves to fire at random for each history the values of these additional parameters, which will be used afterwards in all Petri nets calculations of this history.

3.6. Analysis of the results

The modeling of the dynamics of the system can provide very useful information with regard to the performance of the system. Classical performance indicators can be based on economical performance such as net present value or internal rate of return. Other information can be provided by the analysis of the history of the system. For instance, Fig. 3. represents the contributors to the production stops of the system. Such contributors can be either due to the equipment or to flow failures. The analysis of these results can then provide useful information in order to improve the system performance by adding redundancy or improving the system design.

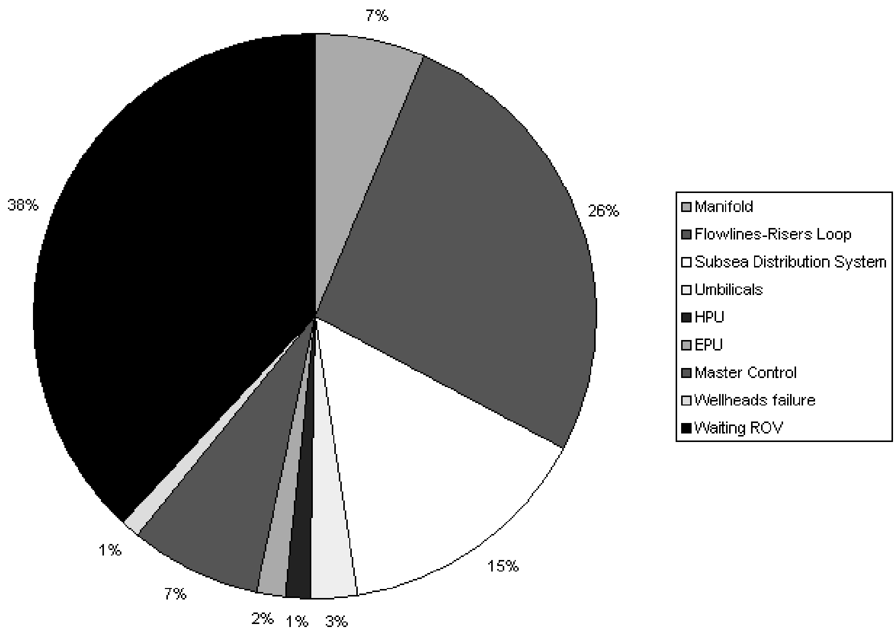

Figure 3. Contributors to the production system stops

4. Conclusion

This paper gives an outline of a methodology developed by IFP to evaluate the risk related to the production of offshore systems. It consists in several steps including a risk identification, a description of the dynamics of the system and a simulation by stochastic hybrid Petri nets. Such a modeling can allow to evaluate the economical performance of the system, as well as identifying the main contributors to the system shutdowns. Current studies are being performed to integrate the flow failures in the approach. This implies a coupling of dependability models and of physical models.

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