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MULTI-AGENTS IN THE NORTH SEA – THE CASE OF OIL AND GAS PRODUCTION

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ABSTRACT

Developing control systems for offshore oil and gas production is a challenging task, due to the complex inherent issues of the domain, i.e. changing properties of the oil and gas reservoirs, and variations in production configuration, due to new wells and production technologies. In this paper, we propose a multi-agent system with a stratified architecture that provides the necessary flexibility to meet the complexity of the domain. Finally, we discuss how the stratified architecture can be evaluated using simulation of a real production-like setup.

KEYWORDS

Multi-agent system, Oil and gas production

1. INTRODUCTION

In today's offshore oil and gas production system, operators are responsible for controlling the production equipment according to high-level directions given by offshore production engineers and onshore planners. Our case study for a multi-agent-control approach in the North Sea deals with the DONG E&P-operated Siri Area.

The Siri Area is located in the Danish Sector of the North Sea as shown in figure 1. The production installation in the Siri Area consists of the main production platform Siri, which has been in production since 1999. In addition to the main platform, there are three unmanned satellite platforms (Nini, Nini East, Cecilie) and one subsea installation (Stine). These four, so-called, tieback fields were deployed after the installation of the main Siri platform. Figure 2 shows the entire area as it looks today.

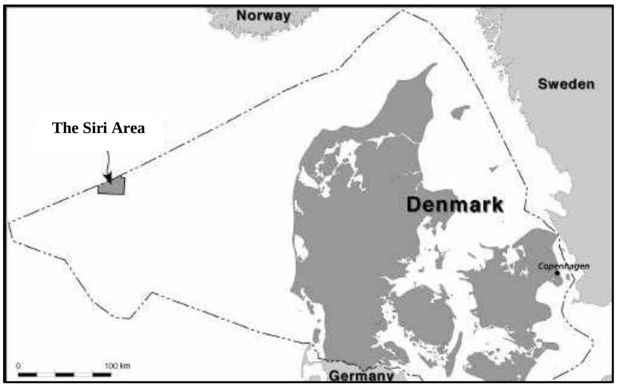

Figure 1. North Sea

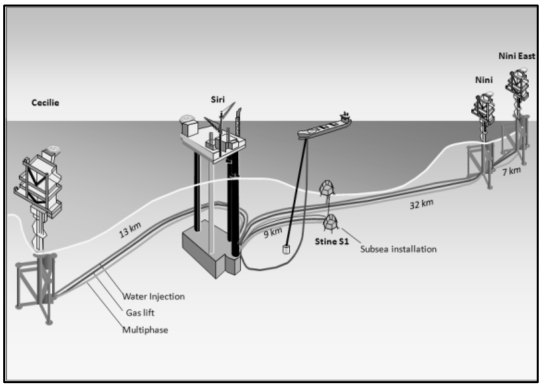

Figure 2. Siri Area

All processing equipment is located at the Siri platform and has been expanded over time in order to handle the tieback fields, resulting in a complex installation. Figure 3 depicts a conceptual process flow diagram using software pipe-filter modeling. The installation inside the dotted box is for a single field; to reflect the complete Siri Area it has to be tripled as the Siri and Stine fields are processed together. The installation outside the dotted box is the shared installation.

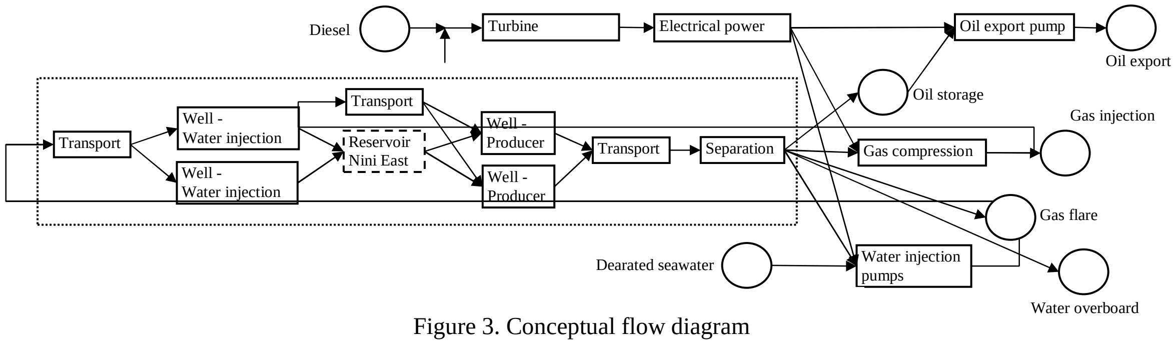

Figure 3. Conceptual flow diagram

The oil and gas reservoirs in the Siri Area are located in thin sandstone layers and are produced through kilometer-long horizontal wells. A reservoir is shown as the dashed box at figure 3. A field can consist of several reservoirs e.g. at Nini with the two reservoirs Nini Main and Nini Ty. The production requires injection of lift gas to get the production wells to flow and water injection to provide the necessary pressure in the thin sandstone layers to maintain an economically feasible production. Water injection is an effective means to prolong the life span of an offshore oil field. As the reservoirs in the Siri Area are thin they mature rapidly, thereby changing from producing a multi-phase of oil and gas to a multi-phase of oil, gas and water. The unavoidable presence of water constitutes a production problem, as it may result in slugs. Slugs are fluctuations in the flow of oil, gas and water. Handling of slugs through the individual process steps has a significant impact on the overall production throughput of the platform. Hence, production performance depends on the ability of the system operators to coordinate the control strategies of the individual process steps accordantly to the dynamic properties of the multi-phase. Furthermore, the dynamics of the multi-phase also evolves over time, and the control strategies are therefore subject to continuous changes. Such changes present a software maintenance challenge, as the control logic related to different control strategies is typically tangled and scattered across the control system's software components. Hence, any change to the control system's implementation requires a full inspection of the system's software components to ensure that the change does not conflict with any other part of the control system's logics. Also the intrinsic complexity of the domain with indirect cross-production dependencies in the environment has to be addressed, as e.g. shared limited resources like water injection, lift gas, transport and production capacity can result in unforeseen interactions.

Today, optimization is done offline, resulting in relatively fixed production schemes, which is suboptimal. Several optimization studies indicate that an increase in production throughput would be possible, if a more flexible approach to control was taken. Hence, there is a need for developing high-level decision-support systems, which allow the dynamics of the production processes to be explored in real-time. There are emerging works in the field, such as the work of (Bieker et al., 2006) who promote a scheme that uses a mathematical model of the plant for closed-loop real-time optimization. The main issue for this approach is to have a valid mathematical model in a dynamic production environment. Other preliminary decision-support (Ølmheim et al., 2010), and distributed optimization (Wartmann et al., 2008) have also been tested.

However, as none of these approaches have the ability to provide the required flexibility for handling the changing operational conditions of evolving oil and gas fields, we propose to bridge this gap by using a stratified multi-agent architecture. The proposed architecture makes it possible to adapt to new operational conditions, as it will be possible to introduce and remove control strategies dynamically without the need to modify and to inspect existing strategies, as the multi-agent control system takes responsibility for coordinating these dynamically.

2. MULTI-AGENT SYSTEM

To meet the challenges of controlling a dynamic offshore oil and gas production environment, a multi-agent system with the characteristics of natural decomposition of action, perception, and distributed problem solving seems to be a promising approach (Demazeau, 1995), as it provides the required flexibility. The first example of applying a multi-agent system approach to control production can be found in the ARCHON project which proposed to encapsulate entities with a cognitive layer (Jennings et al., 1996). Intelligent Manufacturing Systems have also shown the benefits of multi-agent systems for flexibility (Bussmann, 1998). In our system, perception of the environment will be achieved through the existing control system's sensor-system which provides a comprehensive number of measuring points from downhole pressure and temperatures to top-side flows, pressure, temperatures etc. The multi-agent system will also have the option to perceive the run-time state of the processing installation e.g. running pumps, compressors. Using distributed problem solving, we argue that it will be possible to adapt new production configurations and philosophies. The intrinsic tangling of control strategies in today´s control systems is especially a problem when new control strategies or production configurations, which could not be foreseen in the initial design phase, are introduced at a later point of time.

3. STRATIFIED MULTI-AGENT CONTROL SYSTEM

In our approach, the whole offshore installation and process is included, as there are several important cross-production dependencies and resource conflicts herein, which potentially can be handled by emerging behaviors when using a multi-agent system. During our domain analysis, we identified the following properties, which made us propose a stratified multi-agent system with three architectural layers:

1. A strategic layer handling planning with goals in the range of days/weeks/months/years
2. A tactical layer handling allocation with goals in the range of hours/days
3. A operational layer handling optimization with goals in the range of minutes/hours

Real-time control is handled by the existing control system e.g. PID (**P**roportional–**I**ntegral–**D**erivative) control loops, and is therefore excluded from figure 4. Figure 4a depicts the three layers with goal input and interface to the installation. Figure 4b indicates the roles of today's onshore planners, offshore production engineers and operators.

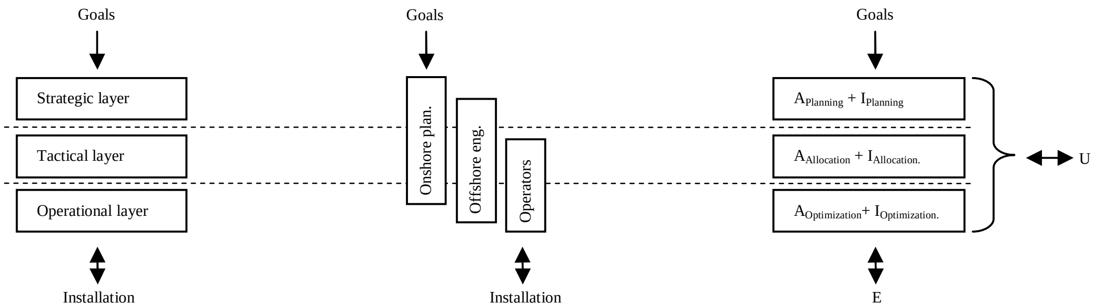

Figure 4a. Layers   Figure 4b. Overlap of roles   Figure 4c. Layers & VOWELS concepts

As seen in figure 4b there is an overlap of roles which potentially can lead to conflicts. It is these conflicts that have to be untangled and made subject for negotiation in the MAS (multi-agent system). Figure 4c shows our three layers using VOWELS formalism (Silva and Demazeau, 2002). VOWELS is used to decompose multi-agent systems into five components: **A**gents, **E**nvironments, **I**nteractions, **O**rganizations and **U**sers. It is appropriate here even if other alternative classical formalisms could have been also considered. The $MAS_{Opt.} = (E + (A_{Opt.} + I_{Opt.}) + U)$ handles optimization of the environment e.g. wells, separators, gas compressors, water injection pumps. The $MAS_{Opt.}$ has to have resources allocated e.g. lift gas, injection water, production capacity by the $MAS_{Allocation}$. $E_{Alloc.} = MAS_{Opt.}$ giving $MAS_{Alloc.} = (MAS_{Opt.} + (A_{Alloc.} + I_{Alloc.}) + U)$. The $MAS_{Planning}$ handles the global planning e.g. maintenance, production and injection plans, offload activities, where $E_{Plan.} = MAS_{Alloc}$. The first analysis of the proposed stratified multi-agent system indicates that it will be beneficial to have the three MASs wrapped in a facilitating MAS handling e.g. conflicts and system transparency.

Our generic modeling approach allows the system to be deployed in other oil and gas fields. The modeling is based on a more fine-grained process flow diagram than the conceptual diagram shown at figure

3, as the flow diagram consists of wells, pipelines, heaters, risers, separators, oil-handling equipment, gas compressors and water injection pumps. The information gained by the flow diagram is limited to equipment used and direct dependencies. Based on the proposed stratified architecture, the flow diagram and domain knowledge about indirect dependencies, we can create an impact-and-conflict diagram. An impact-and-conflict diagram is used to organize the control concepts and show how they impact other control concepts. Figure 5 depicts a small part of the Siri Area, i.e. the satellite platform Nini East with reservoir.

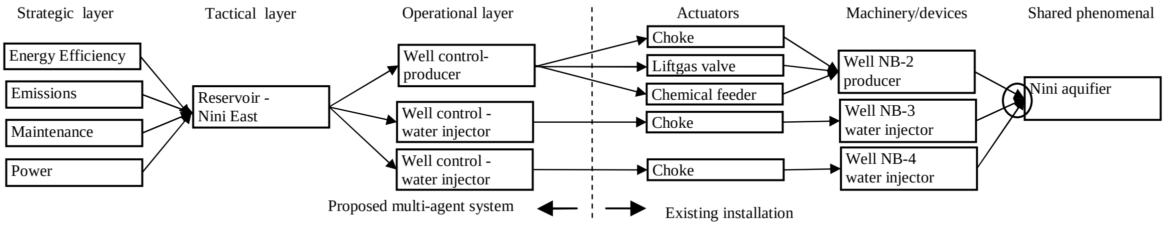

Figure 5. Impact-and-conflict diagram

The diagram can also be used to identify potential conflicts; it is where the arrows meet. As an example there is a potential conflict through the indirect dependency in the Nini Aquifer, marked at figure 5 by a circle. The water below the oil and gas in the reservoir is called an aquifer and helps to push the oil to the production wells. In the case of the Nini East aquifer the indirect time dependency is in the range of a month, which indicates that the control should be handled at the strategic layer. The Nini East and Nini aquifer are very slow compared to the other aquifers in the Siri Area, e.g. the Stine aquifer dependency is down to hours. Conflicts can occur at all layers and their nature can be very complex. Therefore, conflicts have to be thoroughly evaluated and control strategies put in place to handle them accordantly. However, this can involve new control strategies at several layers. The focus for the rest of this section will be water injection at Nini East, as this compressed example can illustrate how the control concepts will be implemented as a number of independent agents. Each agent is handling a single control strategy to ensure clear separation of individual control strategies hereby providing the required flexibility.

Figure 6 depicts the three layers of the proposed multi-agent system for the water injection at the Nini East. The semantic of the diagram of figure 6 is as follows: the boxes with dotted lines are the three negotiation contexts, the "opened" circles (white) are outputs and they are open for negotiation, the closed circles (black) are inputs and they are closed for negotiations, whereas the boxes with solid lines represent agents. The strategic layer handles the long-term planning based on strategic considerations. As an example with regards to water injection at Nini East there is a power issue when exporting oil, as the total electrical power available does not allow full gas compression, water injection and oil export simultaneously. This issue has to be handled at the strategic layer and not at the tactical layer as water injection impacts the long-term production ability and eventually the environment. A number of protocols used for negotiation running in cooperative mode have to be tested. The outputs from the strategic layer are production strategies, availability and priority plans. The tactical layer allocates the resources in respect of availability, production strategies, priority, operational and production constrains e.g. pumps out of service, current flow-rates, and process stability. The protocol used for negotiation at this level is based on constraint solving in cooperative mode. The outputs from the tactical layer are resource allocations and goals. The goals

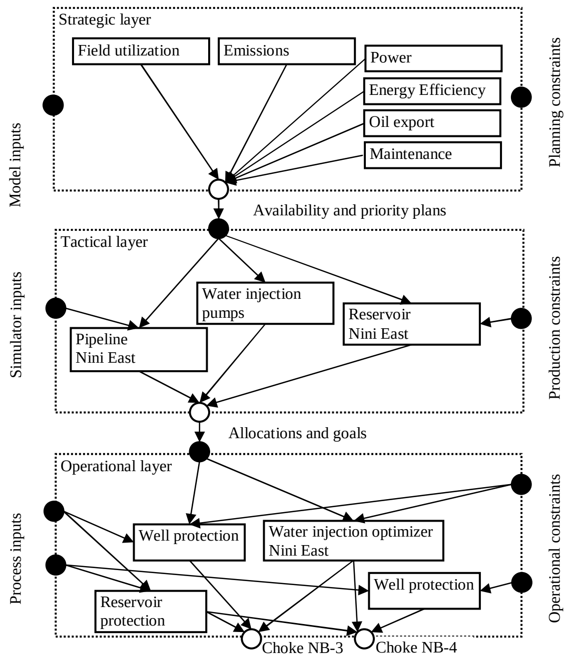

Figure 6. Stratified MAS for water injection at Nini East

will be given a Quality of Service index: $goal_{QoS}$. The execution layer will perform runtime optimization and the negotiation is in a competitive mode where the $goal_{QoS}$ will give the agents room for competition. As the different responses of the aquifers are examples of $goal_{QoS}$ for the water injection.

Mechanisms to identify hard conflicts and propagating them to a higher level have to be developed, so that constraints can be changed for the lower level MAS.

4. EXPERIMENTAL VALIDATION

The multi-agent control system can be evaluated during development using production simulation based on existing models from the domain. The simulation will provide production and process data allowing us to measure quantitatively how well our approach performs, before the system may be tested at the Siri platform in a live production environment giving the operators decision support. In the long run production simulation can be used by users to run if-then scenarios. As DONG E&P continuously aims to optimize production there is an ongoing effort in developing new production methods and control strategies. These new methods and strategies will continuously be used to evaluate our stratified multi-agent control system.

5. CONCLUSION

With a stratified multi-agent control system we expect to meet the requirements of today and handle the challenging tasks of tomorrow with a smaller environmental impact and a better economical outcome. A stratified multi-agent control system has been proposed to meet the continuously changing operational conditions on the oil and gas fields in the North Sea. The success criterion of the described stratified multi-agent control system is to demonstrate, in a realistic simulation of the Siri production platform, that it is possible to introduce new and replace or remove existing control strategies at all layers of control without the need to rewrite or test existing code.

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