Fast and safe subsea control structures, based on approved conventional technologies

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Motivation

Increasing demands for hydrocarbons make exploration and production activities in ultra-deepwater areas (≥1.500 mwd) with huge step-out distances more attractive and remunerative. These areas are often characterized by harsh environments and/or ice coverage. As result modern production techniques work with completely submerged facilities and do not employ surface piercing fixed or floating platforms. Latest developments are made for the north part of the North Sea (Figure 1) as well as the Barents Sea (Snøhvit, Statoil).

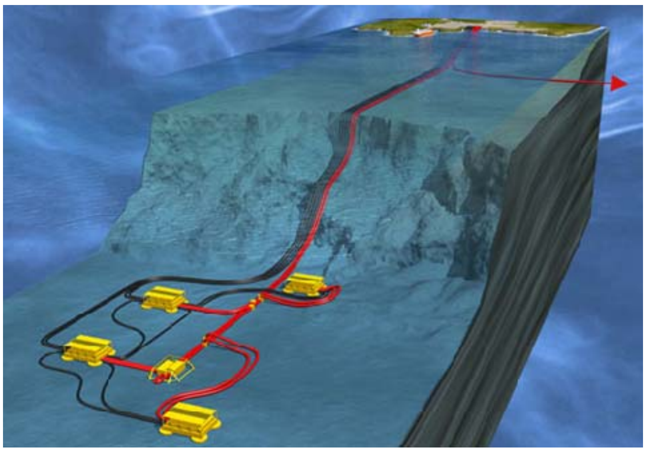

Figure 1: Scheme of a modern subsea production facility = no surface piercing offshore platform (Ormen Lange, StatoilHydro)

The companies IMPaC Offshore Engineering, Aker-Wirth, Bornemann and the IPR (part of the Karlsruhe Institute of Technology, KIT) followed this trend and participated in the ISUP project (Integrated Systems for Underwater Production of Hydrocarbons) which was partly funded by the German Ministry of Economy and Technology (BMWi). Aim of the project was the conception of an innovative underwater production system for hydrocarbons, the so called technology platform, as well as the development of certain new components and subsystems which were focused by dedicated subprojects:

- a modular extendable installation and assembly platform (Aker-Wirth)
- a multifunctional, partly autonomous Seafloor Working Unit (SWU) for installation, operation, enlargement and dismantling tasks (Aker-Wirth)
- a multiphase booster pump to increase the production rate and for flow assurance over long distances to the processing plant (Bornemann)
- a multiphase booster motor to locally produce power for subsea application (Bornemann)
- a modular distributed control and automation system (dCAS) (IMPaC) with remote diagnosis abilities (IPR)

The project lasted three years and was finished with an impressive demonstration of the results end of 2009.

IMPaC-dCAS - Key features

Within the scope of the ISUP project IMPaC developed an innovative control and automation system for the whole production facility called "IMPaC-dCAS" (distributed Control and Automation System).
Due to the electric power supply and the high-speed data transmission abilities this system satisfies requirements defined by the "multiplexed electro-hydraulic" or "all electric" class of control systems (refer standard ISO 13628-6). Based on fiber optic (F/O) lines in the supply umbilical and subsea Ethernet switches these systems today offer a transmission bandwidth up to a Gigabit allowing to connect complete subsea production plants with high information density in (near) real-time to the onshore receiving plant with a step-out distance of 100 km and more. Advantages are e.g. very short reaction times for valve and choke actuation as well as reduced risk of hydraulic oil leakages compared to conventional hydraulically controlled systems.
The key priorities to the control system are safety, availability and reliability resulting in a redundant software and hardware architecture.

Figure 2: Local Control Room with web based SCADA (IMPaC)

In the concept all major subsea field development modules like e.g. XTree's, manifolds, (multiphase-) pumps, (wet gas-) compressors and separators are equipped with so called "Orange Boxes", the Subsea Electronics Modules (SCM) providing the underwater part of the control system. In addition the land based control centre of the dCAS is equipped with a state-of-the-art SCADA environment (Supervisory Control and Data Acquisition) with the interactive HMI (Human Machine Interface) (Figure 2).
The redundant software and hardware structure used in all dCAS components ensures secure data transmission and provides functions for remote diagnosis and remote control.
As one key facility of the Underwater Production System (UPS), the IMPaC-dCAS control system shall be responsible for the safe and reliable data distribution, control and automation of the production, resulting in a more effective and economic operation. Thus all features required for a state-of-the-art (near) real-time asset management strategy for the underwater process plant can be made available.
The dCAS uses future-proof components and subsystems with fully ‚open' (standardized) architecture and interfaces to provide a sustainable and resource-friendly production technology. Thus the system facilitates a maximum degree of integration allowing a variable set-up of subsystems so that the IMPaC-dCAS is generally (easy) integrable in existing systems or new concepts.

dCAS for subsea – the caged "Orange Boxes"

The dCAS subsea modules are designed to work in ultra-deepwater. For cost effective maintenance these modules are wet replaceable due to the use of latest wet mateable connector technology for power transfer, standard data transfer as well as data transfer with high-bandwidth based on single or multi mode fiber optic technology.

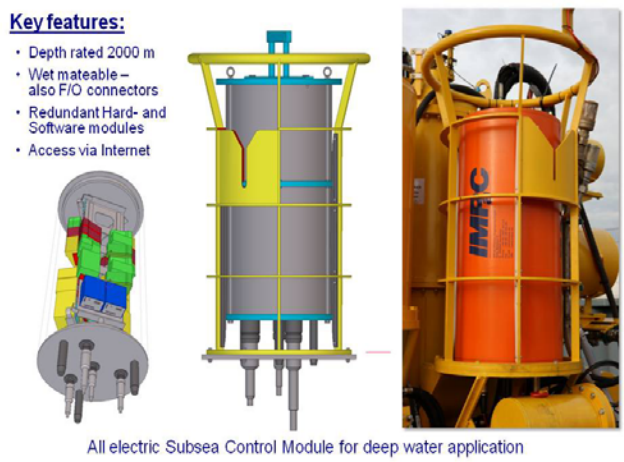

Figure 3: dCAS subsea box with installation cage from 3D design to the real test system (IMPaC)

By definition the dCAS is an open system so all relevant types of connectors defined by any client specific application can be generally integrated.
The currently selected family of connectors is rated for use up to full ocean depth. As consequence the overall water depth rating of the dCAS subsea modules depends on the strength of the pressure resistant and water tight cylindrical housing only.
The kernel of each subsea box comprises electronic modules for uninterruptable power supply, programmable logic controller (PLCs), digital and analog inputs and outputs as well as the Ethernet network switches. The switches are equipped with single mode F/O interface sockets to allow data transfer with high bandwidth over step-out distances up to 100 km and more.
The type and number of each electronic component can be widely adapted to meet specific application needs. The hardware used in the ISUP dCAS (test) application follows a strict regime of simplicity with maximum reliability. To gain optimal system availability all relevant functionality is equipped with redundant hardware components. Only the specialized safety PLC is - by definition - not redundant implemented. To meet the ISUP specific requirement of a fully open architecture off-the-shelf components meeting highest German industry standards were used; in the current stage of development no custom made or modified hardware was employed. Nevertheless, it might be necessary to replace certain components with especially designed and tested units to meet the requirements of a long-term housed subsea application when it comes to real world implementation – refer comments given below in chapter 'Tests with the Demonstrator' for details.

SCADA and Human-Machine-Interface

Professional SCADA environment software was developed as frontend to the control and automation system. The SCADA contains the Human-Machine-Interfaces which are developed with a hierarchical architecture. The general idea is to enter the system from top to bottom, from the overview to the detail views.
Referring Figure 4 the SCADA concept considers all different 'intelligent' subsea aggregates in the process control layer as well as the different clients and asset manager (operating/ monitoring layer) served by the HMI surfaces (Figure 5). These instances are grouped around the data management kernel where the standardized OPC data exchange servers, the servers for the mirrored process database and the video data server are concentrated. All data are subject to problem specific logging, alarm or online handling allowing initiating and focusing on case dependent information and reaction procedures of the operator.

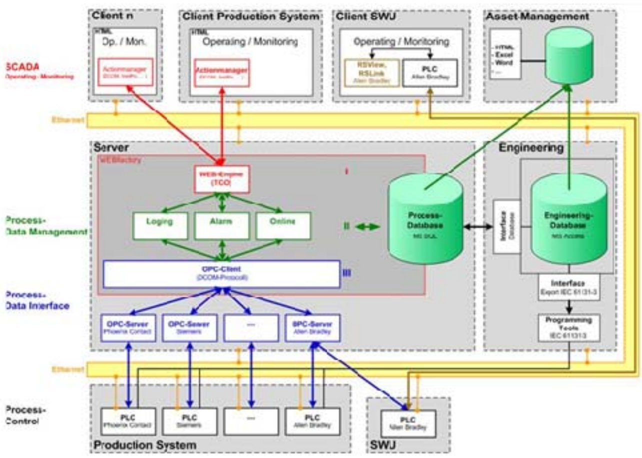

Figure 4: Concept of the web based SCADA (IMPaC)

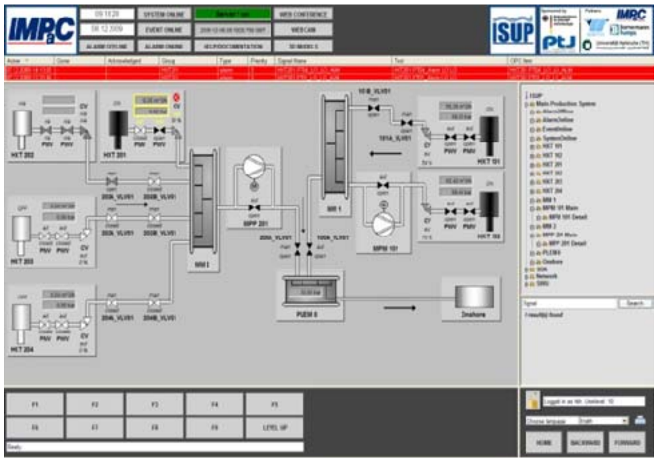

Figure 5: Exemplary HMI surface of the ISUP SCADA (IMPaC)

Access to various HMI user levels is organized by means of an authentication procedure allowing distinguishing between the different purposes of e.g. software service technicians, process operators as well as business managers.
The programming of the SCADA and the HMI surfaces follows standards like IEC 61131-3.

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Oil and Gas production via Internet?

Bi-directional communication between the production facilities with its various sensors and information levels and volumes as well as between these structures and the local and global control centers is basic for a sustainable asset management. The IMPaC-dCAS provides the hardware and software components and functions needed to realize a high potential communications network. Again it was essential to use today's standards for the development of the communications architecture within the ISUP project.

The system basically connects the (subsea) Local Area Network (LAN) build by the infield dCAS boxes mounted to each of the 'intelligent' process facility modules with the operators and worldwide located client applications (Figure 6). Safe access is realized by firewalls implemented at both 'ends' of the public network, the Internet. An encoded dialog is organized with authentication and establishment of Virtual Private Network (VPN) gateways where an encapsulated Internet Protocol (IP) package control takes place.

Due to the high bandwidth (in the current stage up to a Gigabit) it is possible to remote control even the video assisted complex operations of unmanned vehicles and tools like the Seafloor Working Unit (SWU) from Aker-Wirth (Figure 7).

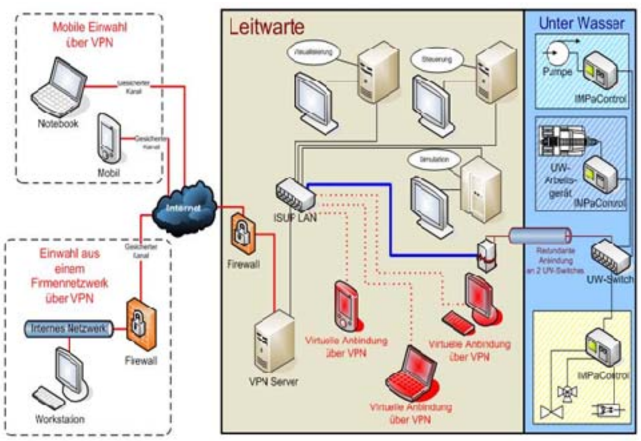

Figure 6: Concept for the safe communication via Internet using VPN (IPR)

Tests with the "Demonstrator"

The ISUP project comprised specific Factory Acceptance Tests (FAT) for each subsystem developed by the project partners. After that the SWU from Aker-Wirth, the new designed multiphase pump from Bornemann as well as a XTree dummy and the operator environment from IMPaC were arranged in a set-up called the 'Demonstrator'. These main subsystems were equipped with identical dCAS subsea boxes from IMPaC. For the Demonstrator the SWU and the XTree dummy were transported to a shallow water test area at the Blohm+Voss ship yard in the harbor of Hamburg (Figure 7). Only the pump was installed in a test basin at the remote Bornemann facility in Obernkirchen near Hannover, which is about 200 km away from the Hamburg test area. In addition the colleagues from IPR were online at its offices in Karlsruhe (distance to Hamburg approx. 620 km). They acted as 'external experts' and were implemented in the tests and during the presentations with their remotely running simulations and diagnosis tools. Each subsystem was connected via its dCAS box and F/O cables either directly or via Internet with the operator place (located in Hamburg). Thus the configuration of the different test locations used for the Demonstrator represented a very huge 'production area' and Internet based client structure, respectively, almost comparable with realistic field scenarios.

Figure 7: The IMPaC-dCAS subsea boxes with the Seafloor Working Unit from Aker-Wirth during trials

Aim of the tests with the Demonstrator was to get validation of the functionality of the implemented mechanical, electrical and data interfaces and the proper high-speed data distribution – especially when used with wet mateable underwater connectors - as well as to establish a first exemplary network build by the dCAS in a heterogeneous application.

During the tests relevant control values of the new designed multiphase pump as well as a basic test version of a multiphase motor was made available and online implemented as dynamic data in the SCADA. In parallel an online simulation of basic physical processes were simulating the effect of e.g. opening and closing of valves determining changes in pressure and velocity of the fluid in the flowlines. A remote diagnosis algorithm working with the real values provided by the multiphase machines started to determine the process dependent remaining system availability. All these data were safely transferred between the different test locations by means of the dCAS and its data management system.
Although these tests were carried out with good success important and required tests are still needed to meet the market needs: shock tests, vibration tests and temperature tests, partly coming as long time tests (refer standard ISO 13628-6).

Conclusion

The project ISUP was dedicated to the development of a new modular underwater production system as well as certain exemplary subsystems providing a simplified test application for this system. As part of the ISUP system the distributed control and automation system (dCAS) developed by IMPaC uses standardized interfaces, programming languages and functions wherever possible and feasible. Also standards with regard to reliability, availability, lifetime, maintainability and HSE requirements were taken into account (e.g. IEC 61131, ISO 61508, ISO 13628).
All relevant components and functions are redundant to provide a high level of availability. Its state-of-the-art fully open architecture provides web based (near) real-time access to any subsea production facility equipped with the dCAS "Orange Box". Thus the operator and any of its externally located experts will be able to perform an efficient asset management based on high-speed data transfer with up to Gigabit bandwidth.
The new dCAS provides remote control, automation and diagnosis capabilities for the whole subsea production plant enabling modern subsea-to-beach applications with access from all over the world via safe internet infrastructure.

Acknowledgements

The authors wish to express their gratitude to the German Federal Ministry of Economics and Technology (BMWi) and Project Management Jülich (PTJ) for funding the joint research project 'ISUP — Integrated Systems for Underwater Production of Hydrocarbons' (FKZ 03SX229).
Special thanks also to the colleagues from IPR (Karlsruhe Institute of Technology) for fruitful discussions and cooperation in the specific fields of safe data transfer, data management and remote system diagnosis.
The authors want to acknowledge the contribution of all project involved colleagues from Bornemann, Aker-Wirth and IMPaC.

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