SUBSIS – world's first subsea separation and injection system

SUBSIS is a subsea separation and injection system from ABB, developed to increase recovery and improve the economics of offshore oil and gas fields while also having a positive impact on the environment. The key task of SUBSIS is to separate the bulk water from the wellstream and to treat it for either discharge into the sea or re-injection into the reservoir. A full-scale pilot plant will be installed in Norsk Hydro's Troll field, in the North Sea, in 1999. ABB is already planning a next-generation subsea process plant with the aim of producing directly to shore. Modularized and self-contained, it will set new standards for the economic and environmentally friendly production of oil and gas.

There are strong signs that the traditional offshore oil and gas industry is becoming mature; several field developments have already passed their production plateau, while new finds seem increasingly difficult to exploit. Typically, the older fields also produce large amounts of formation water. Countering this trend is a drive to increase field lifetime, utilize the existing infrastructure better and get more out of the reservoirs. New field developments, on the other hand, are designed for higher recovery from day one, with innovative technology also utilized to a much higher degree than before.

Increased recovery is one of the key forces driving the market today. Subsea three-phase separation, with re-injection of water and/or gas and fluid flow boosting, is an area with considerable potential for increasing recovery and improving the economics of subsea fields over their life-cycle. The same systems also offer potential for a substantial reduction in the environmental impact of oil and gas production.

Troll Pilot contract is awarded

In January 1996 ABB launched a development project, called SUBSIS for Subsea Separation and Injection System, with a total budget of more than US$ 10 million **1**.

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ABB Corporate Research, Norway

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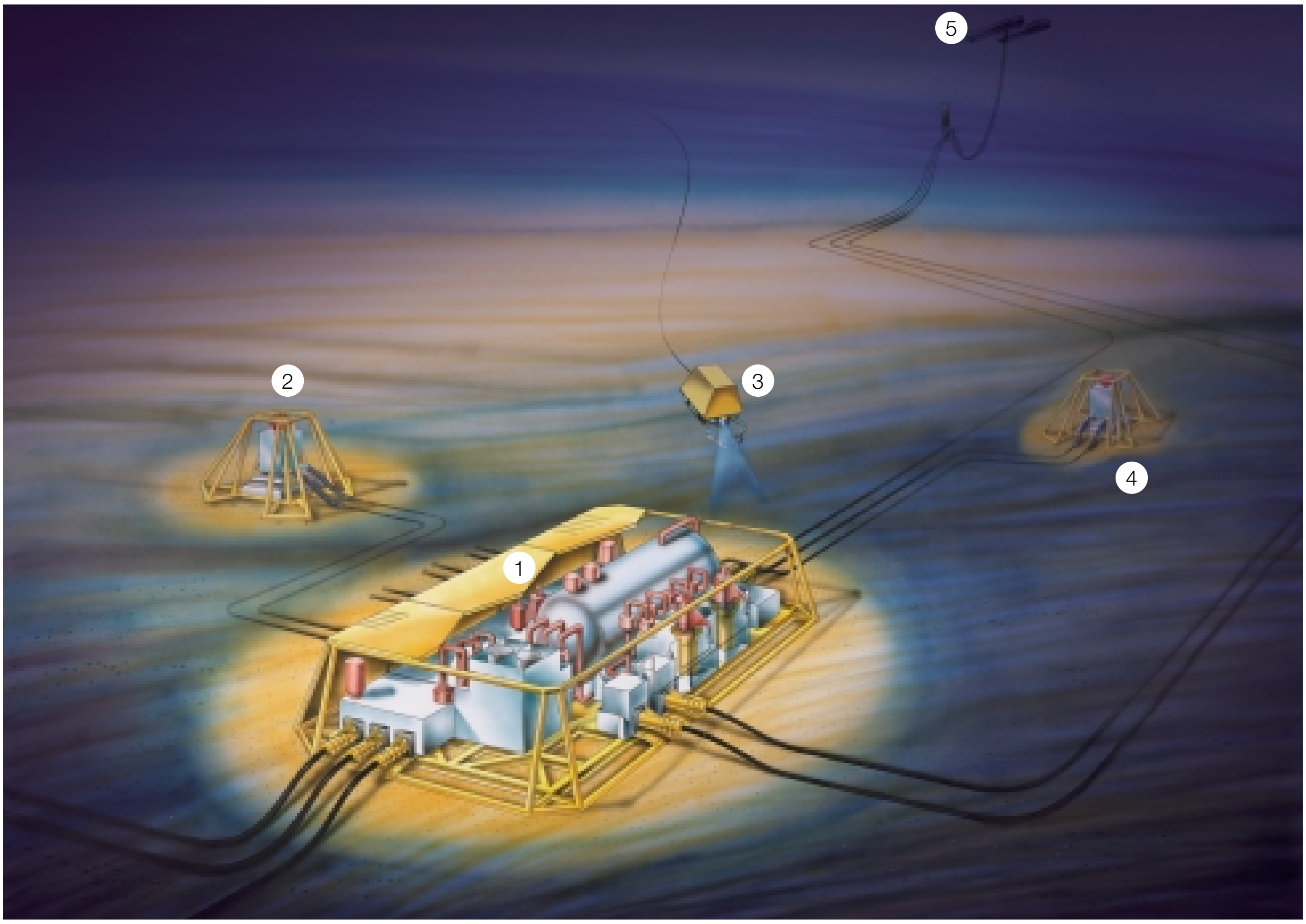
The project started out as a so-called High Impact Project, or HIP. At the start the main participants were ABB Offshore Technology and ABB Corporate Research in Norway, other partners, such as ABB Seatec, ABB Industry, Norsk Subsea Cable and Framo Engineering, joining as the project progressed. As a result of this initial work, the world's first commercial contract for such a system – the Troll Pilot subsea separation project – was awarded by Norsk Hydro in June 1997, with delivery due in late 1999. The contract, which is worth US$ 25 million, also includes options for six additional systems. Most of the major international oil companies are currently evaluating subsea separation for old as well as new field developments.

This project and the associated work have led to the establishment of a new business group within ABB Offshore Technology focusing on subsea processing and related technologies. ABB Corporate Research acts as a technology partner in these business activities.

The project as well as discussions with several potential future clients have revealed that the complexity of such systems in the future will call for completely new and ultra-reliable technology covering, among other areas, separation, wet gas compression, control of the separation process, and high-voltage subsea power distribution. Ongoing R&D projects at ABB are addressing most of these issues and realistic solutions will be available soon.

Advantages of subsea processing

Future field development will present new challenges due to the increased water depths and longer distances to the infrastructure. A water content as high as 90 % in the wellstream, demands for improved



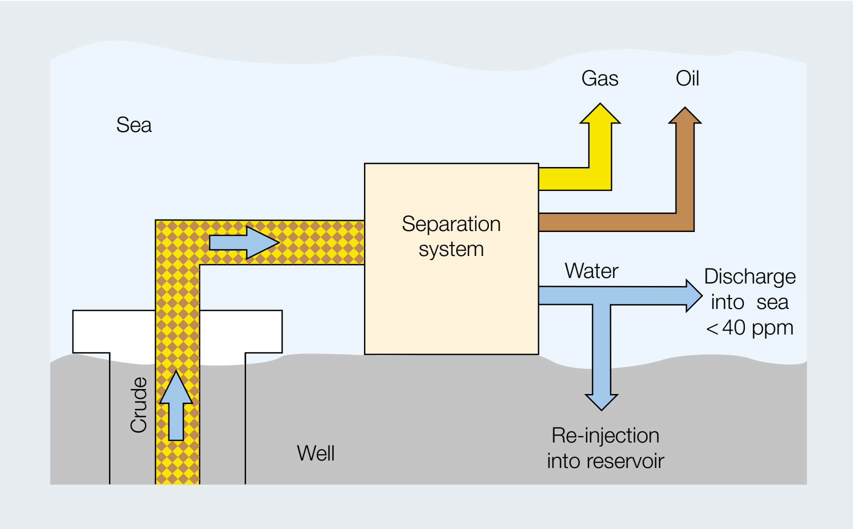
Subsea Separation and Injection System (SUBSIS), designed for increased recovery from offshore oil and gas fields **1**

1 *SUBSIS*
2 *Production well*
3 *Remotely operated vehicle*
4 *Water injection well*
5 *Floating production platform*

reservoir exploitation and, not least, increased ecological awareness and stricter legislation designed to protect the environment, call for innovative thinking and new solutions.

In this context SUBSIS offers a whole range of benefits:

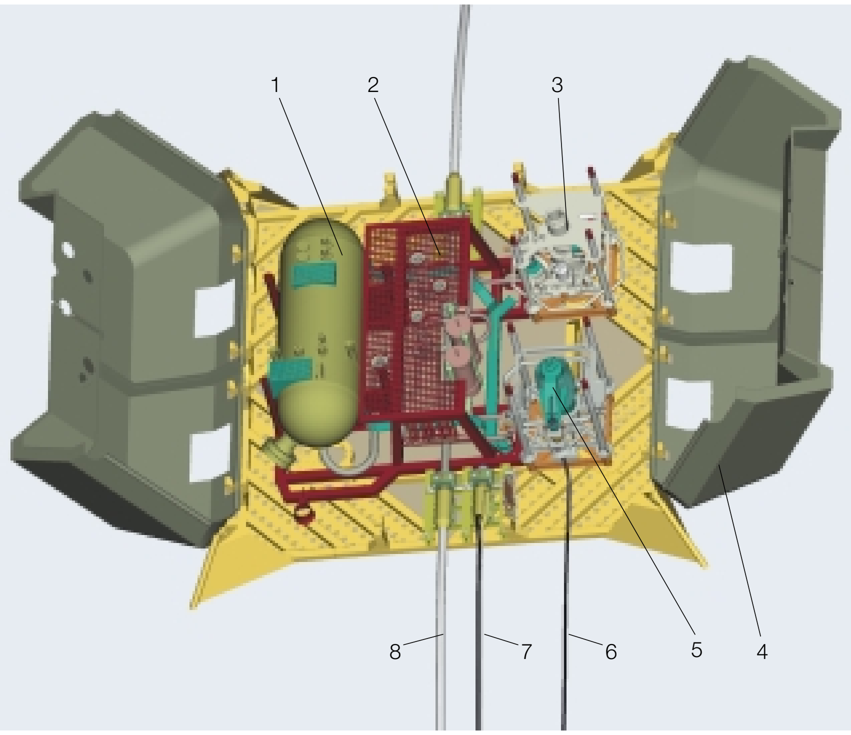
- *3 to 6% increase in oil and gas recovery*, achieved by reducing the back-pressure (the water is removed at the wellhead), increased water injection capacity and improved start-up and shut-down conditions.
- *Improved pipeline transportation conditions*, obtained by removing water from the wellstream. Multiphase transportation problems (eg, hydrate formation, slugging) are avoided. The flow is more stable and the transported volume can be reduced, allowing smaller pipeline sizes or an increased capacity.
- *Reduced environmental impact*, due to lower energy consumption, a reduction in the chemicals used to inhibit corrosion, hydrates, wax, etc, in the transportation system, and, not least, prevention of pollution caused by the produced water, which can be re-injected on site. It has been estimated that the amount of polluted water produced on the Norwegian Shelf alone will increase from about 40 million t/year in 1996 to some 120 million t/year in 2000. SUBSIS has the potential to improve this situation considerably.
- *Improved safety for personnel;* since the entire system is remotely operated under normal service conditions no site personnel are needed, eliminating the need for personnel transportation.
- *Reduced size and cost of new platforms and floaters*, by eliminating costly topside water separation, treatment and injection systems.
- *Cost-effective development of marginal fields* through re-use of the existing infrastructure. By removing the water at the subsea site, existing topside



SUBSIS separates the bulk water from the wellstream and treats it for either discharge into the sea or re-injection into the reservoir **2**

Typical SUBSIS layout on a standard subsea template. Each module can be retrieved separately. **3**

1 *Separator tank*
2 *Manifold, under grating*
3 *Water injection tree*
4 *Cover (GRP laminate)*
5 *Water injection pump module*
6 *HV power cable*
7 *Control umbilical*
8 *Flow line*



facilities without spare water-treatment capacity can receive the fluid for further transportation and export. This will turn marginal fields with unacceptable economics into interesting prospects.

Technical principles

General

The SUBSIS project was conceived to solve the problems posed by the large amounts of contaminated formation water produced by mature subsea fields and large new finds. The wellstream is defined as the fluid mixture coming directly from the reservoir. A multiphase composition, it may include several of the following components: light and heavy oils, gas, condensate, water, sand, minerals, H_2S, CO_2, as well as chemicals which are used to stimulate the reservoir and enhance the flow.

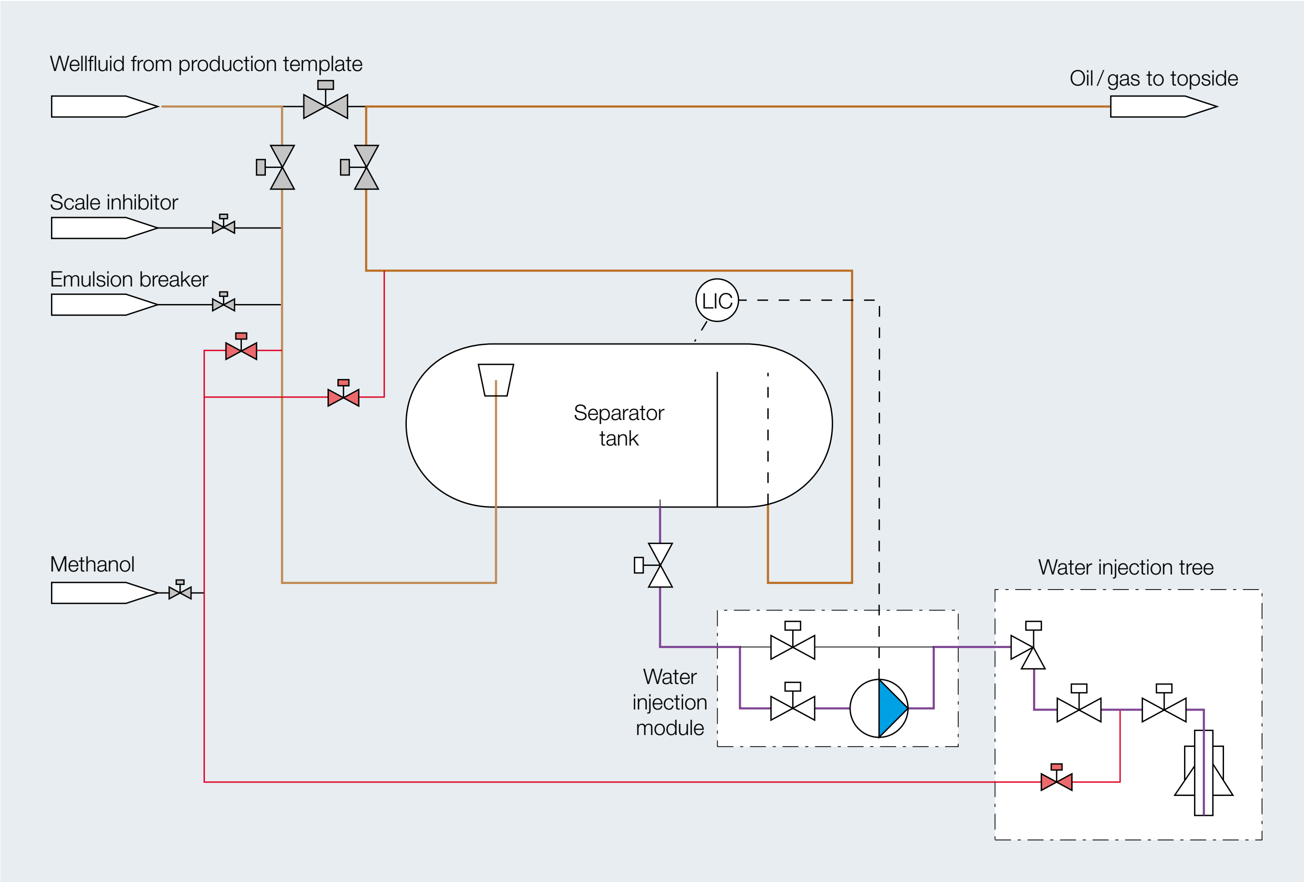
The key task of SUBSIS is to separate the bulk water from the wellstream and to treat it for either discharge into the sea or re-injection into the reservoir **2**.

SUBSIS is configured on a standard subsea template. The system is highly modularized, and each module can be retrieved separately for maintenance on the surface **3**.

Process design

The separation principle used is *passive gravity separation*, which also serves the additional purposes of separating gas and sand, resulting in a four-phase separation process.

Gravity separation takes place in a large, dedicated pressure vessel about 10 m long and 3 m in diameter containing a system of specially designed internals. The tank consists of a main cylindrical part with two hemispheric end covers and penetrations for the instrumentation and



SUBSIS process system **4**

LIC *Level instrument cluster*

piping. In principle, the separator is similar to the first stage of a traditional topside process train, but moved down to the seabed **4**.

The function of the internals is to improve and accelerate the separation process and to route the oil, gas and water to dedicated output devices for further transport and boosting. New and innovative inlet and outlet arrangements have been developed for SUBSIS; these designs have made it possible to avoid stacks of coalesher plates, which are normally used in a separator to enhance the formation of oil and water droplets. The novel inlet device, called the semi-cyclone, is of special interest **5**. By gradually reducing the momentum of the gas/-liquid mixture, it avoids small droplets being formed. The gas is pre-separated and exits in the gas phase at the top. The oil and water mixture is fed into the separator below the liquid surface, ie into the water phase. The exit velocity of the liquid is very low, thus preventing undesired mixing. Special systems for collecting and disposing of the produced sand have also been developed.

In addition, the system is equipped with a chemical injection system. Typical chemicals are:

- Methanol, for hydrate inhibition and pressure equalization prior to valves opening
- Scale and wax inhibitors
- Emulsion breaker, to break stable water-in-oil emulsions
- Asphaltene inhibitors

Disposal of produced water

In traditional field developments the produced water is transported back to the platform as a part of the wellstream for separation. Afterwards it is cleaned to a level of 40 ppm oil in water for discharge into the sea or treated and boosted for re-injection into the reservoir through dedicated pipelines. For the latter a cleanliness of approximately 1000 ppm is required. SUBSIS allows both of these approaches to be implemented at the subsea location. Features include:

- *Direct discharge into the sea.* For this option to be environmentally acceptable, the quality of the produced water has to be monitored at the subsea location in real time. Since the required equipment is not commercially available, a separate development programme has been started that will enable advantage to be taken of the obvious cost benefits of this option.

- *Re-injection of the produced water into the reservoir by active boosting.* This is achieved with a water injection module **6** consisting of an electric motor, centrifugal pump, instrumentation, piping and intervention tools. From the module, which is separately retrievable, the water is routed to a water injection valve tree and into the reservoir.

Closed-loop control and level monitoring

Stable oil and water levels in the separator are necessary to ensure optimum conditions and the required retention time for the separation process, plus a stable water and carbohydrate outflow. Typically, two different control indicator systems may be used. The system currently in use is a redundant level monitoring system. In the future, an alternative or back-up system could measure the amount of oil in the produced water. The present design features closed-loop control of the water level via regulation of the pump speed, based on continuous and direct input from one of two independent and physically different water-level monitoring systems mounted close to the water outlet arrangement inside the tanks. Physically, the pump speed is regulated by a frequency converter (adjustable-speed drive) mounted either topside or subsea.

The control system features dual redundancy and is based on standard ABB Advant hardware and software. Communication between the subsea electronics and topside control computers is via a high-speed fiber-optic link and makes use of ABB Advant communication protocols. It can interface with any topside control system.

Power system

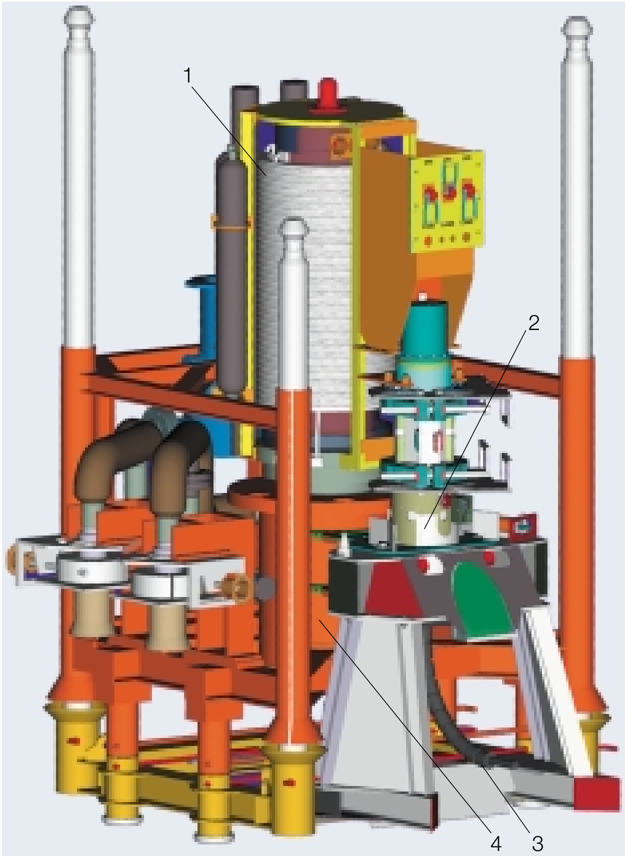
Subsea processing requires subsea-based rotating machinery for pumping, boosting and compression. The power requirement may be up to 2 MW per load. Speed regulation of the rotating

New hydro-cyclone separator inlet. This innovative device prevents small droplets from being formed during the separation process by gradually reducing the momentum of the gas/liquid mixture. **5**

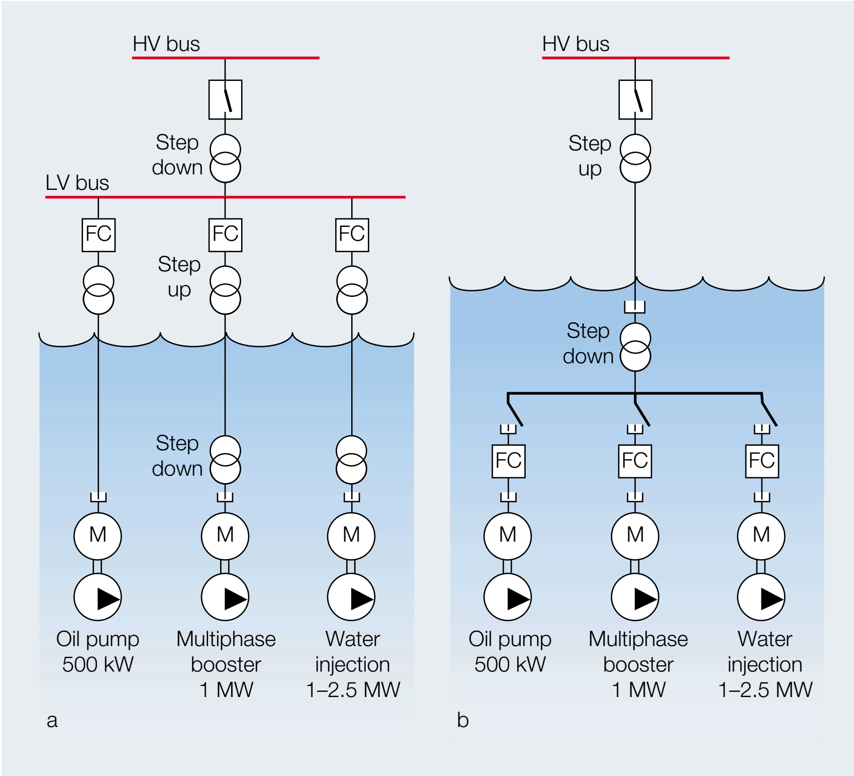
1 *Oil/water/gas*
2 *Gas*
3 *Oil and water*

SUBSIS water injection module for returning the separated water to the reservoir **6**

1 *Electric motor*
2 *HV mateable connector*
3 *Power cable*
4 *Pump*



machinery is also required. In SUBSIS, the speed is regulated by means of an adjustable-speed drive system consisting of frequency converters and step-up and step-down transformers. If there is only one load the whole system is located topside and connected to the load by cable. Where there are several subsea loads at distances of more than a few kilometers, subsea distribution of the power will be required due to the cost of the power cables. In such cases, most of the components are located subsea.



Main components of a conventional topside distributed system (a) and the SEPDIS subsea electrical power distribution system (b) **7**

FC *Frequency converter*

Spin-off projects

In order to provide a complete subsea separation system, ABB needed to close a series of technology gaps. During the SUBSIS development programme it became evident that the technologies required to close these gaps would also give competitive advantages in the market. Separate, fast-track, sub-projects were therefore established to develop and commercialize the required technology. The three main sub-programs were:

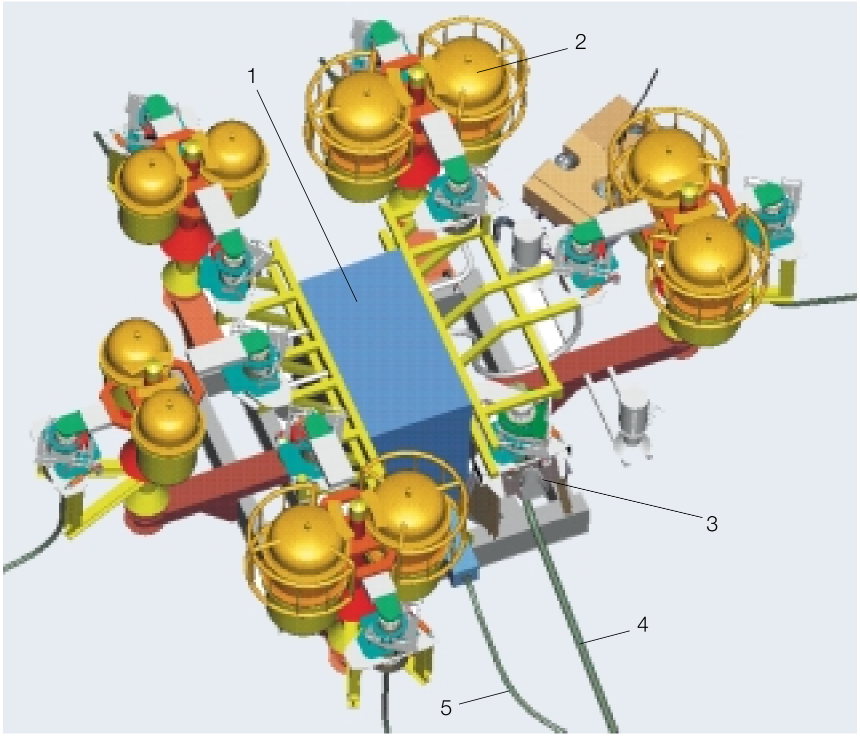
- Subsea Electrical Power Distribution System (SEPDIS)
- High-Voltage Subsea Mateable Connector (MECON)
- Separator Level Detection System

Subsea Electrical Power DIstribution System – SEPDIS

Suppliers to the oil industry have been urged in recent years to develop innovative and cost-effective solutions for subsea processing, pumping, boosting and similar energy-consuming applications. The power rating of a subsea pump, for example, can be 2 MW or higher. Electricity has gained acceptance as the medium most suitable for subsea consumers, both from a technical and an economical standpoint. Several development projects are currently being carried out jointly by the oil companies and the supplier industry.

The goal of the Subsea Electrical Power Distribution System (SEPDIS) project is to develop an electrical power supply and distribution system especially for subsea use. The system is based on conventional power distribution topology plus elements of transmission and industrial distribution system technology. The most important of the components to be moved subsea are the transformers, switchgear and frequency converters. In a topside distributed system, individual cables would have to be run to each consumer and all the drives and distribution components would be located topside on a host facility. Such a system has inherent cost-driving factors (eg, cable and installation costs) and also to some extent limited flexibility in terms of distances and the number of consumers. This triggered the idea of subsea power distribution with one single cable serving several consumers. The challenge is to adapt the electrical system so that it functions with maximum availability, minimum maintenance and the required lifetime under the special conditions imposed by deep-water oil and gas production.

ABB Offshore Technology has joined together with ABB Corporate Research in a project to develop, design and test a full-scale prototype of a complete SEPDIS unit by 2000. Five oil companies, plus the Norwegian Research Council, are sponsoring this Joint Industry Project. Current activities are concentrating on finalizing the detailed engineering and on starting up fabrication of a full-scale, complete



Typical configuration of the SEPDIS subsea electrical power distribution system **8**

1 *Subsea transformer*
2 *Subsea frequency converter and switchgear module*
3 *MECON connector*
4 *HV cable*
5 *Control cable*

system prototype. **7** compares the main components of a SEPDIS system with those of a topside distributed system. **8** shows a typical SEPDIS configuration.

High-Voltage Subsea Mateable Connector – MECON

A prerequisite for a subsea-distributed electrical power system is the ability to retrieve and re-install components needing maintenance and repair. To do this, watertight electrical penetrators and wet mateable high-voltage connectors are required. As none of the connectors available on the market was able to meet ABB's stringent specifications, it was decided to develop a completely new generation of highly reliable and repairable connectors.

The MECON connector, which was developed by ABB Offshore Technology and ABB Corporate Research in Norway, is designed for 36 kV but has been downrated to 12 kV for the Troll field. Unlike other, traditional designs it will have a benign, dielectric fluid environment and feature an all-metal sealed casing around the electrical contacts. State-of-the-art ROV[1] technology for subsea intervention is used for the make/break functions. Another advantage over other systems is that the female connector parts, including seals and components subject to wear, are independently retrievable. These three basic features all contribute to high service-life integrity. The first full-scale prototype is currently being tested and will be delivered to Norsk Hydro as part of the Troll Pilot contract **9**.

[1] ROV = Remotely operated vehicle

Separator level detection system

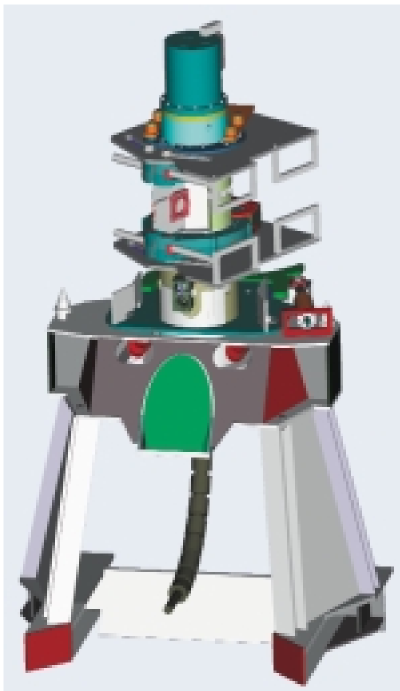
A reliable level detection system is the key to efficient operation of the separator. However, no such system, adapted for subsea use and intervention, is currently available on the market.

ABB Offshore Technology and ABB Corporate Research have together developed three different concepts **10**, employing two physically different principles (nucleonic and electrical), to establish a knowledge base and allow a better understanding of the requirements for such detection systems. The three level monitoring concepts make use of:

Nucleonic measurement (Time of Flight, TOF)

The gamma level monitoring principle **10a** is based on measurement of the density of the mixture inside the separa-

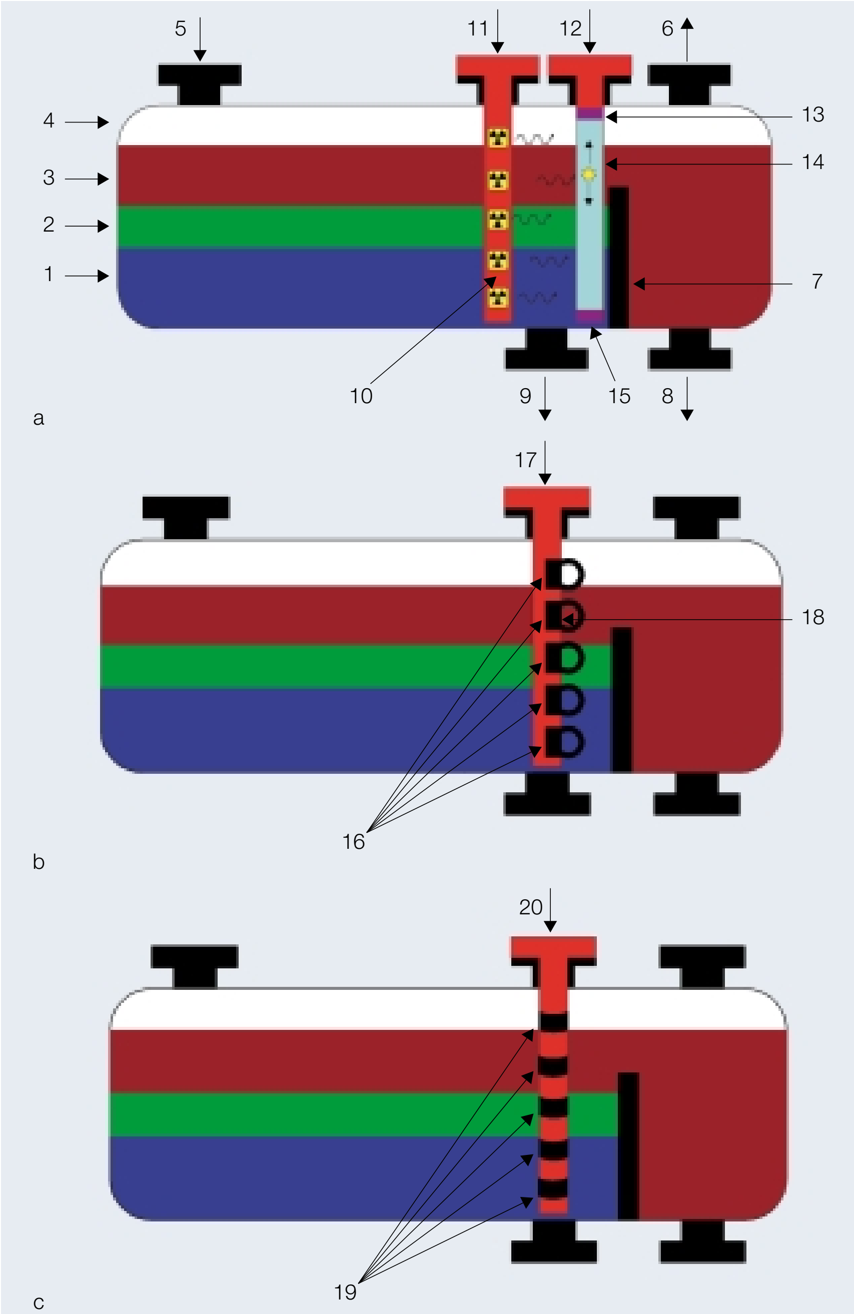
MECON high-voltage subsea wet mateable connector **9**



Working principles of the three methods of separator level monitoring developed for SUBSIS **10**

a Nucleonic: Time of Flight (TOF) measurements
b Electrical: inductance measurements
c Electrical: segmented capacitance measurements

1 Water
2 Emulsion
3 Oil
4 Gas
5 Process flow inlet
6 Gas outlet
7 Weir plate
8 Oil outlet
9 Water outlet
10 γ-ray source
11 Nucleonic source rod
12 Nucleonic detector rod
13 Detector element 1
14 Scintillator rod
15 Detector element 2
16 Measuring coil winding elements
17 Segmented inductance level indicator
18 Measurement volume
19 Measuring electrodes
20 Segmented capacitance level indicator



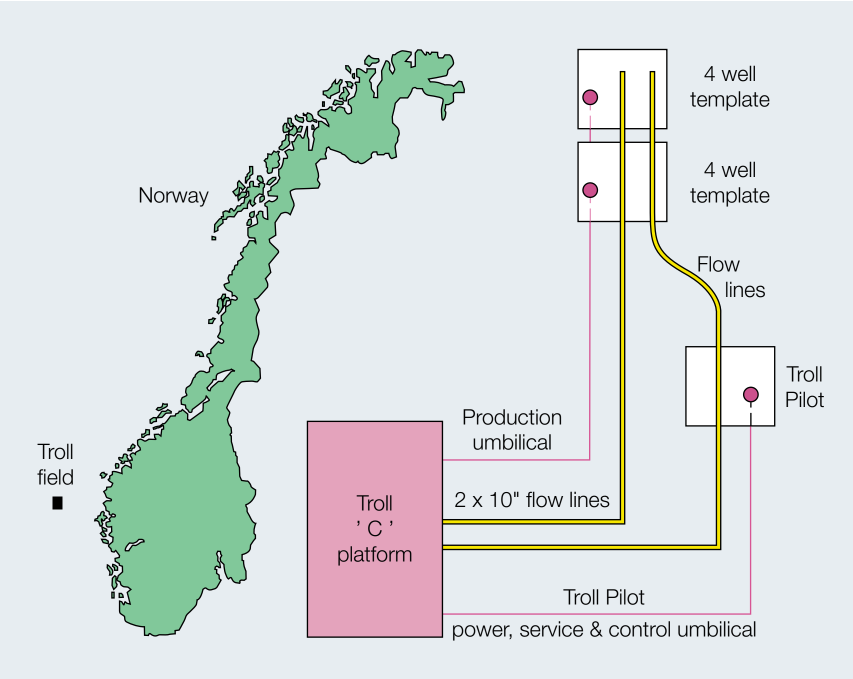
tor. The system comprises a radioactive source and a detector system based on a scintillator rod having a top- and bottom-mounted tube for detecting the radiation intensity at the different vertical positions on the rod. The density profile inside the separator can be deduced from this.

Segmented inductance measurements

The segmented inductance level monitoring principle **10b** is based on measurement of the conductivity of the surrounding liquid (oil/water mixture). Clear results are obtained due to the large difference between the conductivity of the process water (approx 5 Sm^{-1}) and that of crude oil (approx 10^{-6} Sm^{-1}). The interface between the water and oil/emulsion is determined by measuring the conductivity at different vertical positions inside the separator.

Segmented capacitance electrodes

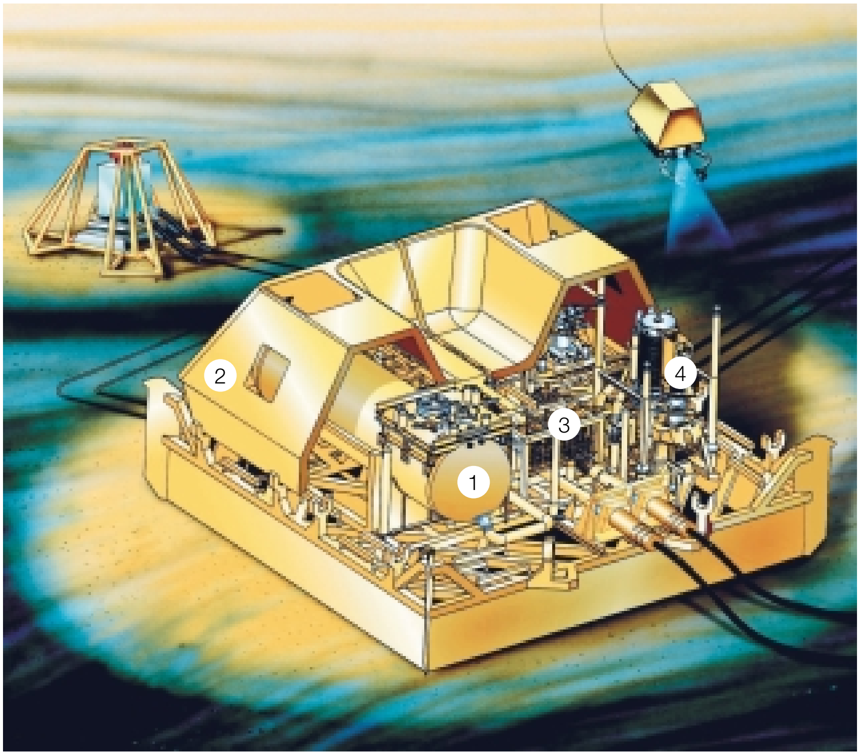
The segmented capacitance rod level monitoring principle **10c** is based on measurement of the relative permittivity at different vertical positions inside the separator. Typical relative permittivity values for crude oil and process water are 2.5 and 70, respectively. The oil/water interface is located by measuring the capacitance between adjacent electrodes.



Field layout of the Troll Pilot subsea separation system **11**

Assembly detail of the Troll Pilot subsea separation system **12**

1 *Separator tank*
2 *Protective cover*
3 *Production manifold*
4 *Water injection module*



In addition, a traditional topside nucleonic level sensor will be adapted for subsea applications.

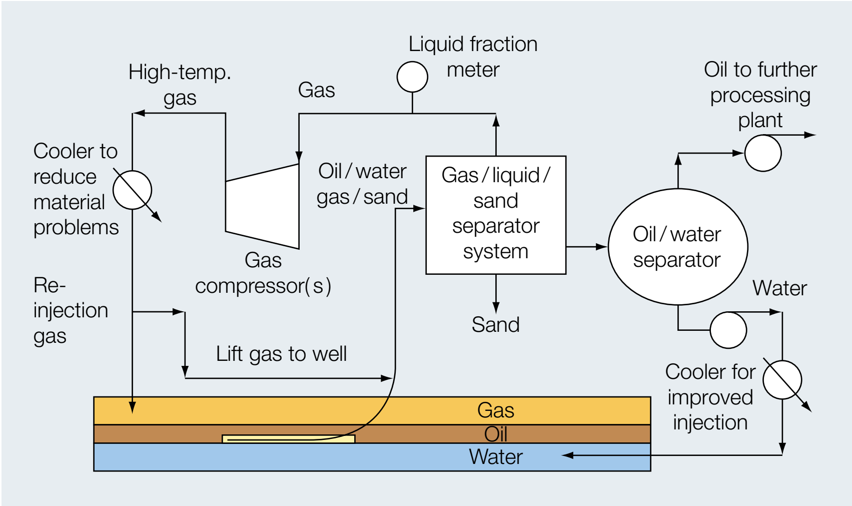
A combination of the two electrical systems is currently being developed. Laboratory prototypes of all the systems have been developed and tested. Detailed engineering of a commercial version of the inductive system is under way.

Commercialization – from SUBSIS to Troll Pilot

The Norwegian oil company Norsk Hydro recognized a need for the described subsea technology in its largest development, the Troll field, and also identified a viable project in which the first SUBSIS plant could be used off the critical line as a pilot installation. The contract to supply the first pilot plant, the Troll Pilot **11**, and an option for six more commercial plants was issued for open international tender in early 1997. The contract, worth about US$ 25 million for the first delivery, was awarded to ABB Offshore Technology in June 1997.

The Troll field, located 100 km west of Bergen, is one of the largest gas fields in the world, but also contains enormous amounts of oil in a very thin layer about 10 to 20 m thick. Troll C will produce significant amounts of water from day one. It will be good economy to produce the oil fast as gas production from other platforms will reduce the reservoir pressure.

The Troll Pilot subsea separation system **12** is designed to remove bulk quantities of water from the wellstream of one production line from templates S1 and S2, which are tied to the Troll C platform. The wellstream enters a specially equipped horizontal gravity separator, where the water is removed. Oil and gas are remixed at the separator outlet and transported through the production pipeline to



Subsea Increased Oil Recovery Station (SIORS) **13**

Troll C, while the separated water is boosted by the re-injection pump and then re-injected into the reservoir through the dedicated injection well.

The design of the Troll Pilot separator is based on the following design parameters:

Maximum oil	6,000 Sm³/day
Maximum water	9,000 Sm³/day
Maximum water injected	6,000 Sm³/day
Maximum liquid	10,000 Sm³/day
Maximum gas	800,000 Sm³/day

The system has a total weight in air of about 390 tonnes and a footprint measuring 16 m by 16 m. Its protective covers are made of a glass-fiber reinforced plastic (GRP) laminate. The separator tank is 11 m long and is designed for an internal pressure of 179 bar.

Troll Pilot will represent the first commercial use of both the MECON connector and the inductive level monitoring system. It will also feature the first use of a closed-loop control system in a subsea location.

Outlook

SUBSIS marks the start of a new era in the exploitation of oil and gas reserves, and will mark the beginning of the end for many large offshore platforms and floaters. The main job of an offshore platform is to treat the multiphase hydrocarbon wellstream in such a way that it can be transported via pipelines or tankers to an onshore terminal. Such treatment basically involves the removal of formation water and sand, the separation of oil and gas and their treatment to a transportation specification, plus the regeneration of chemicals. The further development of seabed-based process systems will enable oil companies to minimize or even eliminate topside facilities, thereby achieving major savings and making new fields commercially attractive. The elimination of platforms, or at least a massive reduction in their complexity, will obviously also have a large impact on personnel safety and environmental protection. In addition, as mentioned above, seabed-based processing increases the recovery from a given field due to the reduced flow resistance in the pipeline and riser systems.

ABB's vision for the future is the complete subsea process plant, capable of producing directly to the onshore terminal or to remote existing infrastructure. Plans for turning this vision into reality already exist. The working title for the project is SIORS, for Subsea Increased Oil Recovery Station. This next-generation subsea process plant will be a modularized, self-contained system which, besides actively separating produced water, will include subsystems for the following **13**:

- Water cooling and re-injection
- Active gas, liquid and sand separation
- Sand disposal
- Liquid fraction metering
- Wet gas compression
- Gas cooling
- Gas re-injection or transportation
- Gas lifting
- Closed-loop, adaptive control
- High-efficiency power supply

With the realization of this vision, ABB will set new standards for the economic and environmentally friendly production of oil and gas.

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