MECON – a novel high-voltage subsea power connector

ABB Offshore Systems has developed a high-voltage subsea connector, called MECON, to support strategic system development in the area of subsea processing, production and power distribution. Using MECON, HV interfaces for offshore projects located on the seabed can be wet-mated down to depths of 500 m. The connector has been designed with an emphasis on high integrity, reliable long-term operation, and retrievability for maintenance and repair using diverless techniques. The first MECON connector system, rated at 240 A/11 kV, will be delivered to Norsk Hydro's Troll Pilot installation in the North Sea in the second half of 1999.

To lower the cost of developing offshore oil and gas fields, production firms are moving increasingly larger parts of the process equipment from the platforms to the seabed. Recognizing this market trend, ABB launched in 1996 a High Impact Project (HIP) by the name of SUBSIS, for Subsea Separation and Injection System [1]. The main task of SUBSIS is to separate the wellstream into water, oil and gas at the seabed. The water can be either treated for discharge into the sea or re-injected into the reservoir to maintain pressure and enhance recovery.

The SUBSIS station consists of separate modules. This is an important design feature, as the cost-effectiveness of installing, maintaining and repairing systems operating on the seabed is a key economic factor in offshore production. A prerequisite for modularization, however, is the availability of reliable subsea connector systems, eg the HV power interfaces associated with pressure boosting equipment. The MECON connector system **1** was developed as an integral part of the SUBSIS concept, which requires transmission and distribution of electric power at levels from 11 kV to 36 kV. The majority of the power consumers are adjustable-speed motor drives rated from 500 kW to 3,000 kW. ABB is also currently developing a Subsea Electrical Power Distribution System (SEPDIS) for the subsea market.

ABB Offshore Systems was awarded the '1999 Woefel Best Mechanical Engineering Achievement Award' for MECON at OTC 99 (Offshore Technology Conference) in Houston, 6 May 1999.

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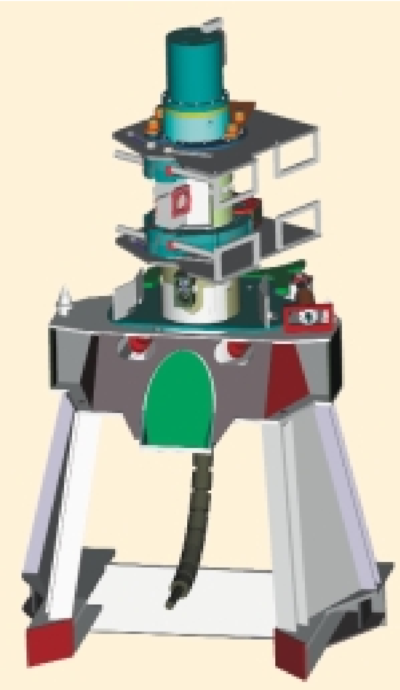
The MECON concept

The MECON connector design [2] features in-situ flushing to remove the seawater and create a benign dielectric environment in which safe and reliable electrical contact can be made **2**. This is in contrast to traditional connectors, where the stab action used to make the electrical contact takes place directly in seawater. MECON has two identical male connecting flanges, each of which is mounted on one of the two modules/components being connected together (eg, a high-voltage cable and a subsea motor **3**). In such a case, one male flange is mounted on the subsea motor and the other on the HV power cable using a newly developed high-voltage subsea cable termination. The connection is made by inserting a female 'mini-spool' between the two male parts. This mini-spool contains two back-to-back mounted female-style shuttle pistons. The pistons have contact sleeves which are hydraulically engaged in the male contacts of the connecting flanges.

One of the goals of the development engineers was to ensure reliable operation of the MECON system in the long term (typically 25 years). To achieve this it is essential to prevent water from entering the HV system. The concept that was chosen for further development features full metal encapsulation of the electrical connecting parts by means of a metal-sealing technology that guarantees the long-term integrity of the seawater barrier.

Solid cast polymer is used for the main insulation. The voids created by the movement of the connector parts are filled with dielectric oil, pressurized to withstand the ambient hydrostatic pressure.

Connection with the MECON system takes place in three steps **2**:



MECON subsea connector system for wet-mating high-voltage electrical interfaces at depths down to 500 m **1**

- Mechanical connection and engagement by the metallic seals of the connection flange
- Flushing of the connecting chambers, followed by replacement of the trapped seawater by dielectric oil
- Electrical connection, in which internal pistons move to make contact with male pins in each connecting flange

The entire operation is completed using diverless intervention techniques, eg Remotely Operated Vehicles (ROVs) **4**. A dedicated tool skid has been constructed for the MECON system.

Operational benefits – new features

Field developments with subsea power distribution systems rated up to 36 kV are possible with MECON. MECON offers higher reliability and better accessibility for maintenance than the standard connectors available on the market, thereby reducing operational costs.

The MECON connector's dielectric-fluid, thermal volume compensation system is based on the 'all-metal barrier' principle. Unlike electrical stab-type connectors with compensators made of elastomer, this system supports the industry goal of long-term electrical integrity.

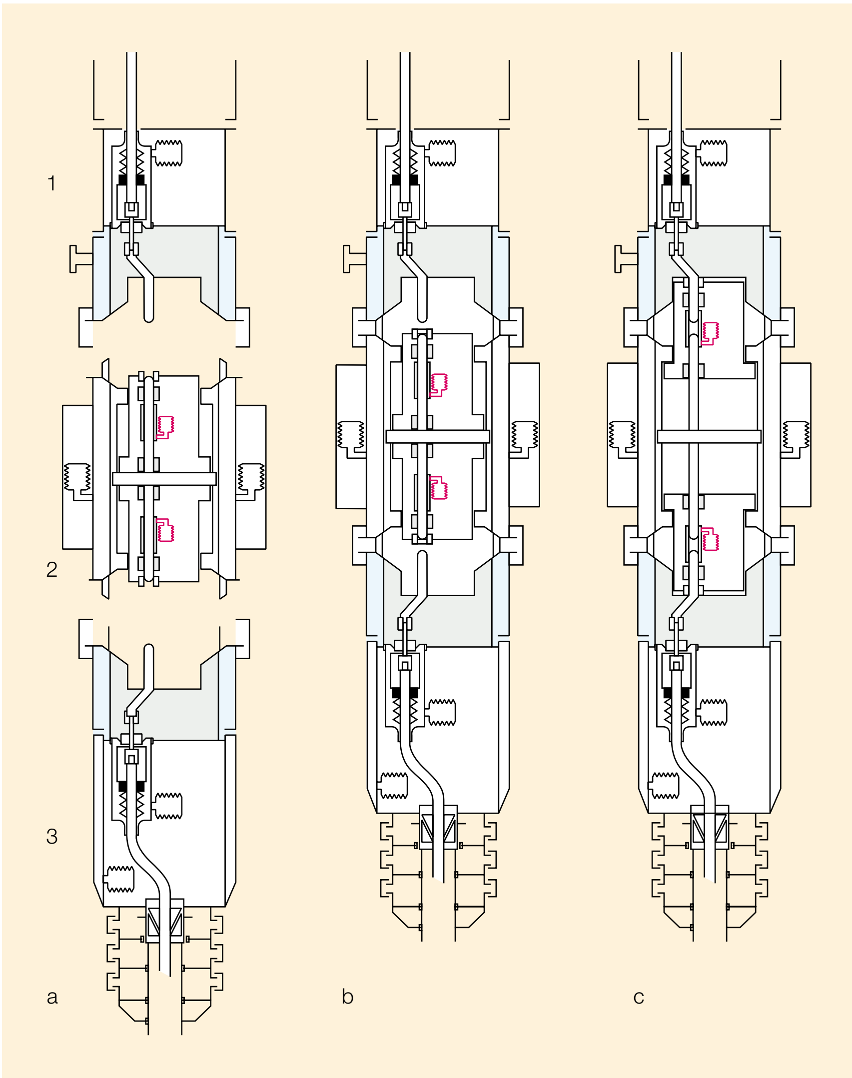
The MECON connector system allows the female connector assembly, including the electrical gland seals, to be retrieved independently of the interconnected modules. This unique feature sets the system apart from traditional connector concepts in which the module attached to the female connector is retrieved. Independent retrieval by ROVs is expected to be an important feature of deep-water applications in the future.

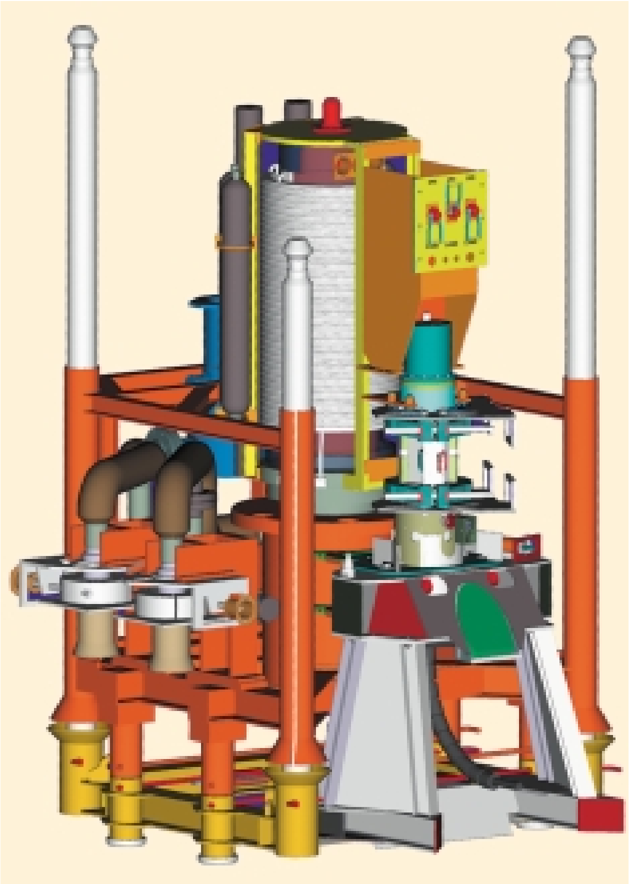
The MECON connector combines the function of a subsea mateable connector with that of a high-voltage disconnect switching device. The disconnect function allows branches to be isolated and electrical faults to be detected – features which

Mating process with the MECON high-voltage subsea connector. In-situ flushing removes the seawater and creates a benign dielectric environment in which electrical contact can be made. **2**

a *Split*
b *Mechanical connection*
c *Electrical connection*

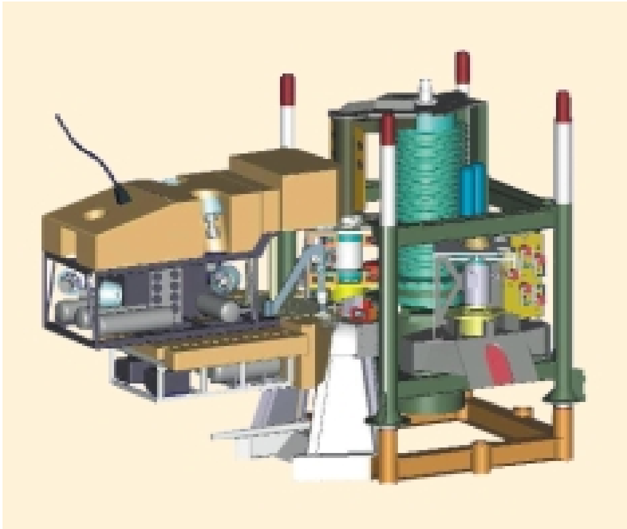
1 *HV motor feeder*
2 *Mini-spool*
3 *HV power cable termination*





Water injection module for Norsk Hydro's Troll Pilot project in the North Sea. The MECON system (foreground, on right) connects the HV cable to the electric motor driving the water injection pump. **3**

Remotely operated vehicle installing the MECON connector on the water injection module **4**



are likely to be essential for all future subsea applications, regardless of the power distribution system employed.

The MECON connector system also incorporates the saver-sub[1)] principle, which ensures that the make-break interface does not involve the power cable end. This reduces the risk of damage to the power cable termination during operation, and therefore the need for repairs which could make it necessary to bring the high-voltage power cable termination to the surface. The 'saver-sub' feature will also be important in future deep-water applications as it allows shorter lengths of cable to be used.

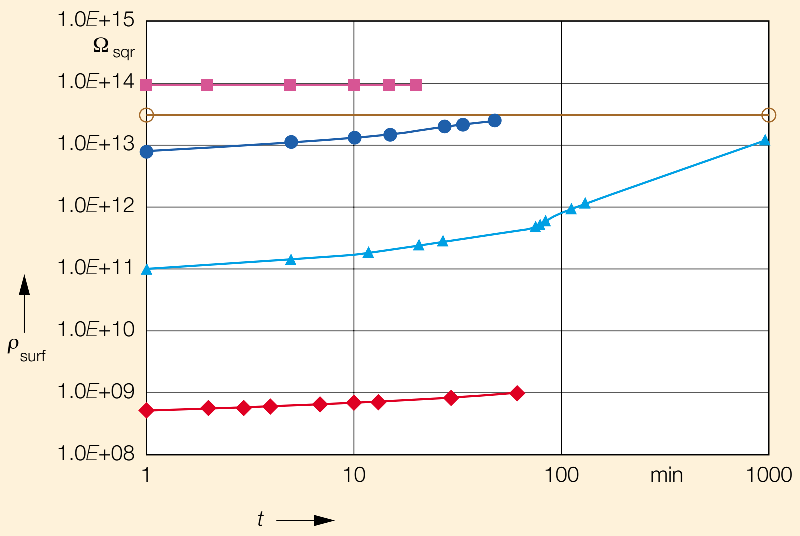
Material selection and testing

Since subsea HV technology makes unconventional demands on the electrical equipment, special research and material tests were an essential part of the MECON development programme. The transition from a highly conductive (saltwater) state to the highly insulated (dielectric fluid) state necessary for long-term HV operation at subsea depths down to 500 m was a particular challenge. The problem was solved by:

- A series of flushing operations, involving various fluids and flushing parameters, through which the change from salt-water to the dielectric fluid takes place gradually.
- Pressure-balancing of the MECON internals.
- Use of a hybrid insulation system consisting of solid insulation and a liquid dielectric, dimensioned such that each guarantees the insulation level by itself in the case of breakdown by one of them.
- Use of fluids and materials with a high tolerance of humid environments and exhibiting good, long-term chemical compatibility.

After the two male connecting flanges have been mated with the mini-spool, the entrapped seawater is removed by a multiple-step flushing sequence of mutually compatible liquids, ending with a dielectric fluid with negligible traces of contaminants. The dielectric properties and the short- and long-term breakdown strength of the fluid were tested for different levels of potential contaminants, and with fluids from actual flushing experiments to derive criteria for the electrical design and the flushing process. The dielectric fluid which is used has a 50 to 100 times higher humidity tolerance than conventional insulation liquids.

[1)] Saver sub: a very short, tubular component made up to and having the same thread as a longer or more valuable component which is connected/disconnected frequently.



Recovery of the surface resistivity of insulation materials after exposure to seawater at 50 bar for 120 hours, followed by flushing **5**

ρ_{surf} *Surface resistivity* t *Time*

Acceptable recovery (measured in air)
Limitation due to dielectric fluid
Acceptable recovery (in dielectric fluid)
Non-acceptable materials/flushing conditions
Non-acceptable materials/flushing conditions

During subsea installation of the system, parts of the insulation material are exposed to saltwater at high pressure for a short time. Hence, traces of water and flushing fluids may penetrate the surface layer of the insulator and reduce its insulation properties. In a series of experiments, different materials were exposed to saltwater at 50 bar for several days, followed by simulated flushing processes and subsequent measurements of their surface resistivity in the dielectric fluid **5**. The surface resistivity ρ_{surf} was observed to drop at first, compared with the initial state ($\rho_{surf} > 10^{14}\ \Omega_{sqr}$), but then recover to a level where it is limited by the finite resistivity of the dielectric fluid. This recovery is due to the out-diffusion of the water molecules into the dielectric fluid, which acts as a drying agent. The dielectric breakdown strengths were determined for the different surface conditions, leading to limits for the critical power density $P \approx E^2/\rho_{surf}$ for a given electrical design field E. From such experiments, materials were selected with a low water intake and short recovery time, and boundary conditions were derived for the flushing cycles and the electrical field design.

Additional input for the dielectric layout came from studies of the breakdown fields for the fluid, the different solid liquid interfaces and the elastomeric seals for various worst-case scenarios. Based on the results, a robust electrical design was found which has large safety margins for testing and operation. Accelerated compatibility tests with clean and contaminated dielectric liquids as well as thermomechanical tests were performed on a wide variety of materials and material combinations prior to final selection of the material.

Proven casting materials are used for the main insulation. Due to the complex shapes and required tolerances the structures, including the conductor parts, are cast under vacuum as semi-finished products. The details are subsequently machined and a surface coat is applied to improve the flushing and hydraulic motion properties. This unconventional approach results in good design flexibility, high material quality and economic production.

State-of-the-art simulations

Simulations were carried out for the purpose of evaluating the early design and to obtain final design verification. Fluid-mechanical analyses based on computational fluid dynamics (CFD) supported the development of the technique for flushing the connector and replacing the trapped seawater by a dielectric fluid prior to the electrical connection.

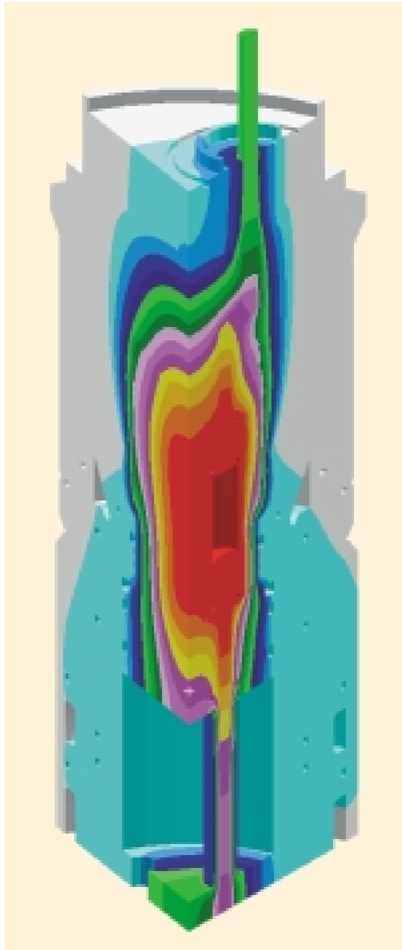
A multi-disciplinary simulation platform was developed alongside the MECON project as part of a European project named MEDUSA (Multi-disciplinary Engineering Design via Unitary Software Applications). As a member of the project team, ABB participated in the simulation of multi-disciplinary problems, ie problems in which mechanical, thermal and electrical stresses are applied simultaneously. The work involved geometry modelling, meshing, solving and presentation of the results. The geometry modeller that was chosen for the MECON project simulation was the Pro/ENGINEER. This enabled a parametric model of the high-voltage connector to be generated and CAD models supplied by ABB to be used.

Four different types of analysis are covered by the simulation platform: electromagnetic, thermal, CFD and structural. For the multi-disciplinary analysis of MECON three different solvers were coupled:

- *ABB's POLOPT (3-D simulation of electromagnetic fields)*, for the electromagnetic analysis (loss density and force density)
- *MSC/NASTRAN (general-purpose finite element analysis program)*, for the thermal/structural analysis
- *AVL/FIRE (finite volume differencing scheme)*, for the CFD analysis

The temperature and stress design requirements lay below the critical limits, suggesting that there is potential for further optimization. Qualification tests confirmed the results of the calculations. Among the results confirmed were the conduction loss distribution **6** in a phase conductor and the subsequent temperature distribution **7** in the connector. The simulation platform will continue to be used in future MECON development and optimization programmes.

Simulation results showing the loss distribution in one of the phase conductors **6**



Temperature distribution due to conduction losses **7**

Testing

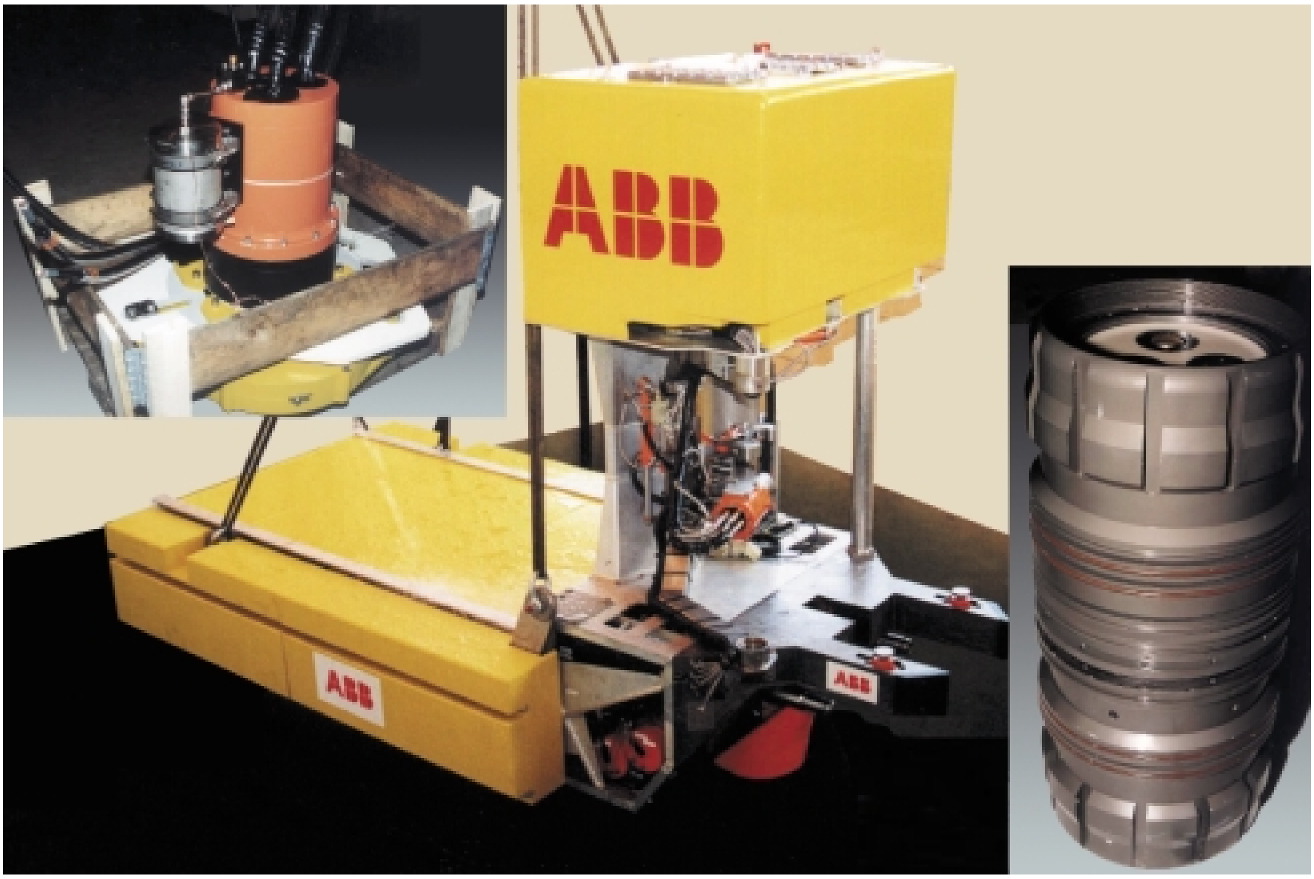
A test dummy was set up and used in a comprehensive test programme designed to qualify MECON for Norsk Hydro's Troll Pilot installation. The programme (*Table 1*) consists of 5 main tests.

The all-important flushing operation has been verified experimentally by fluid flushing tests carried out on a full-scale acrylic model of the connection chamber at DnV Laboratories, Høvik, Norway. The flushing operation has also been tested under simulated ambient subsea conditions to determine the flow rates and flushing time required to achieve sufficient purity for the dielectric oil. The experiments have proved the technical feasibility of the flushing operation and confirmed that all the dielectric requirements are fulfilled. Excellent agreement with numerical (CFD) simulations has been shown.

Two complete connector sets rated at 240 A and 11 kV have been fabricated and assembled for delivery to Norsk

Table 1:
Test programme used to qualify the MECON system for Norsk Hydro's Troll Pilot installation

	Test sequence
Dielectric test	AC withstand test at 52 kV Partial discharge (PD) tests Heat cycling followed by AC withstand and PD test Multiple contact tests followed by AC withstand and PD tests
Short-circuit test	3-phase short circuit at 2400 A
Load-current test	Temperature rise at rated current
Hydrostatic test	2 weeks of operation at a pressure equivalent to a depth of 750 m
Mechanical impact test	Drop shock with 50 *g* acceleration, followed by AC withstand and PD tests



Assembly of a MECON connector system for Norsk Hydro's Troll Pilot project in the North Sea. Shown are the motor feeder (insert, left), the ROV flushing skid (center) and the mini-spool (insert, right) 8

Hydro's Troll Pilot installation in the North Sea 8. They are due to undergo a comprehensive system and integration test programme in the first half of 1999, before being installed in the late summer.

Further development

Future activities will concentrate on three areas: raising the voltage rating to 36 kV, increasing the water depth to 2000 m, and developing a simplified connector for medium-voltage (3–8 kV) power distribution.

The primary application for the MECON system will be in SUBSIS and SEPDIS installations. In addition, it may be offered to the subsea market as a stand-alone product.

References

[1] R. Strømquist, S. Gustafson: SUBSIS – world's first subsea separation and injection system. ABB Review 6/98, 4–13.

[2] I. Østergaard, A. Nysveen: A coupling and switch system for subsea electrical power distribution. WO9821785.

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