Subsea Power Supply& Control System

Introduction

First Edition

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Preface

بسم الله الرحمن الرحيم

This book introduces basic education on subsea power supply and transmission system for students, fresh offshore engineers and universities' staffs. The book consists of eight chapters as follows: The first chapter discusses subsea power supply. In the second chapter, subsea transmission system is explained in detailed. The third chapter discusses transmission system design. The forth chapter comes up with ancillary equipment, the fifth chapter discusses on system integration test, chapter six discusses on installation of umbilical, the seventh and eighth chapters discuss on challenges and solution and industries experiences respectively.

In the book, many pictures and illustrations are enclosed in this book to assist the readers' understanding. It should be noted that some pictures and contents are borrowed from other companies' websites and brochures, without written permit. Even though the exact sources are quoted and listed in the references, please use this book for education purposes only.

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1.0 Subsea Control System

1.1. Introduction

Reliable operation, combined with accurate control and monitoring of subsea installations, is essential to ensure the highest production availability while providing safe and environmentally friendly field operations. Figure 1.1 shows the topsides and subsea equipment the umbilical interfaces with to make up a subsea electrohydraulic control system.

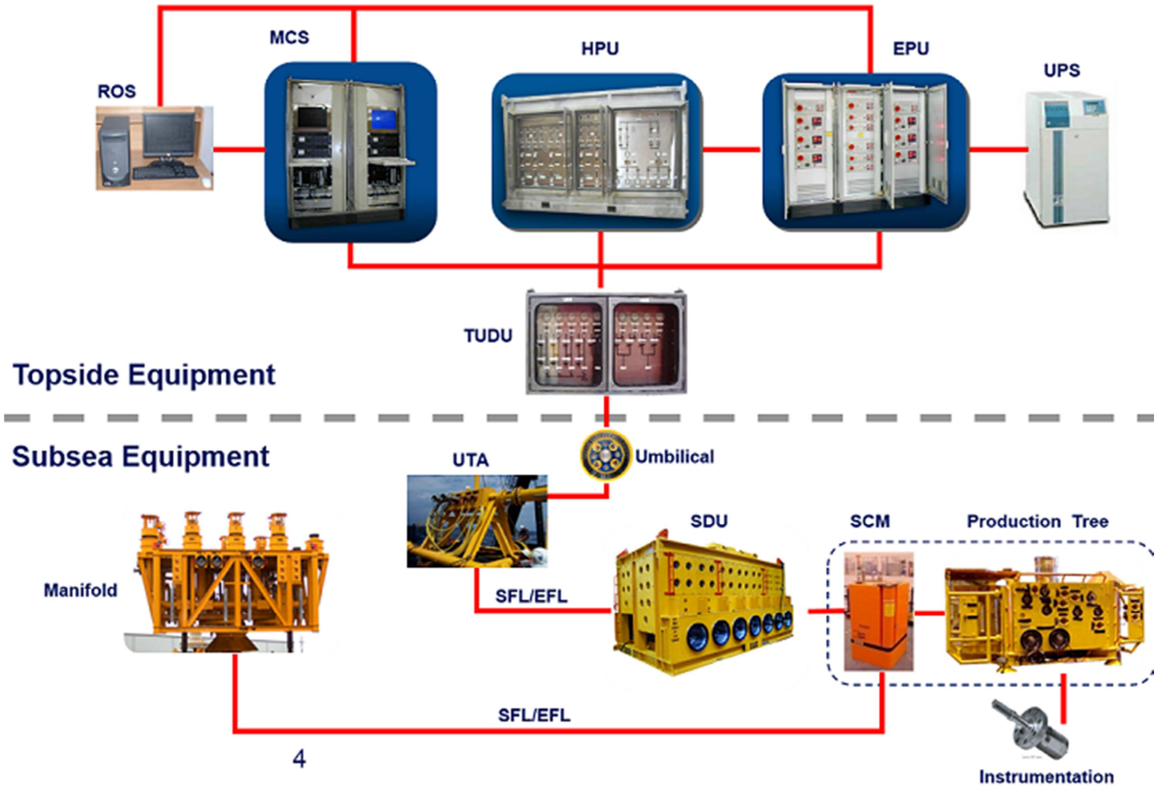

Figure 1-1: Schematic of subsea control system [Subseapedia].

1.2. Subsea Production Control System

The production control system consists of topside controls, power equipment, Subsea Control Modules (SCM) and sensors as well as subsea electrical and hydraulic distribution equipment. Subsea Production Control System components include:

1. Subsea Umbilical Termination Assembly (SUTA) or Umbilical Termination Assembly (UTA)
2. Electrical Flying Lead (EFL)
3. Steel Flying Lead (SFL)
4. Hydraulic Lying Lead (HFL)
5. Subsea Distribution Unit (SDU)
6. Subsea Control Module (SCM)
7. Manifold
8. Production Tree
9. Instrumentation

1.2.1. Subsea Control Module

The main component of the tree mounted control system is the Subsea Control Module (SCM). The SCM contains electronics, instrumentation, and hydraulics for safe and efficient operation of subsea tree valves, chokes, and down-hole valves. Other tree mounted equipment includes various sensors, electrical and hydraulic connectors.

Over 1,000 subsea wells are controlled using tree mounted control systems with an uptime rate of 99 - 100% for most systems. The technology today controls wells at distances up to 120 km, and in water depths of 3,000 m with 15k reservoir pressure rating.

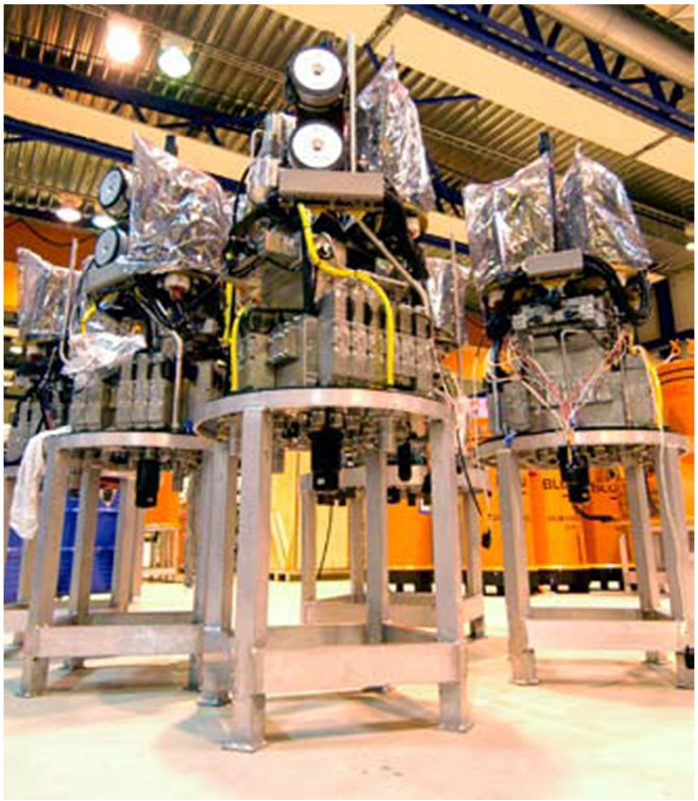

Figure 1-2: Subsea Control Modules [FMC].

1.2.2. Subsea Umbilical Termination Assembly

UTA, sitting on top of a mud pad, is a multiplexed electro-hydraulic system allows many subsea control modules to be connected to the same communications, electrical and hydraulic supply lines. The result is that many wells can be controlled via one umbilical. From the UTA, the connections to the individual wells and SCMs are made with jumper assemblies.

Figure 1-3: Subsea Umbilical Termination Assembly [Oilfield].

1.2.3. Electrical Flying Lead

The Electrical Flying Lead (EFL) connects communication on power circuits between various pieces of subsea distribution equipment. The EFL has different configurations, such as 4-way (with 4 wires), 8-way or 12-way. The connectors at the end of the flying lead can have any plug/receptacle combination. EFLs contain ROV-type connectors at each end to allow for subsea installation and retrieval.

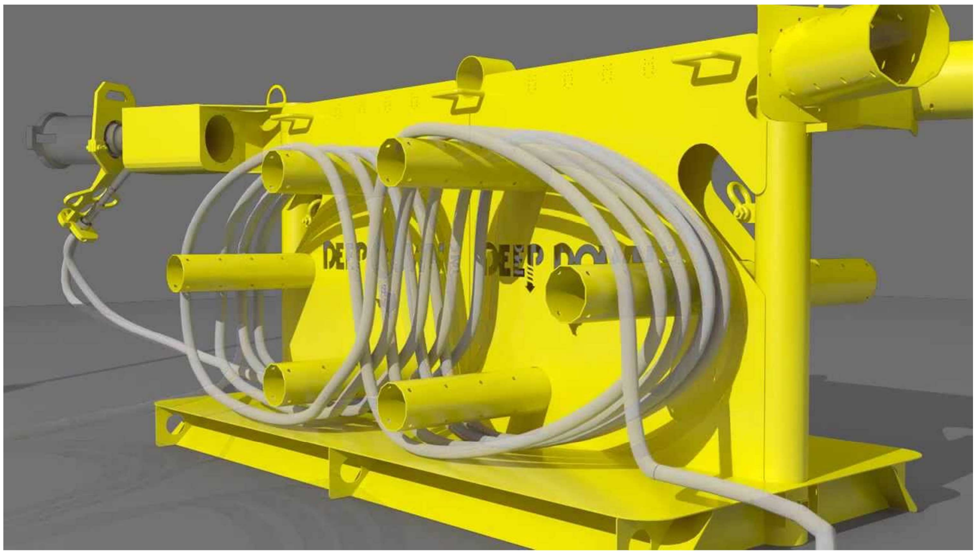

Figure 1-4: Subsea Electrical Flying Lead [Deep down]

1.2.4. Hydraulic Lying Lead

Hydraulic lying lead provides a safe and efficient method of making connections between subsea distribution hardware. Flying leads support the conveyance of hydraulic fluid and/or chemicals between subsea equipment.

Figure 1-5: Hydraulic Lying Lead [Oceaneering]

1.3. Topside Control System

Topside Control Systems incorporate design innovations to adjust to the changing demands of today’s subsea environment. Topside Control System components include

1. Master Control Station (MCS)
2. Remote Operating System (ROS)
3. Hydraulic Power Unit (HPU)
4. Electric Power Unit (EPS)
5. Uninterruptable Power Supply (UPS)
6. Topside Umbilical Distribution Unit System (TUDU), alternatively Topside Umbilical Termination Unit (TUTU)
7. Subsea Power and Communication Unit (SPCU)
8. Topside Termination Umbilical Assembly (TUTA).

The MCS and SPCU are a two of the key components that make up the topside control equipment. This equipment offers various hardware and software options to meet the customer’s immediate needs while providing for future expansion options as required.

- Standardized hardware and software
- Easy incorporation of control system
- expandability
- Modular designs

- Simplified maintenance
- Easy to configure
- Multiple configurations
- Backwards compatible

1.3.1. Master Control Station

The Master Control Station (MCS) is located on the top-side facilities of offshore oil and gas platforms which is a dedicated system that controls and retrieves data from subsea equipment on the ocean floor. The MCS is critical to maintaining safe operating conditions, optimizing production across a field and effectively managing reserves. The UMCS has three main layers: HMI, logic/control and subsea communications to control pods on the ocean floor.

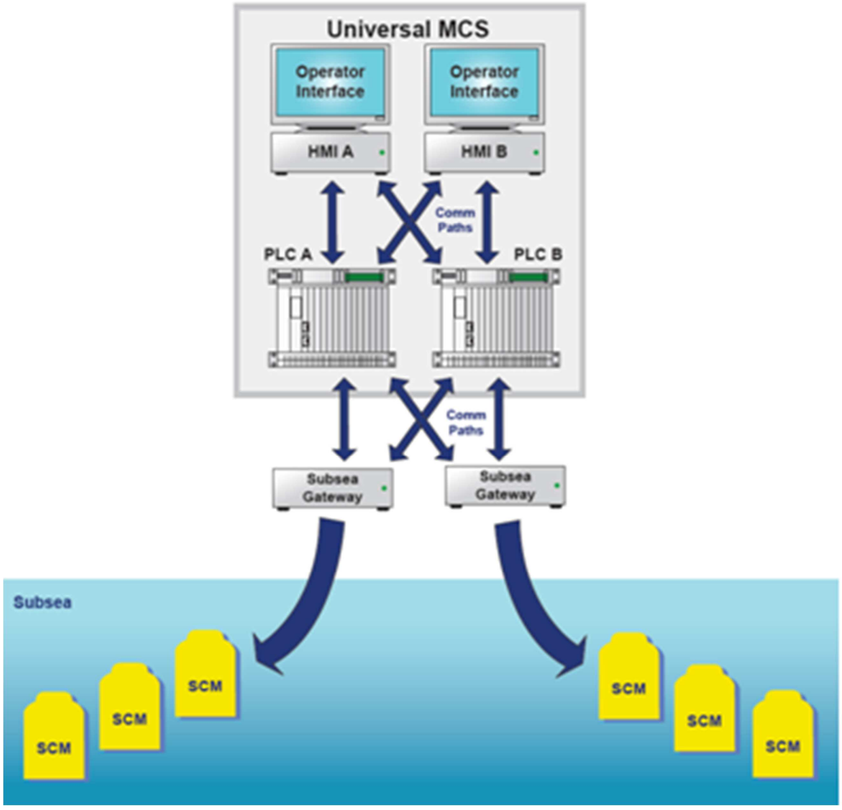

Figure 1-6: Dual-Redundant Architecture of the UMCS [Wikipedia]

1.3.1. Uninterruptable Power Supply

An uninterruptible power supply is an electrical apparatus that provides emergency power to a load when the input power source or mains power fails. Figure 1-7 shows an example of APC Smart-UPS C 1440VA with LC.

Figure 1-7: APC Smart-UPS C 1440VA with LCD [Wikipedia]

1.3.1. Topside Termination Umbilical Assembly

The Topside Umbilical Termination Assembly (TUTA) provides the interface between the main umbilical and the topside control equipment. The unit is a free standing enclosure that can be bolted or welded in a location adjacent to the umbilical hang-off in a hazardous exposed environment onboard the topside facility. These units are usually tailor-made to customer requirements with a view to hydraulic, pneumatic, power, signal, fiber optic, and material selection.

The TUTA usually incorporates electrical junction boxes for the electrical power and communication cables, as well as tube work, gauges, and block and bleed valves for the appropriate hydraulic and chemical supplies.

Figure 1-8: An example of Topside Umbilical Termination Assembly [Frame]

1.4. Subsea Distribution System

Subsea Distribution Systems consist of a group of equipment’s providing communication from subsea controls to topside. This equipment is developed based on field proven technology and years of experience. A few of these equipment’s are:

- Steel Flying Leads (SFL)
- Cobra heads for the SFL
- Multi Quick Connect Plates (MQC)
- Electrical Flying Leads (EFL)
- Umbilical Termination Heads (UTH)
- Deployment Equipment for all the above
- Hydraulic couplers
- Various Subsea Sensors

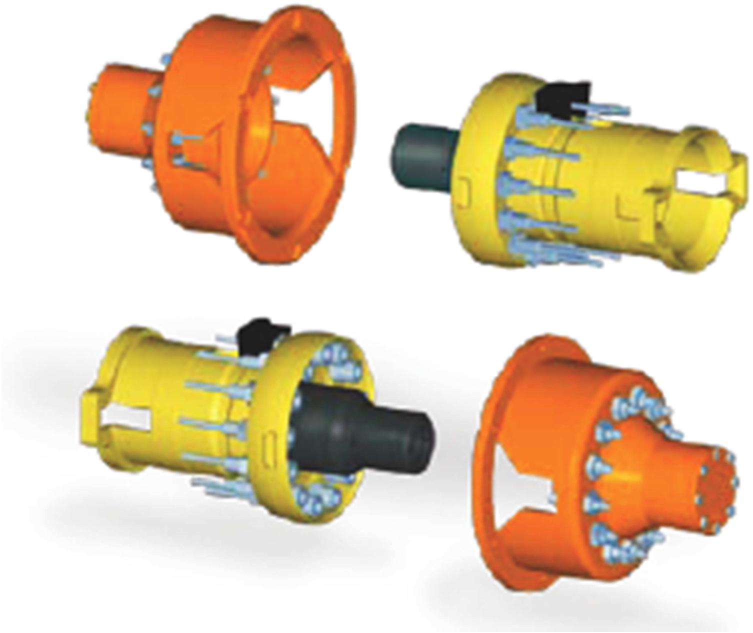

Figure 1-9: Inboard and Outboard MQC’s [FMC]

1.4.1 Steel Flying Leads

Flying leads provide electrical/hydraulic/chemical connections from the UTA to individual trees/control pods. They are part of the subsea distribution system that distributes umbilical functionalities to their intended service targets. They are typically installed after umbilical and connected by ROV.

Figure 1-10: Steel Flying Leads [Oilfield]

Chapter.2

2.0 Subsea Power Supply

2.1. Types of Power System

The power supply for a subsea production system is designed according to the subsea control system. Different control system types require different power system designs. Figure 2.1 shows two types of power systems: an electrical power system or a hydraulic power system.

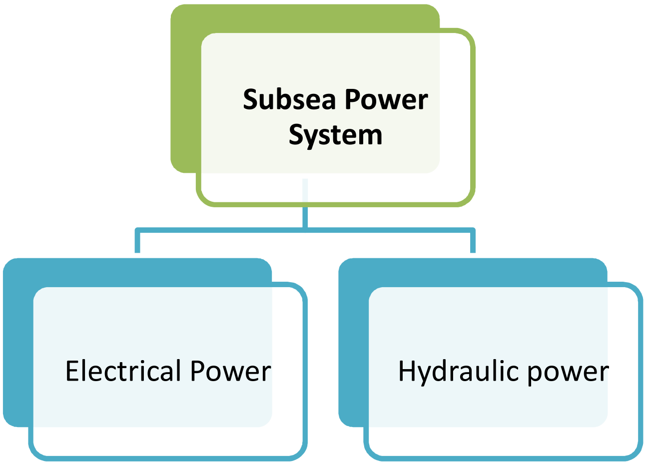

Figure 2.1: Basic subsea power system

The power system supplies either electrical or hydraulic power to the subsea equipment. Figure 2.2 shows subsea equipment such as valves and actuators on subsea trees or manifolds, transducers and sensors, Subsea Control Module (SCM), Subsea Electronics Module (SEM), pumps, motors.

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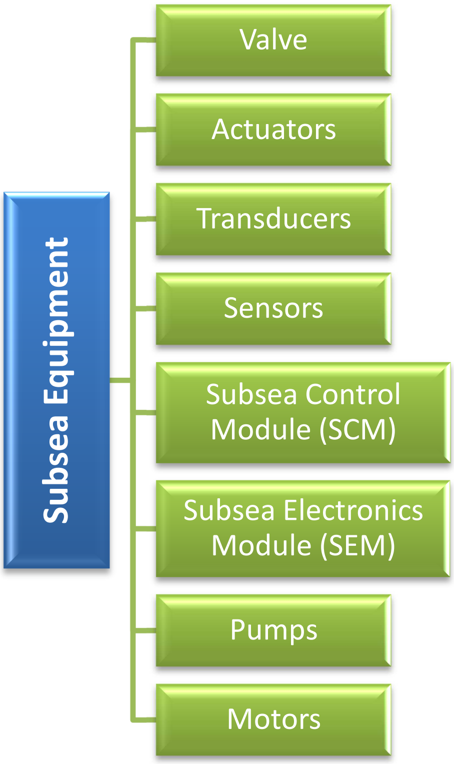


Figure 2-2: Subsea equipment

The power sources can come from either an onshore or from platform or subsea generators. Figure 2-3 illustrates the subsea power distribution when the power sources are generated from hydraulic power unit.

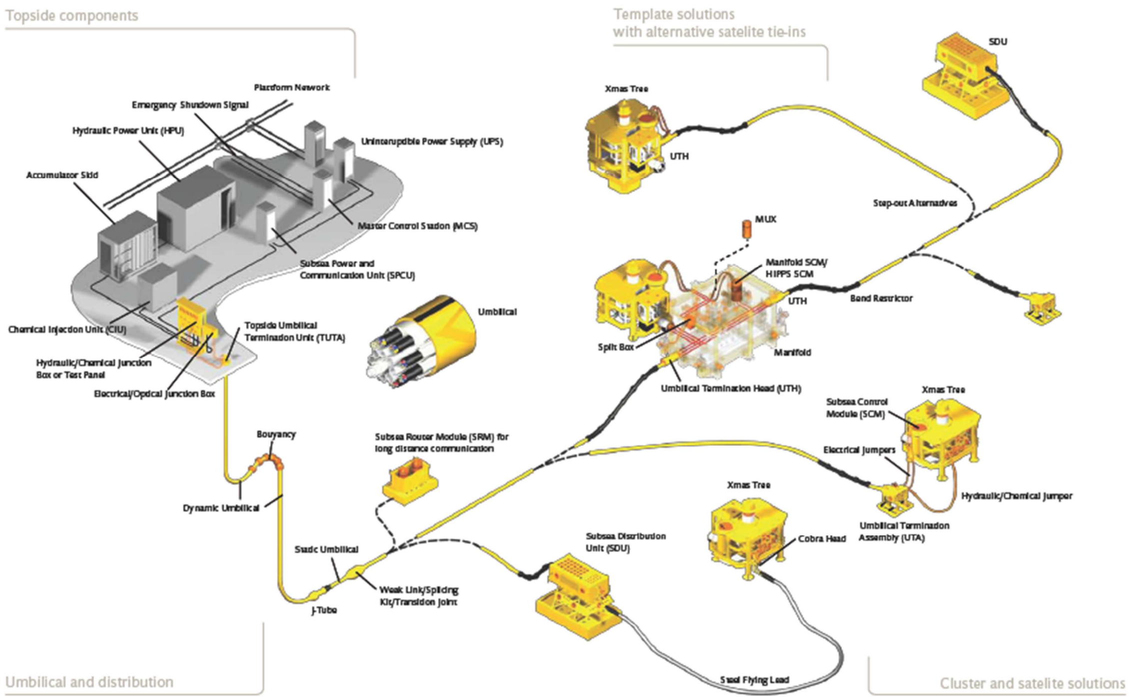


Figure 2-3: Typical Subsea Power Distribution [FMC]

2.2. Electrical Power System

The electrical power system in a typical subsea production system provides power generation, power distribution, power transmission, and electricity from electric motors. The power is either generated on site (from a platform) or onshore (in a subsea-to-beach filed layout). To ensure continuous production from a subsea field, it is of utmost importance that the subsea system's associated electrical power system be designed adequately. Figure 1-4 shows the design process for an electrical power system.

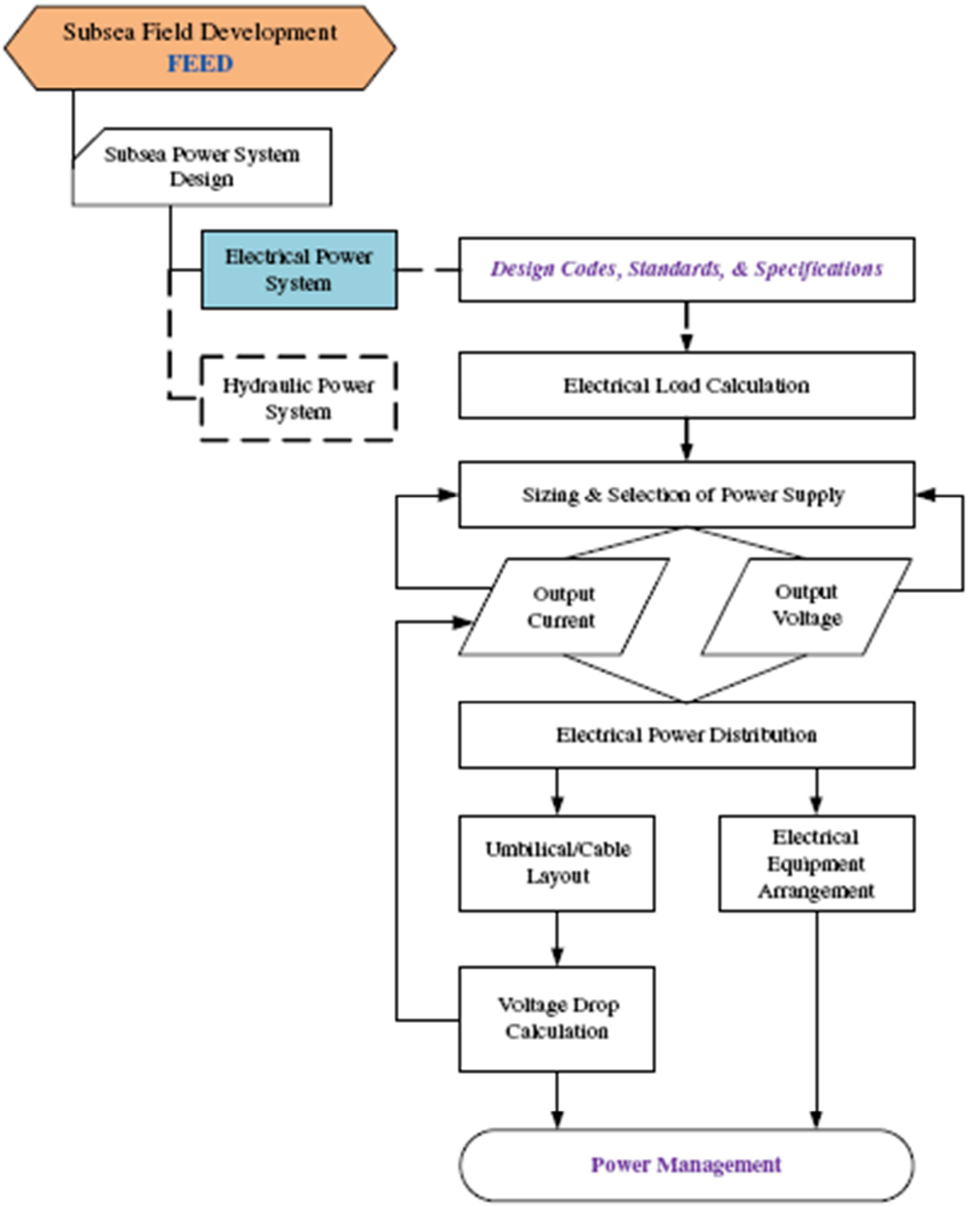


Figure 2-4: Electrical Power System Design Process

2.2.1. Design Codes and Standardization

Various organizations have developed many electrical codes and standards that are accepted by industries throughout the world. These codes and standards specify the rules and guidelines for the design and installation of electrical systems. Tables 2.1 to 2.4 list some of the major international codes and standards used for subsea field development.

Table 2.1: American Petroleum Institute Codes

Codes	Description

API RP 14F	Recommended Practice for Design and Installation of Electrical Systems for Fixed and Floating Offshore Petroleum Facilities for Unclassified and Class I, Division 1 and Division 2 Locations
API RP 17A	Recommended Practice for Design and Operation of Subsea Production Systems
API RP 17H Draft	ROV Interfaces with Subsea Equipment
API RP 500	Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2
API SPEC 17D	Specification for Subsea Wellhead and Christmas Tree Equipment
API SPEC 17E	Specification for Subsea Production Control Umbilicals

Table 2-2: International Electro-technical Commission

Codes	Description
IEC 50 (426)	International Electrotechnical Vocabulary (IEV)-Chapter 426-Electrical Apparatus for Explosive Atmosphere

Table 2-3: Institute of Electrical and Electronics Engineers

Codes	Description
Std. 100	Standard Dictionary of Electrical and Electronics Terms
Std. 141	Electrical Power Distribution or Industry Plants
Std. 399	Recommended Practice for Power Systems Analysis

Table 2-4: International Standards Organization

Codes	Description
ISO 13628-5	Petroleum and Natural Gas Industries -Design and Operation of Subsea Production Systems- Part 5: Subsea Control Umbilicals
ISO 13628-6	Petroleum and Natural Gas Industries -Design and Operation of Subsea Production Systems- Part 6: Subsea Production

2.2.2. Electrical Load Calculation

Electrical load calculation is one of the earliest tasks during electrical power system design. Engineers should estimate the required electrical load of all of the subsea elements that will consume the electricity so that they can select an adequate power supply.

Each local load may be classified into several different categories, for example, vital, essential, and nonessential. Individual oil companies often use their own terminology and terms such as “emergency” and “normal” are frequently encountered. In general terms, there are three ways of considering a load or group of loads and these may be cast in the form of questions as shown in Table 2.5.

Table 2.5: Typical Electrical Load Categories [A.L. Sheldrake]

Load Categories	Classification Questions
Vital	Will the loss of power jeopardize safety of personnel or cause serious damage within the platform/vessel? (YES)
Essential	Will the loss of power cause a degradation or loss of the oil/gas production? (YES)
Nonessential	Does the loss have no effect on safety or production? (YES)

All of the vital, essential, and nonessential loads can typically be divided into three duty categories [A.L. Sheldrake]:

1. Continuous duty;
2. Intermittent duty;
3. Standby duty (those that are not out of service).

Hence, each particular switchboard (e.g., from the EPU) will usually cover all three of these categories. We will call these C for continuous duty, I for intermittent duty, and S for standby duty. Let the total amount of each at this particular switchboard be C_{sum}, I_{sum}, and S_{sum}. Each of these totals will consist of the active power and the corresponding reactive power.

To estimate the total consumption for this particular switchboard, it is necessary to assign a diversity factor to each total amount. Let these factors be D. The total load can be considered in two forms, the Total Plant Running Load ($TPRL$) and the Total Plant Peak Load (TPPL), thus:

$$TPPL = \sum^{n} (D_c \cdot C_{sum} + D_i \cdot I_{sum}) \tag{2.1}$$

$$TPRL = \sum^{n} (D_c \cdot C_{sum} + D_i \cdot I_{sum} + D_s \cdot S_{sum}) \tag{2.2}$$

Where; n is number of switchboards, D_c is diversity factor for sum of continuous duty (C_{sum}), D_i is diversity factor for sum of intermittent duty (I_{sum}), D_s is diversity factor for sum of standby duty (S_{sum}).

Oil companies that use this approach have different values for their diversity factors, largely based on experience gained over many years of designing plants. Besides, different types of host facilities may warrant different diversity factors [A.L. Sheldrake]. Typically, D_c is 1.0 - 1.1, D_s is 0.3 - 0.5 and D_i is 0.0 - 0.2.

The continuous loads are associated with power consumption that remains constant during the lifetime of the system regardless of the operation taking place at any one time. Such consumers would include the Subsea Production Communication Unit (SPCU) which is located on the platform and the monitoring sensors.

Intermittent loads are considered the loads that depend on the operational state of the system. A typical example would be a load due to valve actuation or HPU system activation. For the duration of each operation, the power requirement for the system increases to accommodate the operation. For the definition of the momentary loads, apart from the corresponding power requirement, it is essential to identify the duration and frequency of operations as well as a statistical description of operating occurrences in a specified time period.

Note that at no point during its lifetime should the subsea power system run idle (without load), except for the case of a temporary production shutdown. Tables 2-6 and 2-7 present typical values for continuous and intermittent loads during the operation of electrohydraulic and all-electric production systems, respectively. The data are presented in terms of electrical loads. Note that the use of a choke valve can be either continuous or intermittent, depending on field requirements.

Table 2-6: Load Schedule for an Electrohydraulic Control System [M. Stavropoulos]

Operation	Type	Power Requirement	Frequency (per day)	Duration
HPU	Intermittent	11 kW/pump	2	2 min
Single valve actuation	Intermittent	10 W	1-3	2 sec
Choke valve actuation	Intermittent or continuous	10 W (int)	N/A	2 sec (int)
SEM	Continuous	Max of 80 W	-	-
Sensors	Continuous	Max of 50 W	-	-

Table 2-7: Load Schedule for an All-Electric Control System [M. Stavropoulos]

Operation	Type	Power Requirement	Frequency (per day)	Duration
Single valve actuation	Intermittent	3-5 kW	1~3	45-60 sec
Single valve normal operation	Continuous	20-50 W	-	-
Choke valve actuation	Intermittent or continuous	1e2 kW (int) 60 W (cont	N/A	2 sec (int)
SEM	Continuous	Max of 80 W	-	-
Sensors	Continuous	Max of 50 W	-	-

2.2.3. Power Supply Selection

After the load has been carefully estimated, the ratings for the power supply sources must be selected. For the electrical system applied in offshore oil or gas fields, the power transmission can be from onshore or offshore. Offshore power transmission can occur on the surface or subsea.

2.2.3.1. Power Supply from Topside UPS

Typically, the electrical power supply for a subsea production system is from the Uninterruptible Power Supplies (UPS), which has its own rechargeable batteries. Figure 2-5 shows that for an electrohydraulic control system type, the UPS supplies electrical power to the Master Control Station (MCS), Electrical Power Unit (EPU), and Hydraulic Power Unit (HPU), which then combines the power and other data to the Topside Umbilical Termination Unit (TUTU).

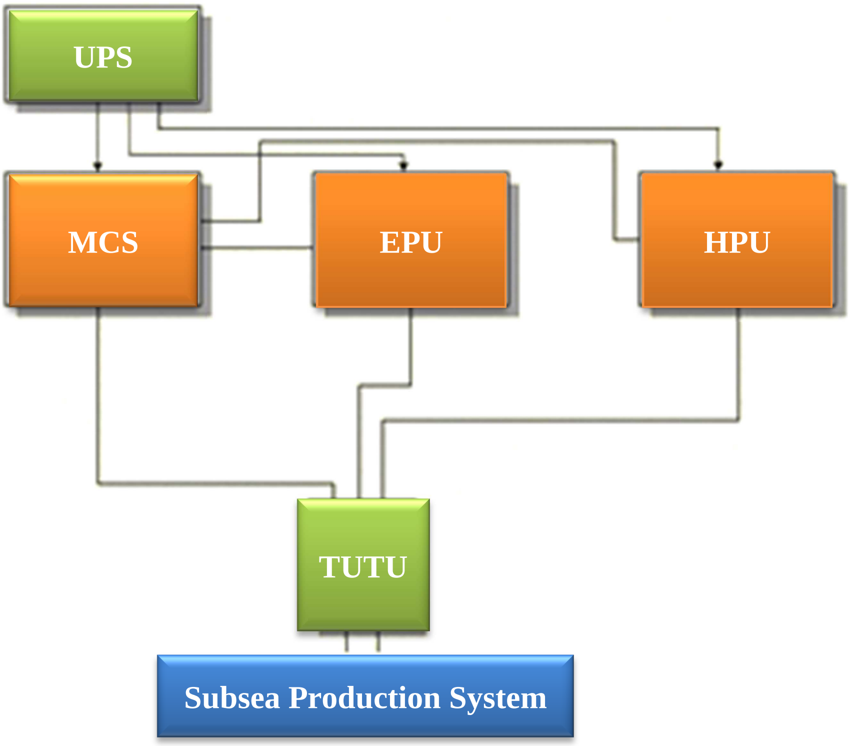


Figure 2-5: Electrical Power Supply for Subsea Production System

Figure 2-6 shows a picture of an Uninterruptible Power Supplies (UPS). The subsea Uninterruptable Power Supply (UPS) provides a reliable power source for a wide variety of subsea applications including Magnetic. The UPS protects the system from electrical power surges and blackouts. Electric power should be supplied from the host platform main supply. The UPS typically operates by rectifying and smoothing the incoming supply, converting it to DC, which can then be used to charge associated batteries. The output from the batteries is then converted back to AC and is ready for use to power the subsea system. In the case of failure of the main incoming supply, the output from the batteries is quickly switched to power the DC-to-AC converter, thus ensuring a constant supply. The UPS builds on proven designs previously deployed and qualified for a 25 year life with a 5 to 10 year battery maintenance cycle.

Figure 2-6: An example of Uninterruptible Power Supplies (UPS).

UPS systems are well known in industry, offices, and today even at home in situations where a power-consuming device must not lose its power supply. UPSs are available in small versions which are able to provide power from about 100 W up to several hundred kilowatts for from a few minutes up to many hours. During this time span the critical equipment supplied with power has either to be transferred into a power-off tolerable state or external power has to be resupplied; that is, grid power has to return or alternative power has to be provided. Usually the UPS is purchased from a specialist manufacture of such devices and is not built by a subsea control system supplier.

2.2.3.2. Power Supply from a Subsea UPS

A UPS is always located as close as possible to the power-consuming device to avoid as many fault sources as possible and is usually under control of the responsible operator of the power-consuming device.

By installing a subsea UPS system, costs may be reduced because fewer cables are required compared to having the UPS located topside because the UPS can be fed from the subsea main power supply. The short-circuit level of a UPS is low and the challenge of having enough short-circuit power available in a subsea installation to achieve the correct relay protection and discrimination philosophy can be solved by having the UPS subsea close to the power consumers.

In general, a subsea UPS can be used in all applications where distribution of low voltage (typically 400 V) is required subsea. The following are typical consumers of low-voltage subsea power supplied by a UPS:

- Several control systems located in a geographically small area;
- Electric actuators for valves;
- Magnetic bearings;
- Switchgear monitoring and control;
- Measuring devices for current and voltage in switchgear, transformers, motors, and other electrical installations.

A conventional UPS comprises an energy storage means and two power converters. A control and monitoring system is also a part of a UPS. Because power conversion involves losses resulting in heat, UPS systems may need cooling systems to transfer the heat to a heat sink [G. Aalvik].

The UPS should be designed to operate safely in the sited environment. The UPS is designed to enable the system to ride through short (seconds to minutes) power losses and to permit sufficient time for a graceful shutdown if necessary.

2.2.3.3. Power Supply from Subsea Generators

Electrical power can also come from subsea generators. Several types of subsea generators have been used in subsea field developments. Autonomous systems consist of an electrical power source which is typically seawater batteries or thermoelectric couplers. The power source utilizes the difference in temperature between the well stream and ambient seawater. The seawater battery solution requires a DC-to-AC converter to transform the voltage from, for example, 1 to 24 V (e.g., an SEM requires a 24-Velectrical power supply). A seawater battery should have the capacity to operate the system for 5 years or more. The thermo-coupler solution requires an accumulator to be able to operate the system when the well is not producing.

2.2.4. Electrical Power Unit

The Electrical Power Unit (EPU) as shown in Figure 2-7 is responsible for providing the electrical power and the communication signal to the Subsea Control Module(s). The EPU is designed with power signal conditioning devices and monitoring instruments to protect the subsea equipment. The panel also typically houses the communications modems and filters to facilitate the communications between the MCS (or SCU) to the Subsea Control Module(s).

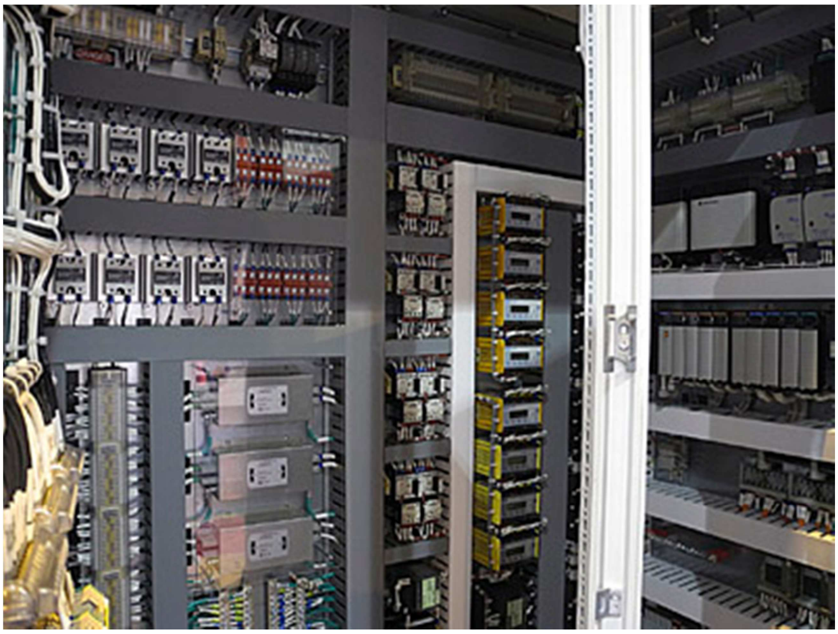


Figure 2-7: Electrical Power Unit [CSE]

The EPU supplies electrical power at the desired voltage and frequency to subsea users. Power transmission is performed via the electrical umbilical and the subsea electrical distribution system.

The EPU should be designed to operate safely in the sited environment and allow for individual pair connection/disconnection and easy access to individual power systems for maintenance and repair. The EPU should contain redundant communication modems and filters to allow user definition of system monitoring, operation, and reconfiguration unless those modems reside in the MCS. The EPU prevents the potential damage (to subsea control modules and MCS) caused by voltage spikes and fluctuations and receives input voltage from a UPS.

The EPU usually has two outputs: a DC busbar and an AC line. The energy storage units are tapped to the DC busbar, whereas the AC output is connected to the SEM.

The typical features of the EPU are as follows:

- Fully enclosed, proprietary powder-coated steel enclosure, incorporated into the MCS suite, with front and rear access;

- Standard design suitable for safe area, that is, a nonhazardous gases area and air-conditioned environment;
- Dedicated dual-channel power supplies, including fault detection to the subsea electronics module;
- Modems and signal isolation to effect the “communications on power” transmission system;
- Control and monitoring to the master control station;
- Electrical power backup input terminal in the event of a power supply outage to both the MCS and EPU.

2.2.5. Electrical Power Distribution

The subsea electrical distribution system distributes electrical power and signals from the umbilical termination head to each well. Electrical power is provided to a subsea system through an electro-hydraulic umbilical. The Subsea Umbilical Termination Assembly (SUTA) is the main distribution point for the electrical supplies to various components of a subsea production system. The SUTA is permanently attached to the umbilical. Hydraulic and chemical tubes from the umbilical can have dedicated destinations or may be shared between multiple subsea trees, manifolds, or flowline sleds.

Electrical cables from the umbilical can also have dedicated destinations to electrical components of a subsea production system or may be shared by multiple SCMs or other devices. The electrical connection is made through electrical connectors on Electrical Flying Leads (EFLs). The number of electrical connectors in series should be kept to a minimum. Redundant routing should, if possible, follow different paths. To minimize electrical stresses on conductive connectors, voltage levels should be kept as low as practical. Figure 2-8 shows the electrical as well as hydraulic power distribution in subsea production system.

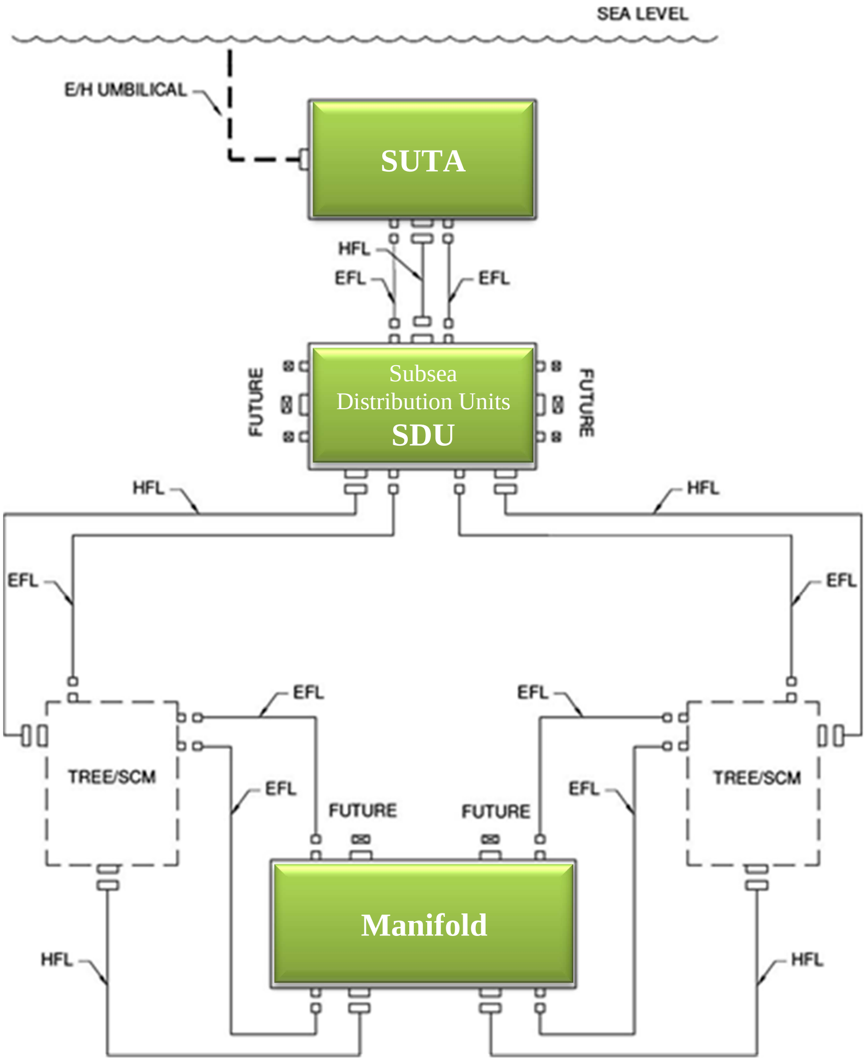


Figure 2-8: Electrical Distribution in Subsea Production System

Connection of electrical distribution cabling and electrical jumpers should be made by ROV or diver using simple tools, with minimum implications on rig/vessel time. Manifold electrical distribution cabling and jumper cables from the umbilical termination to the SCM should be repairable or reconfigurable by the ROV or diver.

The subsea electrical power distribution system differs from a topside system by being a point-to-point system with limited routing alternatives. The number of components shall be kept to a minimum, without losing required flexibility. Detailed electrical calculations and simulations are mandatory to ensure operation/transmission of the high-voltage distribution network under all load conditions (full load, no load, rapid change in load, short circuits).

2.3. Hydraulic Power System

The hydraulic power system for a subsea production system provides a stable and clean supply of hydraulic fluid to the remotely operated subsea valves. The fluid is supplied via the umbilical to the subsea hydraulic distribution system, and to the SCM to operate subsea valve actuators. Figure 2-9 illustrates a typical hydraulic power system.

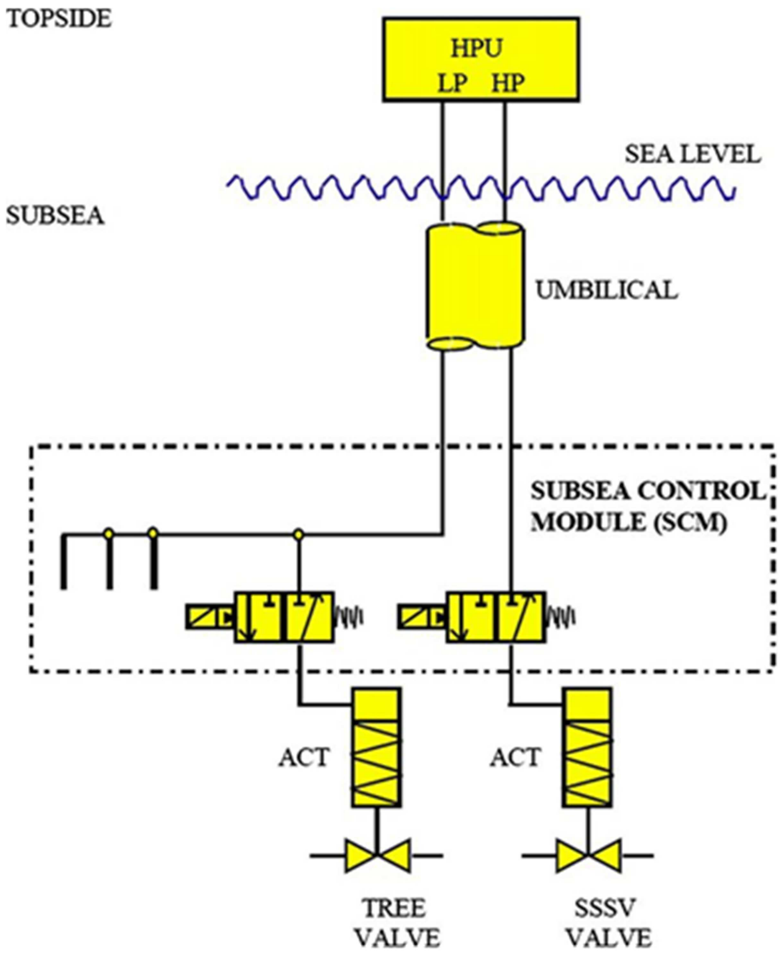


Figure 2-9: Typical Hydraulic Power System

Hydraulic systems for control of subsea production systems can be categorized in two groups as shown in Figure 2.10. The open circuits return fluid from the control module is exhausted to the sea. Open circuits utilize simple umbilicals, but do need equipment to prevent a vacuum in the return side of the system during operation. Without this equipment, a vacuum will occur due to a check valve in the exhaust line, mounted to prevent seawater ingress in the system. To avoid creating a vacuum, a bladder is included in the return line to pressure compensates the return line to the outside water. The closed circuits return fluid is routed back to the HPU through a return line.

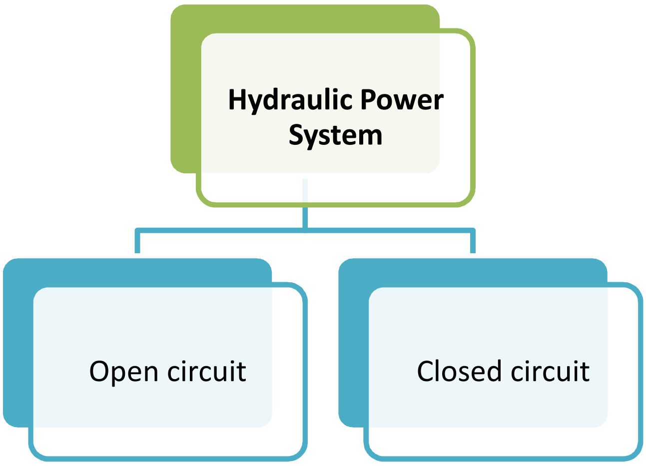


Figure 2.10: Hydraulic power system.

The hydraulic system comprises two different supply circuits with different pressure levels. The LP supply will typically have a 21.0-MPa differential pressure. The HP supply will typically be in the range of 34.5 to 69.0 Mpa (5000 to 10,000 psi) differential pressures. The LP circuits are used for subsea tree and manifold functions, whereas the HP circuit is for the Surface-Controlled Subsurface Safety Valve (SCSSV).

The control valves used in a hydraulic control system will typically be three-way, two-position valves that reset to the closed position on loss of hydraulic supply pressure (fail-safe closed). The valves will typically be pilot operated with solenoid-operated pilot stages to actuate the main selector valve. To reduce power consumption and solenoid size, but increase reliability, it is common practice to operate the pilot stages for the HP valves on the lower pressure supply.

2.3.1. Hydraulic Power Unit

The Hydraulic Power Unit (HPU) is a skid-mounted unit designed to supply water-based biodegradable or mineral oil hydraulic fluid to control the subsea facilities that control the subsea valves. Figure 2.11 shows a typical HPU.

The HPU normally consists of the following components:

1. Pressure-compensated reservoir;
2. Electrical motors;
3. Hydraulic pumps;
4. Accumulators;
5. Control valves;
6. Electronics;

7. Filters;
8. Equipment to control start and stop of pumps.

Figure 2.11: Hydraulic Power Unit [Oilfield Wiki].

Figure 2.12 shows a typical hydraulic power unit schematic. As introduced before, the hydraulic power unit includes two separate fluid reservoirs. One reservoir is used for filling of new fluid, return fluid from subsea (if implemented), and return fluid from depressurization of the system. The other reservoir is used for supplying clean fluid to the subsea system.

PU) (Courtesy of Oceaneering)

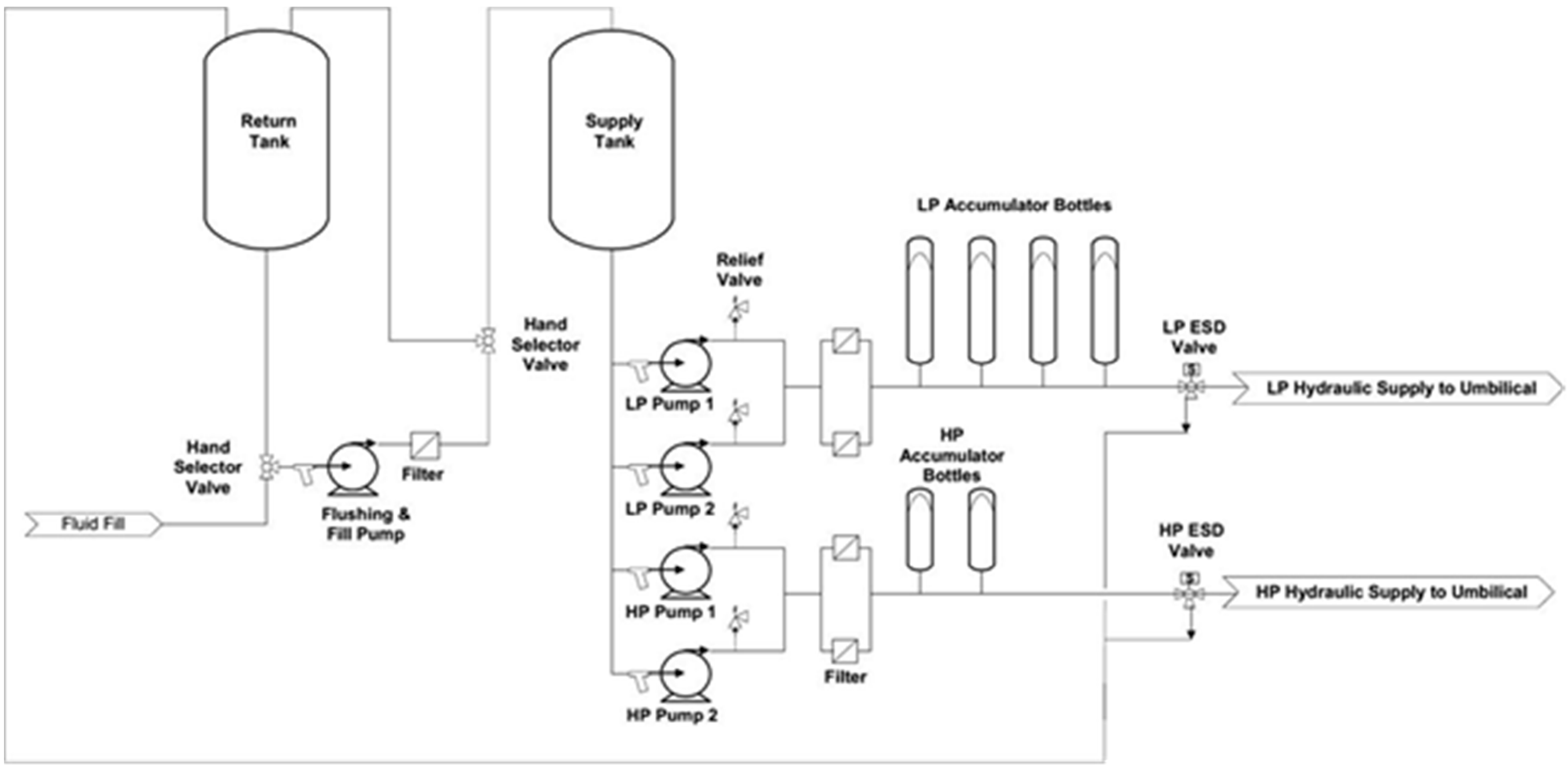


Figure 2.12: Typical Hydraulic Power Unit Schematic

The HPU also provides LP and HP hydraulic supplies to the subsea system. Self-contained and totally enclosed, the HPU includes duty and backup electrically driven hydraulic pumps, accumulators, dual redundant filters, and instrumentation for each LP and HP hydraulic circuit. The unit operates autonomously under the control of its dedicated Programmable Logic Controller (PLC), which provides interlocks, pump motor control, and an interface with the MCS.

Dual hydraulic supplies are provided at both high pressure (SCSSV supply) and low pressure (all other functions). LP supplies are fed to the internal SCM headers via a directional control changeover valve. The changeover valve should be independently operated from the HMI, such that the header can be connected to either supply. Supply pressure measurement should be displayed. HP supplies should be controlled and monitored in a similar manner. The hydraulic discharge pressure of each function is monitored and displayed on the HMI.

2.3.1.1. Accumulators

Accumulators on the HPU should provide pump pressure damping capabilities. They should have sufficient capacity for the operation of all valves on one subsea tree with the HPU pumps disabled. Accumulators would also be of sufficient capacity to accommodate system cycle rate and recharging of the pumps. If all electric power to pumps was lost, the accumulator would have sufficient capacity to supply certain redundancies.

2.3.1.2. Pumps

All pumps should be operational when initially charging the accumulators or initially filling the system on start-up. The pump (and accumulator) sizes should be optimized to avoid excessive pump cycling and premature failure.

The quantity of pumps (and other components) per supply circuit should be determined through a reliability analysis. Pump sizing is deter-mined by hydraulic analysis. Both analyses are performed prior to starting the detailed design for the HPU. Pulsation dampeners are provided immediately downstream of the pumps, if required, for proper operation of the HPU.

All pumps should be electrically driven, supplied from the platform electrical power system. Pumps should have the capacity to quickly regain operating pressures after a hydraulic depressurization of all systems.

There are different types of pumps, but the most common type uses accumulators that are charged by fixed pumps. These pumps, which start and stop at various preprogrammed pressures, are controlled by a PLC.

2.3.1.3. Reservoir

The HPU has a low-pressure fluid storage reservoir to store control fluid and a high-pressure (3000-psi) storage reservoir. One of the two separate fluid reservoirs is used for filling of new fluid, return fluid from subsea (if implemented), and return fluid from depressurization of the system. The other reservoir is used for supplying clean fluid to the subsea system.

Fluid reservoirs should be made from stainless steel and equipped with circulating pumps and filters. Sample points should be made at the lowest point of the reservoir and at pump outlets [NORSOK Standards]. The hydraulic fluid reservoirs should also be equipped with visual level indicators. Calibration of level transmitters should be possible without draining of tanks.

The HPU reservoir should contain level transmitters, level gauges, drain ports, filters, air vents, and an opening suitable for cleanout. The supply and return reservoirs may share a common tank structure utilizing a baffle for separation of clean and dirty fluid. The baffle should not extend to the top of the reservoir so that fluid from overfilling or ESD venting can spill over into the opposite reservoir.

Level Sensor

The reservoir level-sensing system should meet the following requirements:

- The low-level switch should be at a level sufficient to provide a minimum of 5 min of pump operating time.
- The low-level switch should be located at a level above the drain port to prevent the pumps from ingesting air into the suctions.
- The high-level switch should be located at a level equal to 90% of the reservoir capacity.

Control Fluid

The control fluids are oil-based or water-based liquids that are used to convey control and/or hydraulic power from the surface HPU or local storage to the SCM and subsea valve actuators. Both water-based and oil-based fluids are used in hydraulic systems.

The use of synthetic hydrocarbon control fluids has been infrequent in recent years, and their use is usually confined to electrohydraulic control systems. Water-based hydraulic fluids are used most extensively. The characteristics of high water content–based control fluids depend on the ethylene glycol content (typically 10% to 40%), and viscosity varies with temperature (typically 2_ to 10_C). Because government regulations do not allow venting of mineral-based oil into the sea, if the system uses this type of fluid, it must be a closed-loop system, which adds an extra conduit in the umbilical, making it more complex. Required fluid cleanliness for control systems is Class 6 of National Aerospace Standard (NAS) 1638 [National Aerospace Standard].

The water-based hydraulic fluid should be an aqueous solution. The oil-based hydraulic fluid should be a homogeneous miscible solution. The fluid should retain its properties and remain a homogeneous solution, within the temperature range, from manufacture through field-life operation.

The first synthetic hydrocarbon control fluid was utilized on Shell’s Cormorant Underwater Manifold Centre in the early 1980s. This type of control fluid has low viscosity, great stability, and excellent materials compatibility, and is tolerant of seawater contamination. This fluid requires the control system to incorporate return lines and an oil purification system (filter, vacuum dehydration to remove water). The cost of synthetic hydrocarbon control fluids is approximately four times that of mineral hydraulic oils.

The first water-based control fluid was utilized on Statoil’s Gullfaks development in the early 1980s. This type of control fluid has a very low viscosity and is discharged to the sea after use. This fluid requires the control system to incorporate higher specification metals, plastics, and elastomers. The cost of water-based control fluids is approximately twice that of mineral hydraulic oils.

Control fluid performance influences control system safety, reliability, and cost of ownership. Control fluids also affect the environment. The control fluid performances are as follows:

- The control fluid must be capable of tolerating all conditions and be compatible with all materials encountered throughout the control system.

- The control fluid is a primary interface between components and between subsystems. It is also an interface between different but con-nected systems.
- To maintain control system performance, system components must continue to function within their performance limits for the life of the systemdand that includes the control fluid.
- Any reduction in control fluid performance can have an adverse effect throughout the control system. The factors that can reduce the performance of a control fluid in use are as follows:
- Conditions exceeding the operating parameters of the control fluid;
- Poor product stability, resulting in a reduction in control fluid performance over time;
- Contaminants interfering with the ability of the control fluid to function.

2.3.1.4. Control and Monitoring

The HPU is typically supplied with an electronic control panel, including a small PLC with a digital display, control buttons, and status lamps. The electronics interface with other system modules, for remote monitoring and control. The HPU parameters monitored from the safety automation system should typically be:

- Non-regulated supply pressure;
- Regulated supply pressure;
- Fluid levels;
- Pump status;
- Return flow (if applicable).

The control panel may be a stand-alone or an integral part of the HPU. It utilizes a series of valves to direct the hydraulic and/or electric signals or power to the appropriate functions.

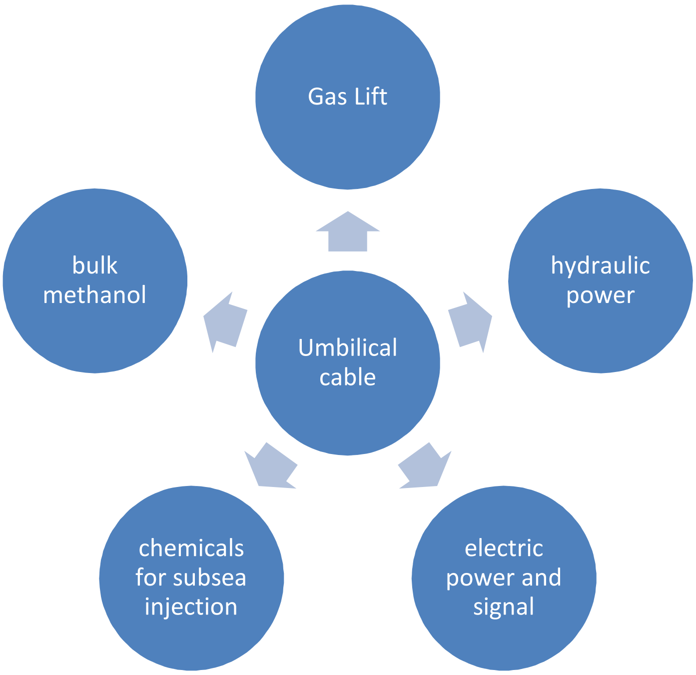
Displays should be required to indicate hydraulic power connections from the HPU to the topside umbilical termination (or distribution) units, riser umbilicals, and subsea distribution to the individual hydraulic supplies to the SCMs. Links should be provided to individual hydraulic circuit displays.

Chapter.3

3.0 Subsea Transmission System

3.1. Umbilical Cable

In subsea operation system, the power and communication are transmitted using a bundle of tubes and cables called Umbilical cable. Subsea umbilical is a cable and/or hose which supplies required consumables to an apparatus. The umbilical cable is able to provide and deliver:



A subsea umbilical can supply air and power to a pressure suit or hydraulic power, electrical power and fiber optics to subsea equipment and divers. Subsea umbilical is installed between the host facility and the subsea facility. In general, the umbilical includes a catenary riser transitioning into a static segment along the seabed to the Umbilical Termination Assembly (UTA) at the subsea facility. For shorter lengths, the segments may be identical. The umbilical pull-head will include a split flange (or other) assembly for hang-off of the umbilical at the host facility. A bend stiffener or limiter may be installed at the top of the catenary riser and at the UTA.

General requirements for the umbilical system include:

- Electrical power, control, and data signals should, as a base case be contained on the same pair of conductors.
- Super duplex steel tubes should be used. (Other materials can be considered but substantial documentation should be required to guarantee their applicability.)
- The umbilical is fabricated in one continuous length.
- The umbilical system is designed without any planned change-out over the design life.

A subsea umbilical is a combination of electrical cables, fiber optic cables, steel tubes, and thermoplastic hoses, or two or three of these four components that execute specific functions. These components are assembled to form a circular cross section. The functions and characteristics of the four umbilical components are described and specified in the following sections of this chapter.

Umbilicals are used in various ways by the offshore industry today. The main functions are listed below and described in the following sections:

- Subsea production and water injection well control;
- Well workover control;
- Subsea manifold or isolation valve control;
- Chemical injection;
- Subsea electrical power cable.

Figure 3.1 shows a typical subsea control umbilical and its cross section. The umbilical delivery procedure typically includes the following steps and schedule:

- Feasibility study;
- Umbilical specifications and request for quotation;
- Qualification tests for fatigue and other tests (specifications and execution);
- Long-lead item procurement;
- Bid evaluation;
- Supplier selection;
- Project sanction and umbilical procurement;
- Detailed umbilical design and analysis by the supplier;
- Third-party design verification by an analysis specialist;
- Prototype qualification tests;
- Umbilical manufacturing (normally requires a period of 1 year);
- System integration test;
- Umbilical delivery to host vessel;

- Commissioning;
- System start-up;
- Project management, QA/QC.

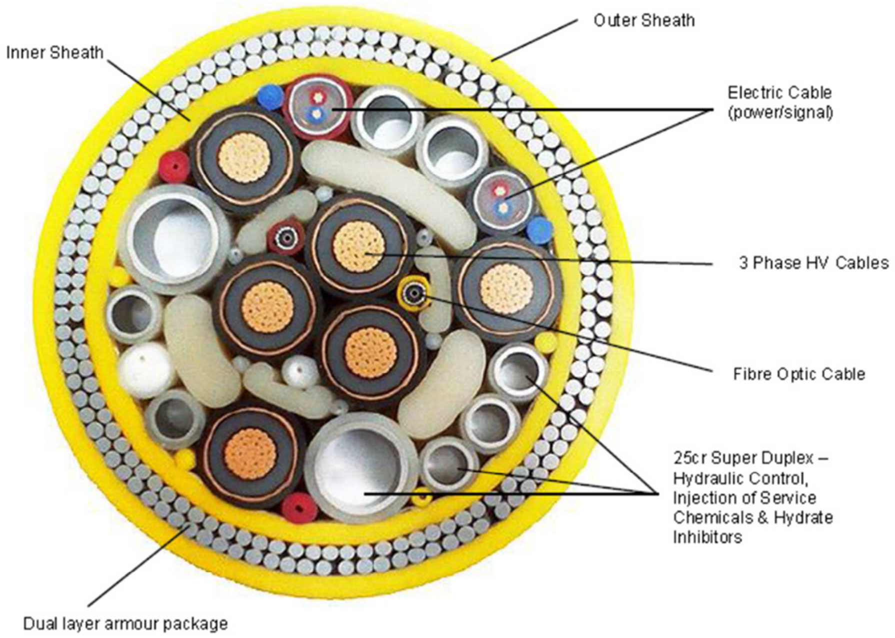


Figure.3.1: Subsea control umbilical example

One of the earliest papers dealing with steel tube umbilical design was “Metal Tube Umbilicals Deep water and Dynamic Considerations” [R.C. Swanson]. Another useful publication for further information is ISO 13628-5 [ISO], which is used as the standard for umbilical design and operation.

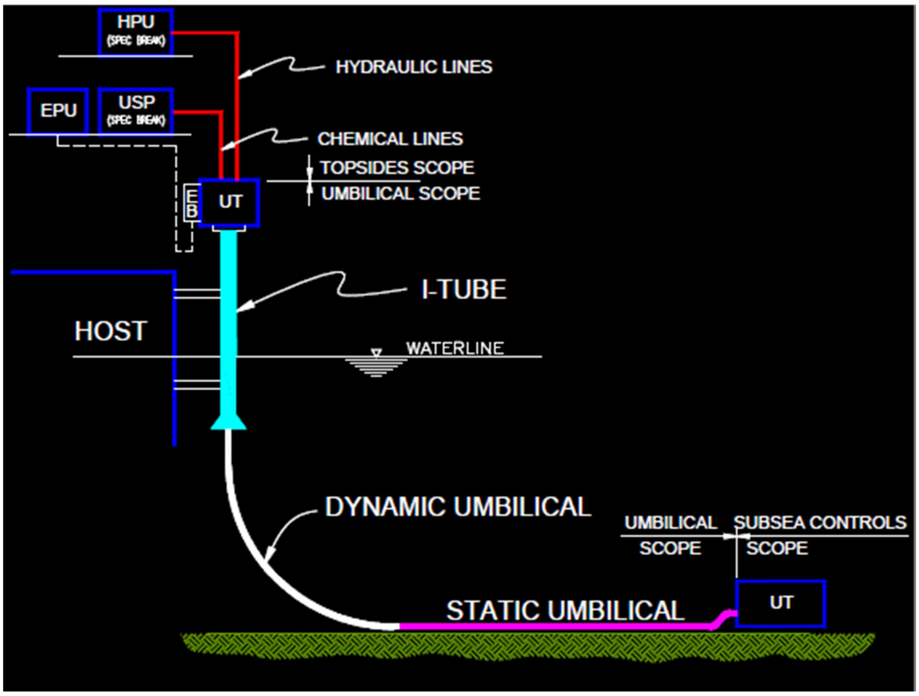


Figure 3.2: Subsea umbilical system diagram [Oildfield]

3.2. Umbilical System Components

A subsea umbilical consists of electrical cables, fiber optic cables, steel tubes, and thermoplastic hoses as shown in Figure 3.3. It may also include two or three of these four components for executing specific functions. The umbilical components are designed and manufactured to meet the umbilical functional and technical requirements. Proper materials are chosen to manufacture the components, and verification and acceptance tests are done to demonstrate the conformance to the component functional and technical requirements. The functions and characteristics of the four umbilical components are described and specified in the following sections.

A deep water umbilical can include Chemical injection tubes, Hydraulic supply tubes, Electrical control signal cables, Electrical Power cables, Fiber optic signal, Large tubes for gas lift.

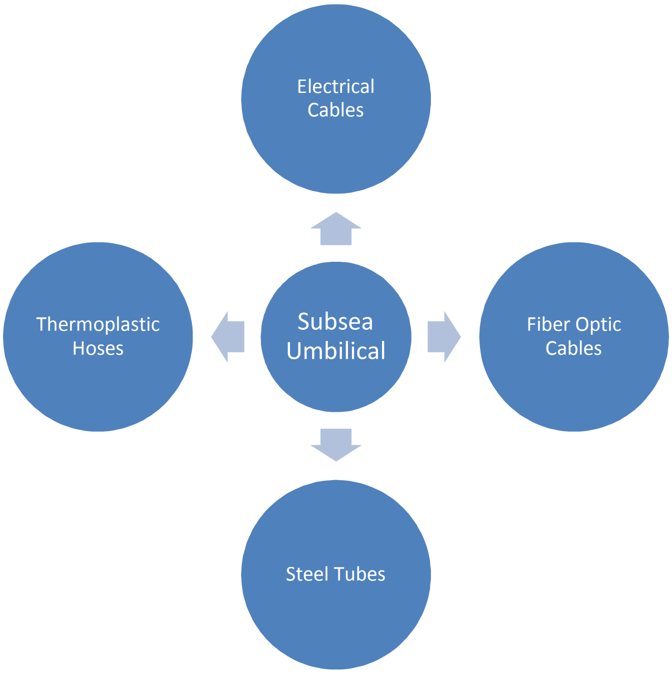


Figure.3.3: Subsea umbilical component

3.2.2. Electrical Cable

The electrical cables are divided into two types: power cables and signal/ communication cables. Usually the power cable and signal cable are combined into one cable, which is called a power and control umbilical.

3.2.2.1. Power Cables

Power cables are used for the power supply of offshore platforms and subsea production equipment, such as control pod, pilot control valve, and electric pumps. According to Section 7.2.2.1 of ISO 13628-5 [ISO], power cables voltage ratings are selected from a range of 0 V up to the standard rated voltages U0/U(Um) ¼ 3.6/6 (7.2) kV RMS, where U0, U, and Um are as defined in IEC 60502-1 and IEC 60502-2.

3.2.2.2. Signal/Communication Cables

Signal/communication cables are usually used for the remote control/ monitoring of subsea production equipment, such as operation of a pilot control valve, feedback of wellhead status, and operating parameters.

According to Section 7.2.2.2 of ISO 13628-5 [ISO], signal/communication cables are selected from a range of 0 V RMS up to U0/U (Um) ¼ 0.6/1.0 (1.2) kV RMS, where U0, U, and Um are as defined in IEC 60502-1 and IEC 60502-2.

3.2.3. Fiber Optic Cable

Fiber optic cables are capable of continuous operation when immersed in a seawater environment. The fiber type is of either single-mode or multi-mode design. The design is as given in the manufacturer's/supplier's specifications. Individual fiber identification is by means of fiber coloring.

The fibers are contained within a package that prevents water and minimizes hydrogen contact with each fiber. The carrier package for mechanical protection and its contents are designed to block water ingress in the event that the fiber optic cable in the umbilical is severed.

3.2.4. Steel Tube

Umbilical steel tube referred to as super duplex steel tube is capable of continuous operation when immersed in a seawater environment and when it meets the requirements of ASTM A240 for either UNS S32750 or S39274 chemistries and the additional requirements specified herein and listed below:

- The tube is made by the pilger or cold-drawn process from tube hollows that should be 100% visually inspected prior to processing. Hollows should be demonstrated to meet the product chemistry requirements.
- The tube is in-line batch or continuously furnace or induction annealed in a nonoxidizing annealing atmosphere at a temperature and quench rate to be determined by the manufacturer.
- The tube may be built up on reels to the specified length by automatic or-bital welding in accordance with preprogrammed and approved procedures.
- The tube meets all of the applicable material and process requirements of NACE MR-01-75.
- All tube lengths are cleaned to NAS 1638 Class 6 and measures taken to ensure contamination do not occur during transport and storage prior to incorporation into umbilical lengths.

3.2.4.1. Steel Tube Materials

Super Duplex Stainless Steel (SDSS) is the preferred material for deepwater umbilicals because it requires no cathodic protection, is lightweight and strong, has been qualified by major operators and manufacturers for dynamic service, is usually pilgered rather than seam-welded, and has a successful track record. The most commonly used is 2507, which contains 25% chromium and 7% nickel.

SDSS is duplex stainless steel which, combined with the high chromium and nickel content, give it a pitting resistance equivalent (PRE) of greater than 40, the threshold for use in a seawater environment of less than 60 degrees Celsius without cathodic protection. PRE is calculated for SDSS using the following formula:

$$PRE = \%Cr + 3.3 \cdot (\%Mo + 0.5 \cdot \%W) + 16 \cdot \%N \qquad (3.1)$$

SDSS is generally more expensive than other materials, and in periods of high activity may add significant time to delivery of the umbilical. Seam welded tubing is available, and is gaining acceptance in some sectors of the market. Welding of SDSS tubing is problematic, particularly in sizes between 1" and 4" diameter.

Zinc-coated Nitronic 19D is a lean duplex stainless steel, which has a lower chromium and nickel content than SDSS. It is lower in cost than SDSS, but has less tensile strength, and requires cathodic protection, provided by the zinc coating which is extruded onto the outside surface of the completed tube. It has been qualified for dynamic service. It is thicker-walled and heavier than SDSS for the same pressures and water depths, and is seam-welded, but may be used where these risks are acceptable, and lower cost drives the decision. Risks of seam welds may be mitigated using full volumetric inspection, or by adding a spare tube to the umbilical.

Fusion-bonded-epoxy-coated Coiled Tubing is used for larger tubes (typically over 1"), where cost and/or delivery are key drivers. It has a standard epoxy coating to protect from corrosion, a layer of bonding agent, and an HDPE outer coating. It is seam welded. Concerns are corrosion due to holidays in the coating, and leaks in the seam welds.

316L Stainless Steel is sometimes used where expected field life is less than 5 years and pressures required are less than 3000 psi. It is not qualified for dynamic service. Its advantages are low cost and quick or even off-the-shelf delivery.

Where mostly low pressure is required (e.g. to operate the valves on a low-pressure tree), but at least one higher pressure tube is required (e.g. to operate the SCSSV), one or more 19D tubes may be added to a mostly 316L umbilical.

3.2.5. Steel Tube Electrohydraulic Umbilical

3.2.5.1. Simple, static umbilical for few wells, shallow to medium depths

The subsea field in the image as shown in Figure 3.4 is a small shallow water development consisting of:

- three wells
- a manifold with a pigging loop
- jumpers from the wells to the manifold (ROV-installed)
- dual pipelines terminating in pipeline end termination skids (PLETs)
- jumpers from the PLETs to the manifold
- an umbilical terminating in an umbilical termination assembly (UTA)
- electrical and hydraulic flying leads from the UTA to each subsea well

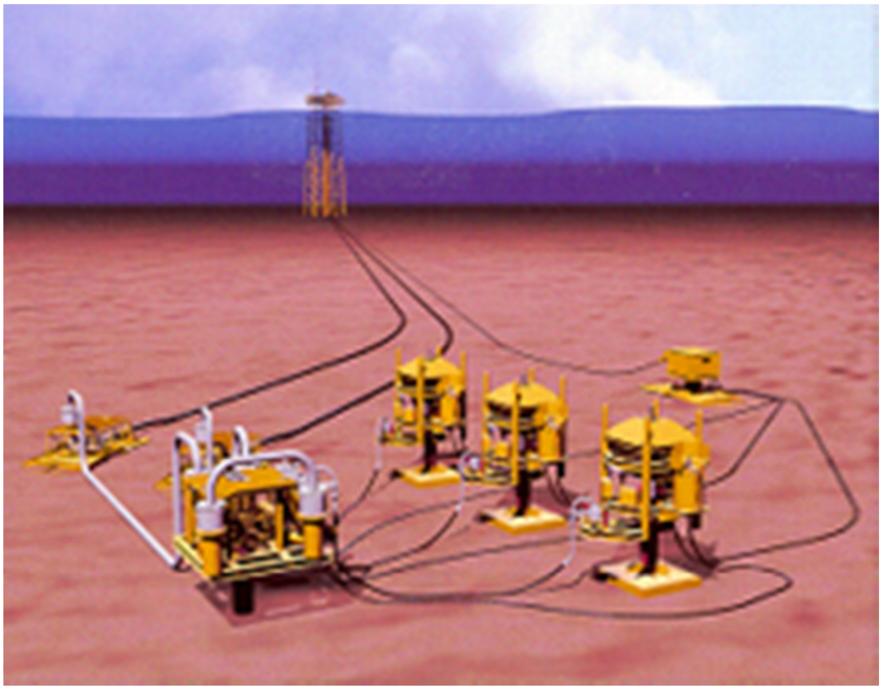


Figure.3.4: Shallow subsea field development

The platform to which all this ties back is a bottom founded jacket-and-pile structure. The umbilical is therefore pulled from the sea bottom to the deck through a tube, or is otherwise supported throughout its entire ascent. It is a static umbilical. Because it is static, and because the field is relatively small, a simple umbilical like the one depicted in the image as shown in Figure 3-5 would work.

A simple electrohydraulic (EH) umbilical will have the following components:

- steel tubes to deliver chemicals and hydraulic power to the subsea production system. There may be one or more backup tubes for use in case of tube failure. Tubes may be sheathed in LDPE to achieve the proper cross-sectional geometry.
- one or more electric cables (usually quads of 4 to 10 square mm)to deliver power and multiplexed signal to the subsea control system, and to carry instrumentation signals back to the surface control station.
- fillers to help create the proper cross-sectional geometry.
- tape which is wrapped around the elements as they are bundled and twisted into an umbilical. This holds the entire assembly together until it is passed through the extrusion head to receive its HDPE sheathe.
- HDPE Sheathe

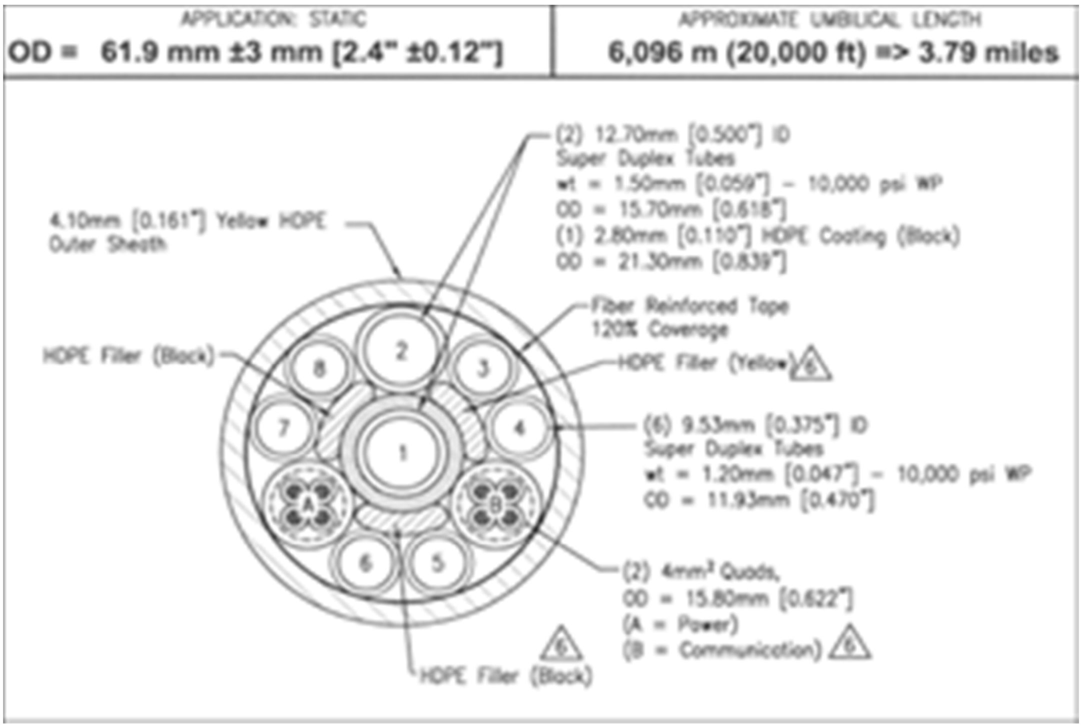


Figure.3.5: Simple umbilical

3.2.5.2. Complex, dynamic umbilical for deepwater, multiple wells or drill centers

The subsea field pictured in the image as shown in Figure 3-6 (left) is a large, complex field, with multiple wells, arranged in multiple drill centers, each with the elements described in the simple well scenario described above. In this case, the umbilical is suspended from a floating host platform, a semisubmersible. It is therefore a dynamic umbilical. A large, complex electrohydraulic (EH) umbilical may have the following features, in addition to those included in the simple umbilical:

- cables will be armored for dynamic applications, at least from the hang-off point through the wave-affected zone, and through the touchdown point
- steel tubes may be sheathed for wear protection where they are in contact with other steel tubes in the dynamic zone
- steel rods or cable may be added to achieve the correct weight-to-diameter ratio to avoid clashing with other risers hung off nearby
- armor may be added for weight-to-diameter ratio, tensile strength, and crush-resistance during installation (above right cross-section)
- fiber optics may be added in place of or in addition to signal cables
- the umbilical may be bundled in two or more passes, necessitating additional layers of tape

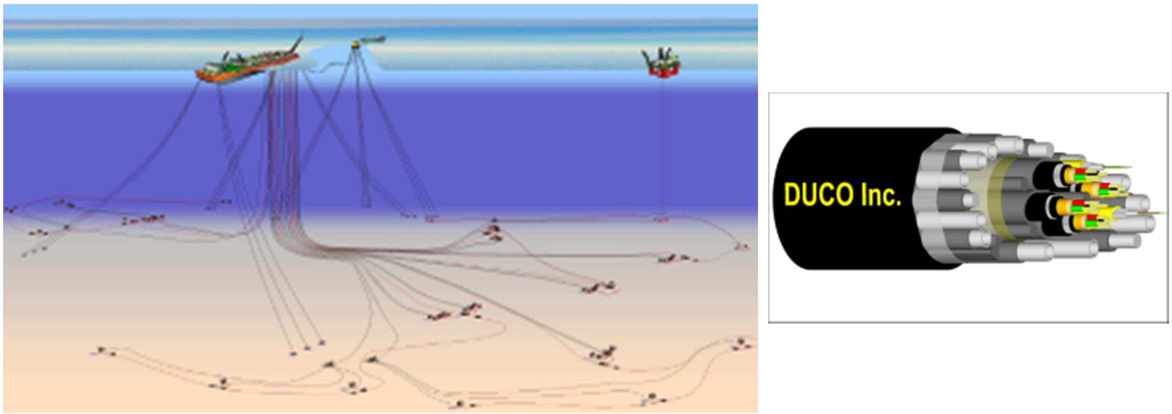


Figure 3-6: Deep water subsea field development

3.2.5.3. Special case- Aker

Aker builds umbilicals slightly differently than other bundlers:

- the pitch of the helical wind is about 2% rather than the usual 6-7%

- the tubes and cables are held in a matrix made up of reeled elements which lock together as they are bundled into the umbilical
- carbon rods may be included in umbilicals designed for very deep water, to provide tensile strength without adding significant weight.

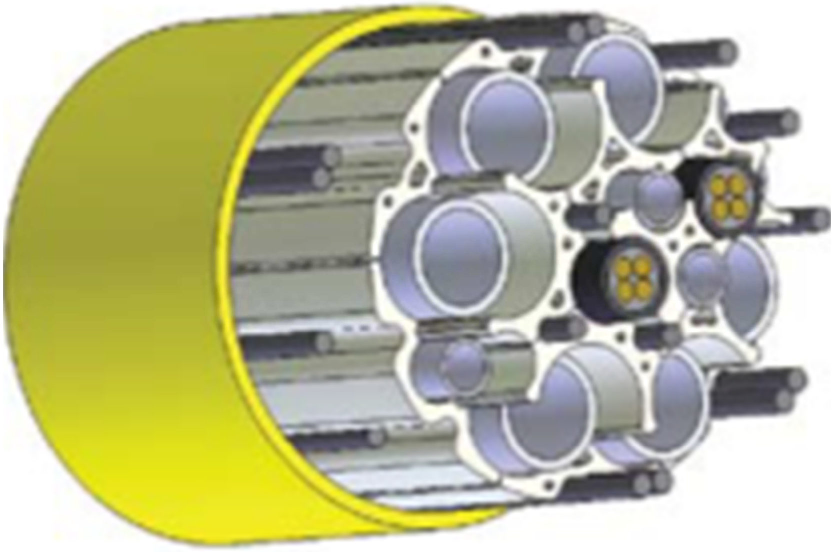


Figure 3-7: Complex umbilical

3.2.6. Thermoplastic Hose

Thermoplastic hose is capable of continuous operation when immersed in a seawater environment.

3.2.7. Thermoplastic Electrohydraulic Umbilical

Thermoplastic umbilicals are constructed from thermoplastic hoses which are kevlar-armored and outer-sheathed by the umbilical manufacturer. The umbilical shown in the image at left does not include cables, but could. No assembly machine with counter-rotating bobbins is required to remove torsion from the tubes and cables because they are not helically wound, but oscillated as they are pulled through the closing die. Typically the umbilical must be armored to provide tensile strength, ensure on-bottom stability, and resist crushing loads from the installation tensioner.

High collapse resistance hoses may be included for umbilical to be deployed at deeper depths. Collapse resistance is provided by an internal carcass, much like flexible pipe.

Chemicals used for injection downhole or further downstream may be incompatible with the hose material. The umbilical manufacturers have experience with many chemical cocktails, so may have experience with the combination of chemicals the operator plans to use. If not,the operator may commission an accelerated compatibility test.

While not suitable for very deep water, and rarely used in the Gulf of Mexico, thermoplastic umbilical is still commonly used in shallow water, and where large swells cause fatigue at the touchdown point, such as Eastern Canada, West Africa, and Brazil.

Armoring Machine

Figure 3.8: Thermoplastic Electrohydraulic Umbilical

3.3. Static and Dynamic Transmission Systems

3.3.1. Static Transmission System

The design of umbilical incorporates mechanical strength to withstand crushing and tensile loads during handling, installation, and service. The umbilical is also of sufficient weight to ensure satisfactory seabed stability. The umbilical and its pulling head/termination design allow for installation into the facility approach.

Wall thicknesses of steel tube elements are sized to meet requirements for allowable stresses under all installation and operational conditions. Other design analyses calculate:

- Maximum allowable tension and minimum breaking strength;
- Recommended back tension during lay;
- Strength of terminations;
- The effect of radial loads (collapse pressure);
- The effect of dropped objects and snagging (e.g., ship’s anchor);
- The effect of installation tensioning devices;
- Maximum allowable impact loads;
- Bend radius and bending stiffness;
- Torsional balance;
- Hydrodynamic stability on seabed;
- Environmental loads and hydrodynamic stability of beach approach;

- Material and outer sheathing suitability for onshore applications.

3.3.2. Dynamic Transmission System

The umbilical system is expected to operate in a static mode after installation. However, the umbilical system will be subject to dynamic loading during installation and to environmental loads in the facility approach. Further, potential unsupported spans along the seabed may be subjected to fatigue owing to vortex-induced vibrations (VIVs). Dynamic and fatigue analysis should be carried out to evaluate fatigue properties of the umbilical system given the anticipated installation and environmental loads and to establish the maximum allowable span lengths. Minimum required fatigue life may be 10 times design life.

3.4. Design of Dynamic Umbilical

The design of a dynamic umbilical is an iterative process, and is time consuming. It may even become the critical path, depending on market conditions for tubes, cables, bundling, etc. if not expedited.

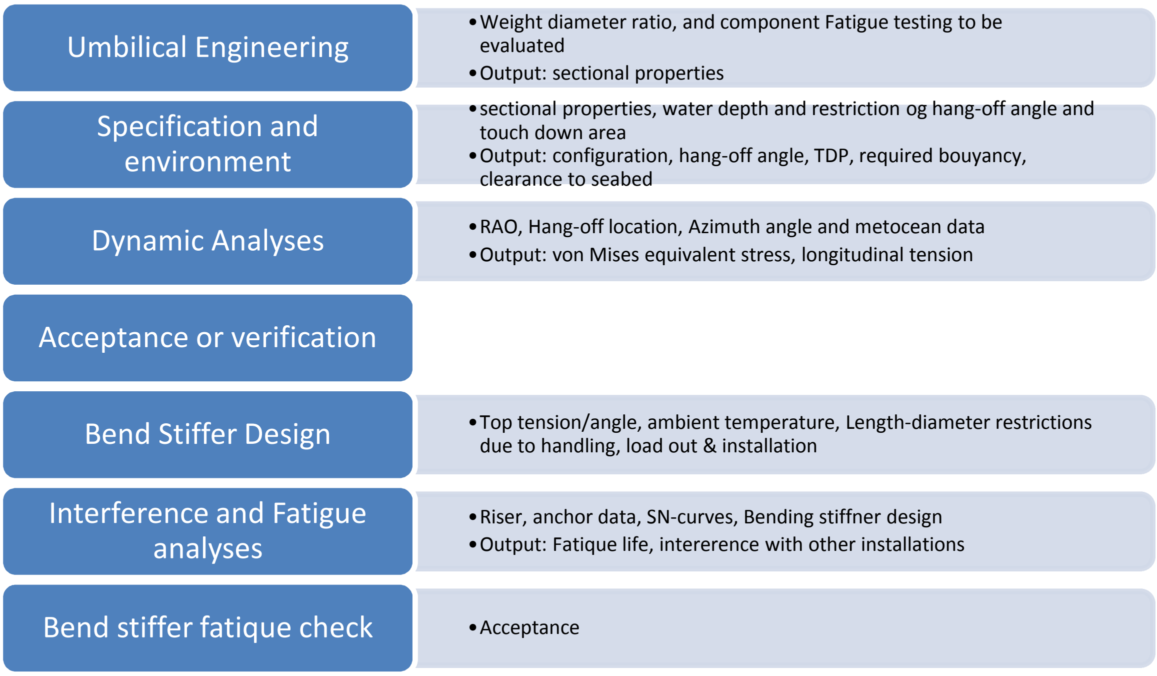
3.2.1. Design Concerns

1. Fatigue(Vessel motion, waves, currents, and vortex induced vibration)
    a. Motions at hang-off point- bend stiffener design
    b. Tube friction
    c. Motions at touchdown point
    d. Vortex induced vibration (VIV)
2. Interference- clashing with other risers- this may be mitigated by
    a. weight to diameter ratio
    b. hang-off angle,
    c. bend stiffener design
3. Accumulated Plastic Strain (Strain Budget)- includes strain from
    a. initial coiling of tubes on bobbins
    b. bundling of umbilical
    c. coiling of umbilical on reel or carousel

   d. installation,
   e. repair (retrieval and re-installation)
4. Hang-off Weight
5. Tensile Strength

3.2.2. Design Process

The following graphic illustrates the iterative nature of umbilical design.



Umbilical Engineering	• Weight diameter ratio, and component Fatigue testing to be evaluated • Output: sectional properties
Specification and environment	• sectional properties, water depth and restriction og hang-off angle and touch down area • Output: configuration, hang-off angle, TDP, required bouyancy, clearance to seabed
Dynamic Analyses	• RAO, Hang-off location, Azimuth angle and metocean data • Output: von Mises equivalent stress, longitudinal tension
Acceptance or verification	
Bend Stiffer Design	• Top tension/angle, ambient temperature, Length-diameter restrictions due to handling, load out & installation
Interference and Fatigue analyses	• Riser, anchor data, SN-curves, Bending stiffner design • Output: Fatigue life, intererence with other installations
Bend stiffer fatique check	• Acceptance

Figure 3-9: Iterative nature of umbilical design.

3.2.3. Conceptual Design

1. Preliminary Cross-Section Sizing
   a. Tube sizing;
   b. Possible interaction with vendors.
2. Preliminary Configuration Design
   a. Strength, interference, etc.;
   b. Preliminary component design;
   c. Early confirmation of feasibility.
3. Early Identification of Manufacturing Issues
   a. Issues affecting bid or spec requirements.

Service Environment

The umbilical is designed for immersion in seawater for the specified design life. Consideration should also be given to

- Storage prior to installation;
- Exposure to service fluids;
- The seabed and topsides environment in terms of radiation, ozone, temperature, and chemicals;
- Imposed dynamic conditions within the free-hanging regions
- Protection against dropped objects.

3.2.4. Detailed Design

Parameters

- Temperature range;
- Maximum working load;
- Minimum breaking load;
- Minimum bend radius;
- Dynamic service life.

On-Bottom Stability Study

The umbilical is designed to be sufficiently stable, when laid on the seabed, for the seabed condition and seabed current values.

The behavior of the umbilical on the seabed can be characterized by friction coefficients in the axial and lateral directions.

Cross-Sectional Design

One of the initial stages in the design of an umbilical is the placing of the components of the umbilical in the cross-section design. The cross section of an umbilical could include various items such as steel tubes for transporting hydraulic and other fluids, electrical cables, fiberoptic cables, steel rods or wires for strength capacity, polymer layers for insulation and protection, and polymer fillers to fill in the spaces between the components and keep them in place.

Manufacture Design

- Lay-up;
- Sub-bundles;
- Inner sheath;
- Armoring;
- Outer sheath.

An outer sheath is applied as a continuously extruded thermoplastic sheath or as a covering of helically applied textile rovings.

3.5. Manufacture

The procedures for umbilical manufacturing should be in accordance with ISO 13628-5 [ISO].

3.3.1. Lay-Up

Lay-up operations are carried out in a clean, dedicated, controlled area, which is subject to a regular cleaning schedule.

Optimum fiber optic cable and hose or steel tube lay-up configurations, fillers, etc., are provided to minimize the overall diameter and weight while meeting the general performance and construction specifications and to ensure good flexibility.

Lay-Up Configuration

The minimum lay angle of the umbilical components should be confirmed. Umbilical components, steel tube, and optical fiber will be laid up in a continuous helix or planetary configuration. If hoses are used an oscillatory cabling technique will be used.

Damaging Pull

The cabling or lay-up is designed so that the individual components will not be strained, deformed, or otherwise affected when the components are subjected to a tensile pull. A table of maximum allowable tension on umbilical components throughout the manufacture process should be summarized and submitted.

Acceptance Testing

After cabling of the umbilical hoses or steel tubes, the following checks are conducted prior to extrusion of the inner/outer sheath on the umbilical. A hydraulic proof test of hoses or steel tubes is conducted after each cabling layer (1.5 times working pressure).

3.3.2. Inner Sheath

The operation is carried out in a clean dedicated, controlled area, which is subject to a regular cleaning routine. The total cabled assembly is protected with an inner sheath extruded tightly over a taped assembly. The extrusion of the inner sheath OD should be monitored in two planes 90_ apart.

3.3.3. Outer Sheath

The total cabled assembly is protected with an overall jacket extruded tightly over the assembly. The extrusion of the outer jacket OD is monitored in two planes 90_ apart.

3.3.4. Marking

The marking of subsea umbilicals should usually be done according to Section 9.14 of ISO 13628-5 [ISO].

3.3.5. Main Manufacturers

The main subsea umbilical manufactures in the world are listed below:

DUCO

Duco offers a comprehensive range of umbilical engineering, design, and support services including:

- Mechanical testing of components and umbilicals;
- Design and supply hardware for topsides and subsea, including pulling heads, umbilical hang-offs, subsea terminations, and repair joints;
- Dynamic analysis;
- Umbilical and hardware analysis, including finite element analysis.

Kvaerner Oilfield Products

Aker Solutions provides cost-effective and technically advanced steel tube umbilical technologies, including:

- Electrohydraulic umbilicals;
- Carbon fiber–enhanced deepwater dynamic umbilicals;
- Large central tube integrated service umbilicals;
- Medium- and high-voltage power umbilicals;
- Reliable horizontal bundling and extrusion machines;
- Deepwater access to installation/transportation vessels;
- High-capacity processing and storage carousels;
- On-site welding and test facilities.

They also provide integrated production umbilicals and deepwater dynamic umbilicals.

Nexans

Nexans is a leader in the cable industry and has developed a new generation of umbilicals that uses stainless steel tubes. Nexans provides umbilicals for many companies and projects. Nexans is furnishing power umbilicals for the King Subsea Pump project, and in the Gulf of Mexico, 117 km of umbilicals for the Atlantis and Thunder Horse projects. For Dolphin Energy in Qatar, it is producing, transporting, and installing a 90-km plus 70-km umbilical.

3.3.6. Sample Manufacturing Plant Layout

Figure 3-1 illustrates the layout of a manufacturing plant for subsea umbilicals.

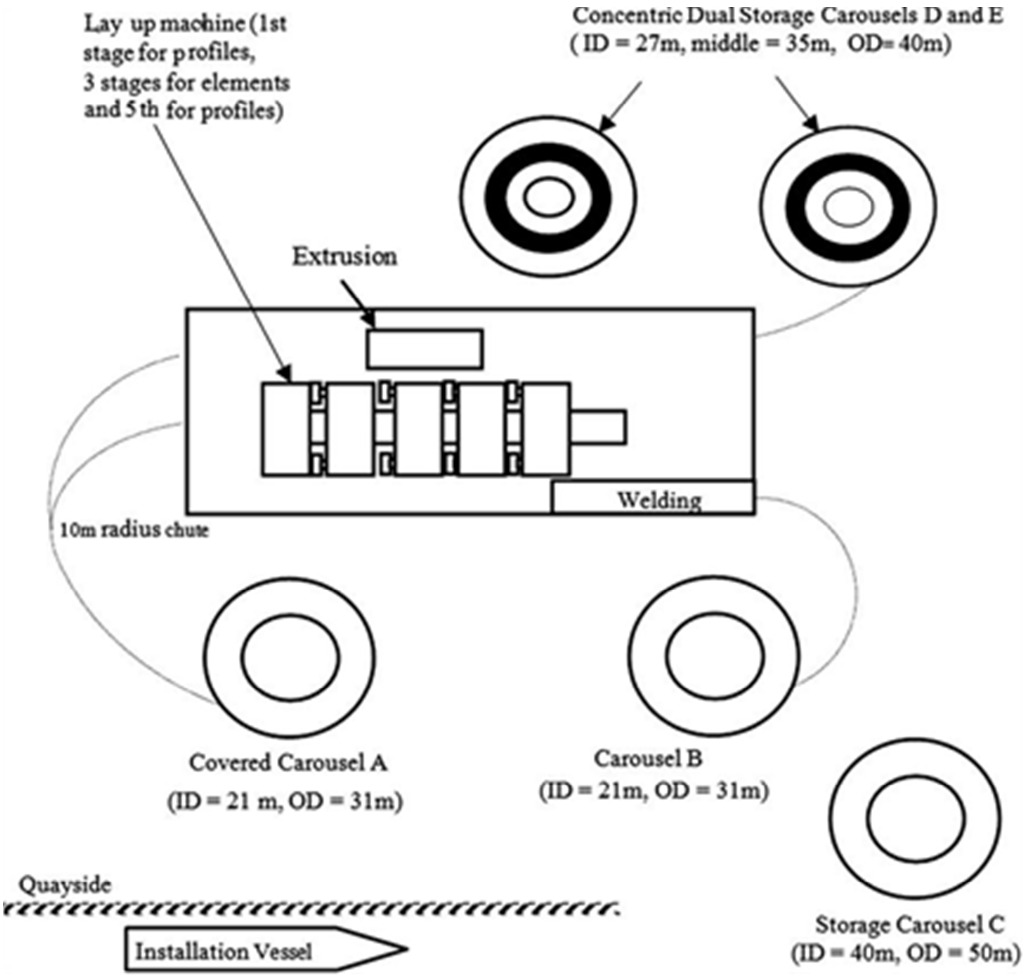


Figure 3-10: Layout of Umbilical Manufacturing Plant

3.6. Verification Tests

3.4.1. Tensile Test

A representative length of the completed umbilical, which takes into account the end effects and pitch lengths of the umbilical components, should be subjected to a two-stage tensile loading program.

3.4.2. Bend Stiffness Test

A representative length of the completed umbilical is subjected to a bend stiffness test procedure.

3.4.3. Crush Test

A sample of the completed umbilical is subjected to lateral loading to allow determination of its resistance to deformation.

3.4.4. Fatigue Test

Mechanical testing is undertaken to determine the fatigue resistance of an umbilical. The test regime is chosen to demonstrate that a particular design or design feature is suitable to withstand the repeated flexures sustained by an umbilical during manufacture, transfer spooling, load-out, I- or J-tube pull-in, burial, and, for a dynamic installation, operational service throughout the service life.

3.5. Factory Acceptance Tests

As the sheathe is extruded onto the umbilical it may be stored to a reel or carousel as shown in Figure 3.11. The size of the storage compartments can be varied by using different sets of circumferential post holes. The picture at right shows an umbilical stored on a standard 8.6 meter reel.

Figure 3-11: Umbilical stored to a reel or carousel

At this point the umbilical is ready for Factory Acceptance Testing (FAT). Tubes and cables are tested and accepted (or not) by the client. A lack of electrical continuity or a leaking or plugged tube can cause lengthy delays, because it is impossible to find the exact location without opening the sheathe and spreading out the components, often multiple times. Repairs must then be done to both the defective components and the overall umbilical.

Once the umbilical passes FAT, applications, or termination activities begin. The umbilical termination head (UTH) and the mudmat, jointly known as the Umbilical Termination Assembly (UTA), is connected to the umbilical at the subsea end. The umbilical manufacturer will weld the umbilical tubes to the tubes entering the UTH, and the contractor supplying the electrical splice enclosures will make the electrical splices. The entire umbilical assembly will now be ready for System Integration Testing (SIT). At this time other equipment such as the subsea distribution unit (SDU) or Surface-Controlled Subsurface Safety Valve (SCSSV) may be incuded in an expanded SIT using the flying leads as shown in Figure 3-12.

Figure 3-12: Umbilical stored to a reel or carousel

The following final testing is conducted on the completed umbilical:

- Visual Inspection;
- Electric cable;
- Hoses;
- Tubes.

All test results are recorded and certified by the umbilical manufacturer.

3.6. Power and Control Umbilicals

As specified above, the power umbilical is used for supplying electrical power from shore to platforms, between platforms, or from platform to subsea equipment. Supplying power to offshore installations from energy sources onshore makes for smaller and lighter offshore structures, reduced personnel requirements, and lower CO2 emission levels.

With this solution any number of installations can be linked and provided with power from an onshore power source. The power supply cable system can be expanded to form a network between offshore fields, providing flexible and safe power utilization for the oil and gas industry. Two types of submarine power cables are to be distinguished: “dry” design or “wet” design, with the former being more reliable but at a higher cost.

Figure 3-13 shows a typical power supply umbilical that has fiber optic cores for a control system. The remote control of unmanned installations is another application for submarine composite cables. Most subsea power cables installed offshore have a fiber optic element containing 8 to 32 optical fibers for signal transmission. The advantages of combining signal and power capabilities into one cable are as follows:

- Communication will not be influenced by weather or surface traffic.
- A greater bandwidth is available compared to radio frequencies.
- Optical fibers provide higher data transmission rates.

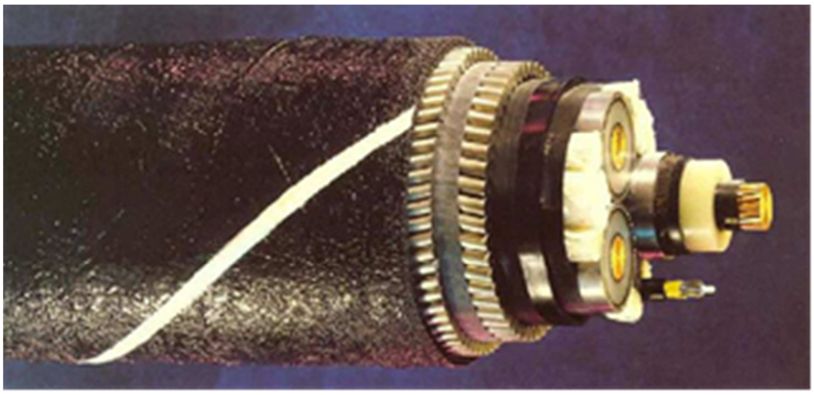


Figure 3-13: Typical Power Supply Umbilical Including Fiber Optic Cores for a Control System

3.7. IPU Umbilicals

IPU umbilicals are designed to combine the normal function of an umbilical with that of a production or an injection line. They are also designed to supply high-voltage power to potential subsea users. It is intended to tie-back one or several subsea wells in one single continuous length. The elements it contains include:

- Service lines;
- Hydraulic lines;
- Chemical lines;
- Fiber optic cores for data transmission;
- Electrical cables for power supply;
- Electrical cables for signal transmission;
- Production line.

Chapter.4

4.0 Ancillary Equipment

4.1. General

The subsea end of an electrical cable, optical fiber, thermoplastic hose, or metallic tube may be terminated in half a connector assembly, which can then be mated underwater. Alternatively, the umbilical components may be terminated directly into a subsea control pod or junction box. The design of umbilical terminations and ancillary equipment is invariably specific to a particular umbilical system and, as such, detailed specification data are the scope of ISO 13628-5 [International Standards Organization].

4.2. Umbilical Termination Assembly

A topside umbilical termination assembly (TUTA) is designed for dynamic umbilicals. A TUTA provides a termination point for the tubes, wires, and optical fibers from the bull nose assembly with stainless steel tube-to-tube fitting connections.

The TUTA assembly includes an electrical junction box for interfacing with the electrical wire and an optical junction box for interfacing with the fiber optic filaments from the bull nose assembly.

The metal tubes route to hydraulic couplers via super duplex steel tube pigtails and tube sockets where they are welded. Each set of electrical wires and fiber optic filaments is terminated with the female half of an electrical or optical connector that can be mated underwater.

4.3. Bend Restrictor/Limiter

The bend restrictor, shown in Figure 4-1, is also called a bend limiter and is used for preventing overstressing when the umbilical is unsupported over a large free span. It is usually used where the umbilical is attached to the umbilical subsea termination point.

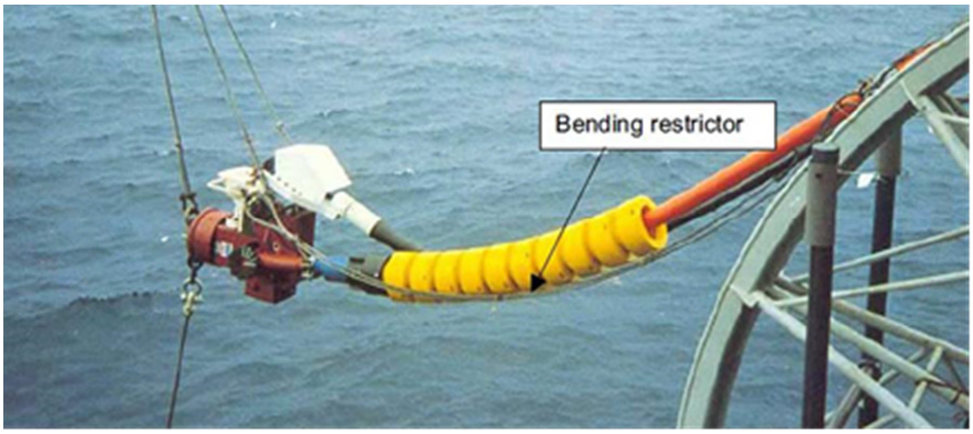


Figure 4-1: Bend Restrictor

4.4. Pull-In Head

A pull-in head is used to pull the umbilical along the seabed or through an I- or J-tube. The pull-in head is designed to withstand installation loads without damage to the umbilical or its functional components. The pull-in head is designed, if possible, to allow uninterrupted travel over rollers/ sheaves and through I- or J-tube risers without damaging or snagging.

4.5. Hang-Off Device

The hang-off device is used for supporting the umbilical to the top of the I-tube or J-tube at the host suspension point. The hang-off point will be on a deck or outboard of the columns in the tubes. Figure 4-2 shows examples of hang-off assemblies.

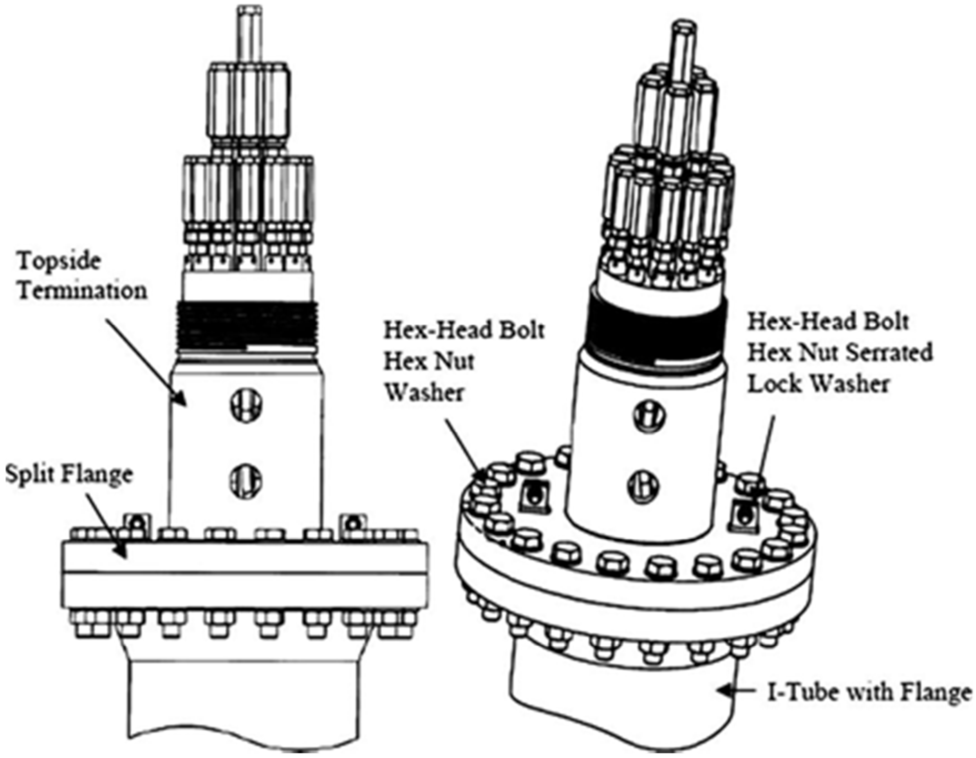


Figure 4-2: Hang-Off Assemblies

4.6. Bend Stiffer

The bend stiffer is a device for limiting the bending radius of the umbilical by providing a localized increase in bending stiffness. It is usually a molded device. Figure 4-3 shows a bend stiffer on a working deck.

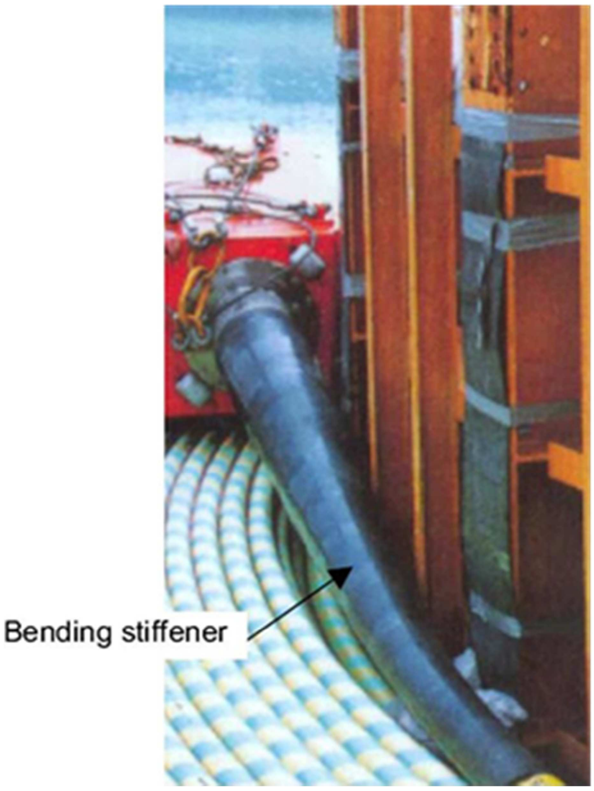


Figure 4-3: Bend Stiffer

4.7. Electrical Distribution Unit (EDU)

The EDU shown in Figure 4-4 provides electrical distribution to a number of end devices, such as individual subsea trees on a template. The EDU is an oil-filled and pressure-compensated enclosure, within which the incoming electrical power and electrical signals are distributed to two or more satellite SCMs. More than one EDU may be chained together, with each EDU serving a number of satellite SCMs.

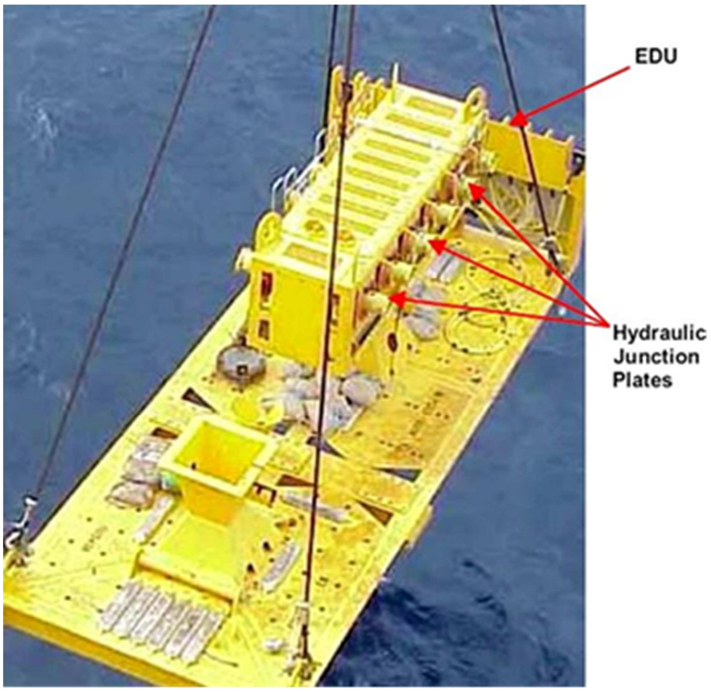


Figure 4-4: Example of a Large Umbilical Termination Assembly with a Large EDU Included

4.8. Weak Link

A weak link is a device used to protect equipment that is permanently installed on a manifold or template, so that in the event of an umbilical being snagged, the umbilical will break away, activating the link and shearing jumpers connecting to the fixed subsea equipment.

4.9. Splice/Repair Kit

A splice/repair kit should be provided to contain the necessary materials and parts to perform repairs on both the main dynamic umbilical and its components and the in-field static umbilical and its components in the event that it should become damaged during the installation process.

4.10. Carousel and Reel

Any reel used is not allowed to violate the MBR of the stored umbilical. Figure 4-5 shows a powered umbilical reel.

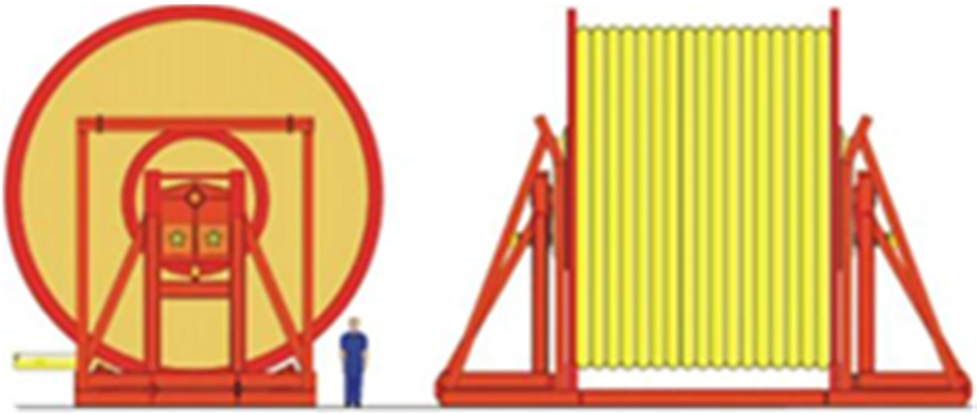


Figure 4-5: Powered Umbilical Reel

4.11. Joint Box

A joint box is used to join umbilical sub-lengths to achieve overall length requirements or to repair a damaged umbilical. Each umbilical end to be joined has an armored termination, if applied. The joint box is of a streamlined design, with a bend stiffer at each end if required, and of compact size to facilitate reeling storage and installation requirements.

4.12. Buoyancy Attachments

Depending on the installed configuration, a dynamic umbilical can necessitate buoyancy attachments in the form of collars, tanks, etc., to achieve the necessary configuration and dynamic motions. The method of attachment does not induce stress cracking in the umbilical sheath, nor allow excessive stress relaxation within the compressive zone of the attachment if clamped, nor allow excessive strain of the umbilical and its component.

Chapter.5

5.0 System Integration Test

5.1. Introduction

The FAT test is always performed to ensure that the individual components and items of equipment meet the specified requirements and function correctly. System integration testing, commonly referred to as SIT, is another process that verifies that the integrated equipment is suitable for use. In another words, it is performed to verify that equipment from various suppliers, which must interface with each other, fits and works together acceptably. These procedures are normally very specific project and relate to various equipment interfaces within the project. Figure 5-1 shows system integration testing of a control umbilical.

Figure 5-1: System Integration Testing of Control Umbilical

Chapter.6

6.0 Installation of Umbilical

6.1. Introduction

Subsea trees are monitored and controlled via umbilicals suspended in a catenary shape and protected at the splash zones by I- and J-tubes fixed to the structures. Figure 6-1 illustrates an umbilical connecting an FPS to a subsea structure in deep water; Figure 6-2 shows an umbilical connecting a platform to a subsea structure in shallow water.

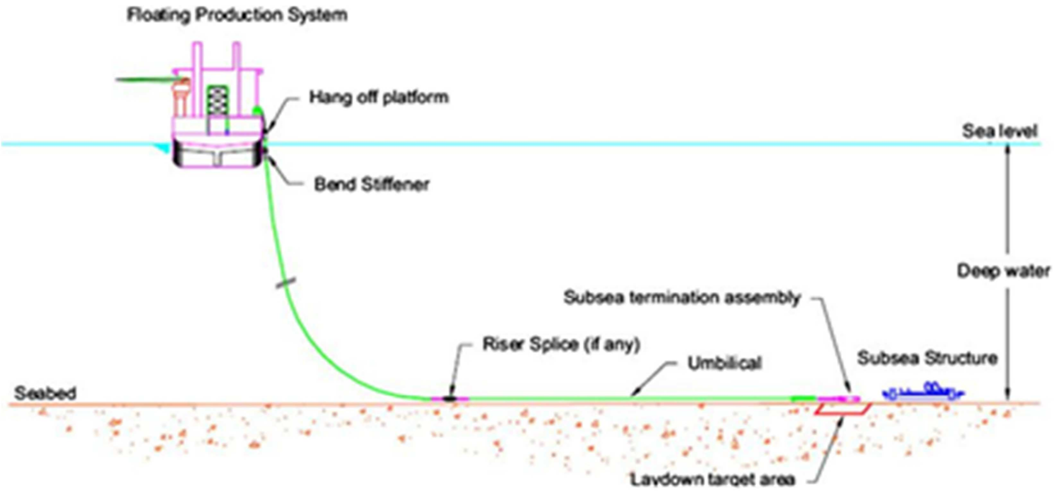


Figure 6-1: Umbilical Connecting an FPS to a Subsea Structure

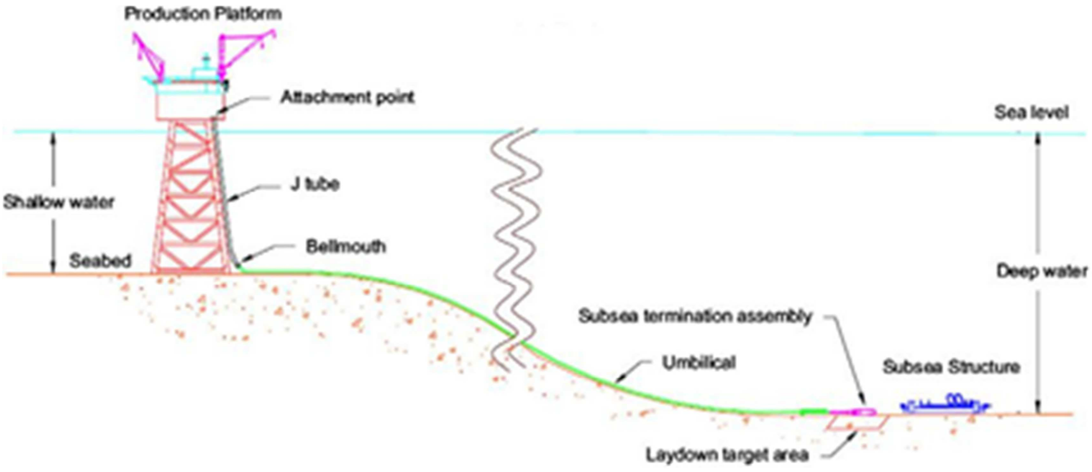


Figure 6-2: Umbilical Connecting a "Host" Platform to a Subsea Structure

6.2. Requirements for Installation Interface

The installation vessel and its installation equipment should be in good condition and working order, and be verified according to relevant regulations and safety plans prior to vessel mobilization. In addition to the requirement of API Recommended Practice 17I, Installation Guideline for Subsea Umbilical, the interfaces relating to the installation of the subsea umbilical should be carefully managed including these items:

- The design and fabrication of the UTAs and their support frames;
- Determination of the design requirements for all cable crossings;
- The design of umbilical supports for crossing of pipelines;
- Protection requirements.

6.3. Installation Procedures

Umbilicals are laid using one of the following typical methods:

- The umbilical is initiated at the manifold with a stab and hinge-over connection or a pull-in/connection method and terminated near the subsea well with a second-end lay-down sled (i.e., infield umbilical connection from manifold to satellite well). The connection between the umbilical and the subsea well is later made using a combination of the following tie-in methods:
    1. rigid or flexible jumper,
    2. junction plates, and
    3. flying leads.
- The umbilical is initiated at the manifold with a stab and hinge-over connection or a pull-in/connection method. It is laid in the direction to the fixed or floating production system and pulled through an I- or J-tube or cross hauled from the laying vessel to the floating production vessel.
- The umbilical can also be initiated at the fixed or floating production system and terminated near the subsea structure with a second-end umbilical termination assembly (termination head, lay-down sled, umbilical termination unit, etc.). A pull-in and connection tool operated by an ROV may be used to connect the umbilical to the subsea structure.

Umbilical installation can be carried out in the following cases:

- Umbilical installation between subsea manifold and tree;

- Umbilical installation with first-end initiation at subsea structure;
- Umbilical installation with first-end initiation at floater.

6.4. Fatigue Damage during Installation

The issues that need to be considered when dealing with fatigue damage during installation of steel tube umbilicals are as follows:

- The contribution to accumulated plastic strain during reeling and potential retrieval;
- Low cycle fatigue during reeling and potential retrieval;
- Dynamic wave frequency fatigue contributions during the critical stages of installation, that is, midlay and handover/pull-in.

The methodology for accounting for accumulated plastic strain and low cycle fatigue will be considered in Section 7.2. The calculations for accumulated plastic strain and low cycle fatigue are carried out for both fabrication and installation together.

The methodology for the calculation of wave-induced fatigue damage during the critical stages of installation is similar to the in-place fatigue assessment described in Section 7.3. However, some aspects of installation fatigue analysis do not apply to in-place fatigue analysis:

- Since the umbilical changes configuration and is subject to different loads during various stages of installation, different umbilical models are needed to model the various stages of installation that require analysis.
- For installation fatigue analysis it is appropriate to use a time-domain approach. A frequency-domain analysis would not adequately predict the fatigue damage suffered during installation due to the highly irregular loading that the umbilical experiences during this stage of its life.

Chapter.7

7.0 Challenges and Analysis

7.1. Deep Water

Some of the technological challenges are faced for subsea power supply and transmission system deep water, long distances, high power cables, integrated production umbilical (IPU) and extreme environmental condition.

The deepest umbilical installation to date (Apr, 2010) is the Perdido 1TOB umbilical in 2946m in Gulf of Mexico [Technip]. Some other deepwater umbilicals in Gulf of Mexico are Shell's Na Kika project in 2,316m, the Thunder Horse umbilical in 1,880m of water, and the Atlantis umbilical in 2,134m of water [N. Terdre]. A challenge in design is that steel tubes are under high external pressure as well as high tensile loads. At the same time, the increased weight may also cause installation problems. This is particularly true for copper cables because the yield strength of copper is low. In ultra-deep water, a heavy dynamic umbilical may present a problem to installation and operation because its hang-off load is high.

For design and analysis of an ultra-deep water umbilical, it is important to correctly model the effect of stress and strain on an umbilical and the friction effect. Sometimes, bottom compression may be observed for an umbilical under a 100-year hurricane scenario. In this scenario, the design solution may be to use a lazy-wave buoyancy module or to use carbon fiber rods. The use of carbon fiber rods allows umbilicals to have a simple catenary configuration, without the need for expensive, inspection/maintenance demanding buoyancy modules. The carbon fiber rods enhance axial stiffness because they have a Young's modulus close to the value of steel but with only a fraction of the weight.

One of the concerns surrounding the use carbon fiber rods is their capacity for compressive loads. Hence, it is beneficial to conduct some tests that document the minimum bending radius and compressive strength of the umbilical.

If the currents an ultra-deep water umbilical will be subjected to are severe, it might be necessary to use strakes for VIV protection, although the use of strakes has so far not been required. The strakes may, for instance, be a 16D triple start helix with a strake height of 0.25D.

7.2. Long Distances

The length for the Na Kika, Thunder Horse, and Atlantis umbilicals is 130, 65, and 45 km, respectively. The longest yet developed is 165 km in a single length, for Statoil's Snohvit development off northern Norway. One of the constraints on umbilical length is the capacity of the installation equipment. The Nexans-operated installation vessel Bourbon Skagerrak can carry up to 6500 tonnes of cable, which equals a length of 260 km, assuming the umbilical unit weight is 25 kg/m.

7.3. High-Voltage Power Cables

The design constraints are the low yield strength of copper, which requires an increasing amount of protection as depths increase, and the weight of steel armoring employed to provide that protection as depths increase. Fatigue of copper cables in dynamic umbilicals is another technical challenge.

7.4. Integrated Production Umbilical (IPU)

Heggadal [O. Heggdal] presented an integrated production umbilical (IPU) in which the flowline and the umbilical are combined in one single line as shown in Figure 7-1. The IPU cross section consists of the following elements:

- A 103/4-in. flowline with a three-layer PP coating (its thickness is 4 and 14 mm for the static portion and dynamic portion, respectively).
- Around the flowline, there is an annular-shaped PVC matrix that keeps in place the spirally wound umbilical tubes and cables and provides thermal insulation to the flowline.
- Embedded in the PVC matrix, but sliding freely with it, are the various metallic tubes for heating, hydraulic, and service fluids, the electrical/ fiber optic cables for power and signals, and the high-voltage cables for powering the subsea injection pump.
- It has an outer protective sheath of polyethylene 12 mm thick.

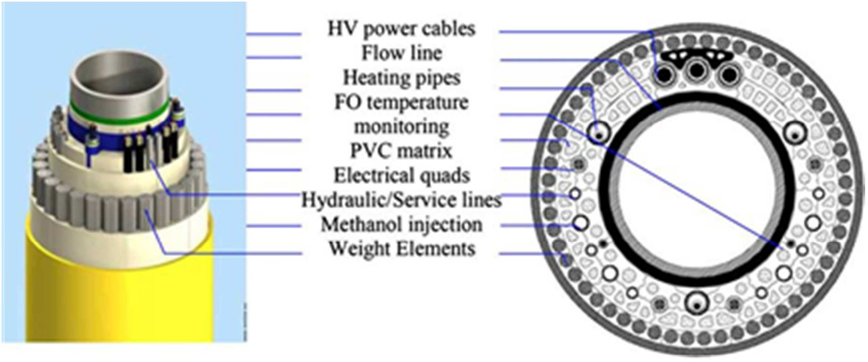


Figure 7-1: IPU Dynamic Cross Section, Super Duplex Flowline [O. Heggdal]

To qualify a new design concept like this, a series of analysis and qualification tests were conducted [O. Heggdal]:

1. **Analysis**
   - Global riser analysis and fatigue analysis;
   - Corrosion and hydrogen-induced cracking assessment;
   - Thermal analysis;
   - Structural analysis (production pipe, topside and subsea termination);
   - Reeling analysis;
   - Electrical analysis;
   - Reel/trawler interaction and on-bottom studies.

2. **Basic Tests**
   - Mechanical material tests, fatigue, corrosion, etc.

3. **Fabrication Tests**
   - Fabricationand closing test;
   - STS injection test;
   - QC tests and FAT;
   - Pre/postinstallation tests.

4. **Prototype Tests**
   - External hydrostatic test;
   - Impact test;
   - Model tensioner test;

- Reeling and straightening trials;
- Stinger roller trial;
- Repair trial;
- Vessel trial;
- System test;
- Dynamic riser full-scale testing.

7.5. Extreme Wave Analysis

An important aspect of the umbilical design process is an analysis of extreme wave/environmental conditions. A finite element model of the umbilical is analyzed with vessel offsets, currents and wave data expected to be prevalent at the site where the umbilical is to be installed. For example, in the Gulf of Mexico, this would include an analysis for a 100-year hurricane, 100-year loop current, and submerged current. The current and wave directions are applied in a far, near, and cross condition. This analysis is used to determine the top tension and angles that the hang-off location of the umbilical is likely to experience. These values are then used to design an adequate bend stiffener that will limit the umbilical movements and provide adequate fatigue life for the umbilical. Design analysis based on extreme wave analysis includes:

1. The touchdown zone of the umbilical is analyzed to ensure an adequate bending radius that is larger than the minimum allowable bending radius. It is also important to check that the umbilical does not suffer compression and buckling at the touchdown zone.
2. A polyurethane bend stiffener has been designed to have a base diameter of x inches, and cone length of y ft. This design is based on the maximum angle and its associated tension, and maximum tension and its associated angle from dynamic analysis results using the pinned finite element model.
3. The maximum analyzed tension in the umbilical was found to occur at the hang-off point for the 100-year hurricane wind load case when the vessel is in the far position.
4. The minimum tension in the umbilical may be found to occur in the TDP region for the 100-year hurricane wind load case when the vessel is in the near position.

5. The minimum bend radius (MBR) is estimated over the entire umbilical, over the TDP region and the bend stiffener region, respectively. They are to be larger than the allowable dynamic MBR.
6. The minimum required umbilical on-seabed length is estimated assuming it is subject to the maximum value of the extreme bottom tensions.

7.6. Manufacturing Fatigue Analysis

A certain amount of fatigue damage is experienced by a steel tube umbilical during manufacturing, and this needs to be evaluated during fatigue analysis. The two main aspects of umbilical manufacturing fatigue analysis that require attention is accumulated plastic strain and low cycle fatigue. These are explained next.

7.6.1. Accumulated Plastic Strain

Accumulated plastic strain is defined as “the sum of plastic strain increments, irrespective of sign and direction” in DNV-OS-F101 and DNV-RP-C203 [DNV]. Accumulated plastic strain can occur in the steel tubes of an umbilical during fabrication and installation. The accumulated plastic strain needs to be maintained within certain limits to avoid unstable fracture or plastic collapse for a given tube material and weld procedure. Accumulated plastic strain is the general criteria used by umbilical suppliers to determine whether the amount of plastic loading on the steel tubes is acceptable. An allowable accumulated plastic strain level of 2% is recommended for umbilical design.

Figure 7-2 shows a schematic of deformations that are likely to take place during the fabrication and installation of a steel tube umbilical. All of the processes shown in this diagram are likely to induce plastic strain in the umbilical.

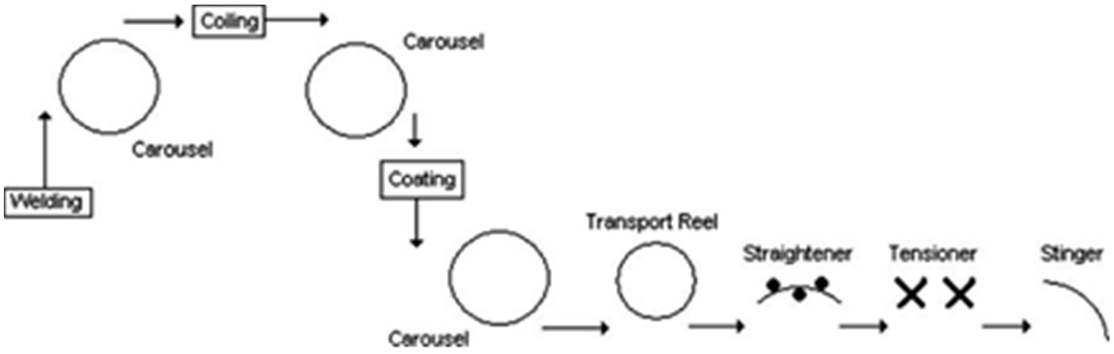


Figure 7-2: Diagram of Deformations during Fabrication and Installation

7.6.2. Low Cycle Fatigue

The umbilical steel tubes are subject to large stress/strain reversals during fabrication and installation. Fatigue damage in this low cycle regime is calculated using a strain-based approach.

For each stage of fabrication and installation, the fatigue damage is calculated by considering the contributions from both the elastic and plastic strain cycles. The damage calculated from low-frequency fatigue is added to that from in-service wave and VIV conditions to evaluate the total fatigue life of each tube of the umbilical.

7.7. Site Fatigue Analysis

The methodology used to assess wave–induced, in-place fatigue damage of umbilical tubes can be summarized as follows:

1. Selection of sea-state data from a wave scatter diagram;
2. Analysis of finite element static model;
3. Umbilical fatigue analysis calculations;
4. Simplified or enhanced approach;
5. Generation of combined stress history;
6. Rain flow cycle counting procedure or spectral fatigue damage;
7. Incorporation of mean stress effects in histogram.

The first three items of fatigue analysis mentioned above are described in the following three subsections. The main difference between fatigue analysis for an umbilical and a SCR is the effect of friction when the tubes in the umbilical slide against their conduits and each other due to bending of the umbilical. The methodology discussed here for umbilical in-place fatigue analysis is based on two OTC papers [J. Hoffman, W.K. Kavanagh]. In-place fatigue analysis is required to prove that the fatigue life of the umbilical is 10 times the design life.

7.7.1. Selection of Sea-State Data

The wave scatter diagram describes the sea-state environment for the umbilical in service. It is not practical to run a fatigue analysis with all of the sea states described in a wave scatter diagram. Hence, the usual methodology is to group a number of sea states together and represent these “joint sea states” with one significant wave height and wave period. The values of the wave height and wave period are chosen to be conservative.

This methodology results in the reduction of the wave scatter diagram to a “manageable” number of sea states (say, about 20 to 50). This enables the analysis to be carried out in a reasonable amount of time. It is also very important to accurately consider the percentage of time that the umbilical is expected to be affected by these different sea states.

7.7.2. Analysis of Finite Element Static Model

A finite element static analysis is carried out for a model representing the steel tube umbilical. The static solution is used as a starting point for a time-domain or frequency-domain dynamic FEA.

7.7.3. Umbilical Fatigue Analysis Calculations

Fatigue damage in an umbilical is the product of three types of stress. These are axial (σ_A), bending (σ_B) and friction stress (σ_F). The equations defining these stress terms are as follows:

$$\sigma_A = 2\sqrt{2} \cdot \frac{SD_T}{A} \tag{7-1}$$

$$\sigma_B = 2\sqrt{2} \cdot E \cdot R \cdot SD_k \tag{7-2}$$

Where; SD_T is standard deviation of tension, A is steel cross-sectional area of the umbilical, E is Young’s modulus, R is outer radius of the critical steel tube and SD_k: standard deviation of curvature.

The critical steel tube is the tube in the umbilical that experiences the greatest stress. This is usually the tube with the largest cross-sectional area and furthest from the centerline of the umbilical.

The friction stress experienced by the critical tube is the minimum of the sliding friction stress (σ_{FS}) and the bending friction stress (σ_{FB}). This is based on the theory that the tube experiences bending friction stress until a point is reached when the tube slips in relation to its conduit. At this point the tube experiences sliding friction stress. This is represented by Figure 7-2. Therefore, according to Kavanagh et al [W.K. Kavanagh]:

$$\sigma_F = min(\sigma_{FS}, \sigma_{FB}) \tag{7-3}$$

$$\sigma_{FS} = \frac{\mu F_C}{A_t} \tag{7-4}$$

$$\sigma_{FB} = E \cdot R_L \cdot \sqrt{2} \cdot SD_k \tag{7-5}$$

Where, μ is friction coefficient, F_C is contact force between the helical steel tube (defined below), A_t is cross-sectional area of the critical steel tube within the umbilical, R_L layer radius of the tube (this being the distance from the center of the umbilical to the center of the critical steel tube).

$$F_C = \left[\frac{T \sin^2 \emptyset}{R_L} + \frac{EI_{tube} \sin^4 \emptyset}{R_L^3}\right] \cdot L_P \tag{7-6}$$

Where; T is mean tension, $\emptyset$ is tube lay angle (this being the angle at which the tubes lie relative to the umbilical neutral axis), EI_{tube} is individual tube bending stiffness and L_P is tube pitch length/2.

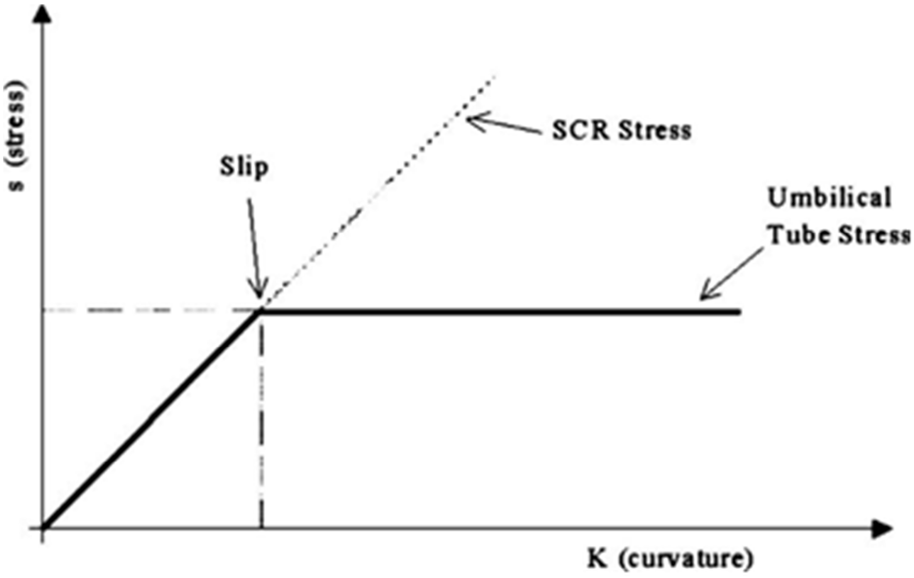
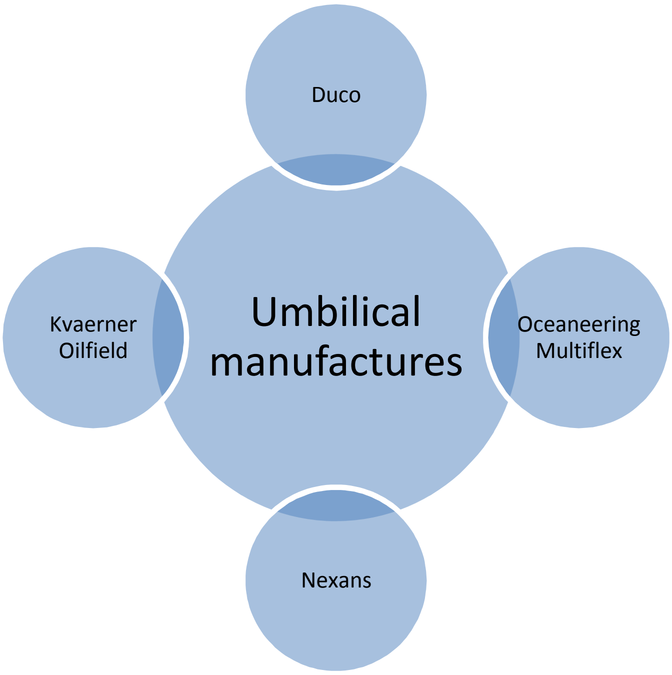


Figure 7-3: Representation of Umbilical Friction Stress [W.K. Kavanagh].

Chapter.8

8.0 Subsea Power and Transmission Industries

Historically the umbilical market was dominated by several companies. Firstly, Duco is a subsidiary of Technip and Oceaneering Multiflex is part of the Oceaneering group. Two other manufacturers have made significant inroads with steel tube umbilical designs, namely, Nexans and Kvaerner Oilfield Products.



A number of manufacturers specialize in dynamic umbilicals for ROVs. These include JDR Cables and Cortland Fibron. There are only two major electrical connector manufacturers:

- Tronic (part of the Expro Group) located in Ulverston, Cumbria (UK);
- Ocean Design located in Florida (USA).

The majority of subsea connectors employed in the North Sea and Northern Europe are provided by Tronic, whereas Ocean Design has been the major supplier within the Gulf of Mexico.

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Autobiographies

Jaswar Koto was born on October, 1970. He is a descendant of the Prophet Rasullullah S.A.W through Husein R.A. He is a President of Ocean and Aerospace Research Institute, Indonesia. Professor on offshore engineering and also President of International Society of Ocean, Mechanical & Aerospace for scientist and engineers.

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He received his bachelor degree in 1994 from Institut Teknologi Sepuluh Nopember (ITS), Indonesia, Curtin University in 1996 and Notre Dame University in 1999. In 2003 he has completed PhD with receiving award in engineering form Aerospace and Marine Engineering, Osaka Prefecture University, Japan.

He has started his researches since 1994 on structure analysis of fluid flow in subsea pipelines, subsea pipeline corrosion due to Carbon Monoxide, design and hydrodynamic analysis of AUV in Australia. Then, he joined Research and Development Institute, Sumitomo Heavy Industries -Marine Engineering-, Japan. In 2005, he joined ExxonMobil projects. Since 2010, he has a contract with Department of Aeronautical, Automotive, and Ocean Engineering, Faculty of Mechanical Engineering. He is also appointed as head of High Performance Computing, CICT, Universiti Teknologi Malaysia.

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