PDHonline Course E443 (4 PDH)

Introduction to Subsea Engineering for Electrical Engineers

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Table of Content

List of Figures

List of Tables

Acronyms

API	American Petroleum Institute
DHPTT	Downhole Pressure and Temperature Transmitters
EDM	Electrical Distribution Manifold/Module
EFL	Electrical Flying Leads
EPU	Electrical Power Unit
ESP	Electric Submersible Pump
FPSO	Floating Production Storage and Offloading
HPU	Hydraulic Power Unit
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Standards Organization
MCS	Master Control Station
MQC	Multiple Quick-Connect
P&ID	Piping and Instrumentation Diagram
PIG	Pipeline Inspection Gauge
ROV	Remotely Operated Underwater Vehicle
SAS	Safety Automation System
SCM	Subsea Control Module
SDU	Subsea Distribution Unit
SEM	Subsea Electronics Module
SIT	System Integration Test
SUTA	Subsea Umbilical Termination Assembly
TUTA	Topside Umbilical Termination Assembly
ULM	Umbilical Line Module
UPS	Uninterruptible Power Supply

1. Introduction

Subsea engineering encompasses multiple fields of professionals, including chemical, control system, petroleum, mechanical, electrical, and reservoir engineers in addition to technologists and geo-technicians. The subsea industry has become more significant in recent decades due to the rising demand for oil and gas and the advance of subsea technology. According to a study by Rigzone.com, subsea engineering jobs were the fourth highest paid within the oil and gas industry. Subsea engineering is one of the most important, yet most technically difficult, aspects of the offshore petroleum industry.

Oil and gas fields reside beneath many inland waters and offshore areas around the world. In the oil and gas industry, the term *subsea* refers to the exploration, drilling, and development of oil and gas fields in underwater locations. Underwater oil facilities are generically referred to using a subsea prefix, such as subsea well, subsea field, subsea project, and subsea development. Subsea oil field developments are usually split into shallow-water and deepwater categories to distinguish between the different facilities and approaches that are needed for each location. Figure 1 shows a typical subsea oil field.

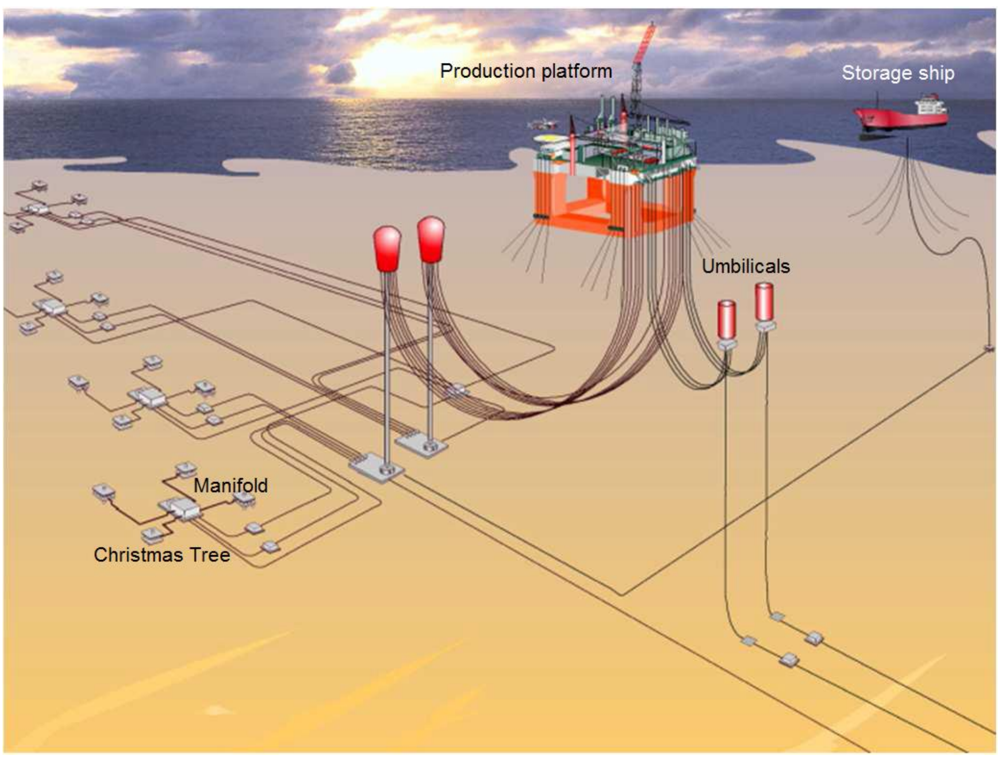


Figure 1: Typical Subsea Oil Field

Subsea completions can be traced back to 1943 with the Lake Erie completion at a water depth of thirty-five feet. The land-type Christmas tree well required diver interventions for installation, maintenance, and flow-line connections. Current technology allows for subsea development at a water depth of 10,000 feet. The first known subsea ultra-high-pressure waterjet system was developed in

2010 by Jet Edge and Chukar Waterjet. It was capable of operating below 5,000 feet and was used to blast away hydrates that were clogging a containment system at the Deepwater Horizon.

Currently, there are almost 800 offshore rigs (jack-up rigs and semi-submersible platforms) around the world. There are over 100 rigs off the southern coast of the United States in the Gulf of Mexico. The world's deepest oil platform is the Perdido, a spar platform located in the Gulf of Mexico in a water depth of 8,000 feet. Offshore production regions represent nearly 650 billion barrels of oil, or 20% of known remaining global oil reserves. The offshore industry produces about twenty-five million barrels per day, or 30% of global production. To keep up with the increasing public need for oil and natural gas, more subsea fields will be opened up for exploration, drilling, and production.

Subsea technology in offshore oil and gas production is a highly specialized field with particular demands on engineering and simulation. Most of the new oil fields are located in deep water, a term often used to describe offshore projects located in water depths greater than around 600 feet. These deepwater oil fields, which are generally referred to as deepwater systems, frequently use floating drilling vessels and oil platforms and require remotely operated underwater vehicles (ROVs) because manned diving is impractical.

The development of subsea oil and gas fields requires specialized equipment. Producing oil from these fields sets strict requirements for verification of the various systems' functions and their compliance with current safety and environmental specifications. The equipment must be reliable enough to safeguard the environment and make the production of subsea hydrocarbons economically feasible. The deployment of such equipment requires expensive, specialized vessels, which need to be equipped with diving equipment for relatively shallow equipment work and robotic equipment for deeper water.

Subsea engineering has recently become a formal category in engineering education. For example, both the University of Aberdeen in the United Kingdom and the University of Houston in the United States offer a master of science in subsea engineering. Texas A&M University will offer a master's degree in subsea engineering starting in the fall of 2014. The master's degree programs focus on the practices and basic sciences involved in underwater engineering. The programs include courses such as pipeline and riser design, heat transfer, applied mathematics and flow assurance, subsea materials, corrosion, offshore structures, oil rigs, and underwater robotics.

Although this course does not cover all aspects of subsea engineering, it provides an introduction to subsea engineering for electrical engineers.

2. Subsea Production Systems

Subsea production systems range in complexity from a single satellite well with a flow line linked to a fixed platform with floating production storage and off-loading (FPSO) or an onshore installation to several wells on a template or clustered around a manifold and transferring to a fixed or floating facility or directly to an onshore installation.

Subsea production systems can be used to develop reservoirs or parts of reservoirs, which requires drilling the wells from more than one location. Deepwater or ultra-deepwater conditions can dictate the development of a field by means of a subsea production system because traditional surface facilities, such as on a steel-piled jacket, might be either technically or economically unfeasible due to the water depth.

The structure of a typical subsea production system is shown in figure 2. It consists of:

1. A reservoir
2. Production wells
3. Manifolds
4. Flow lines to the surface
5. A first-stage separator at the surface facility

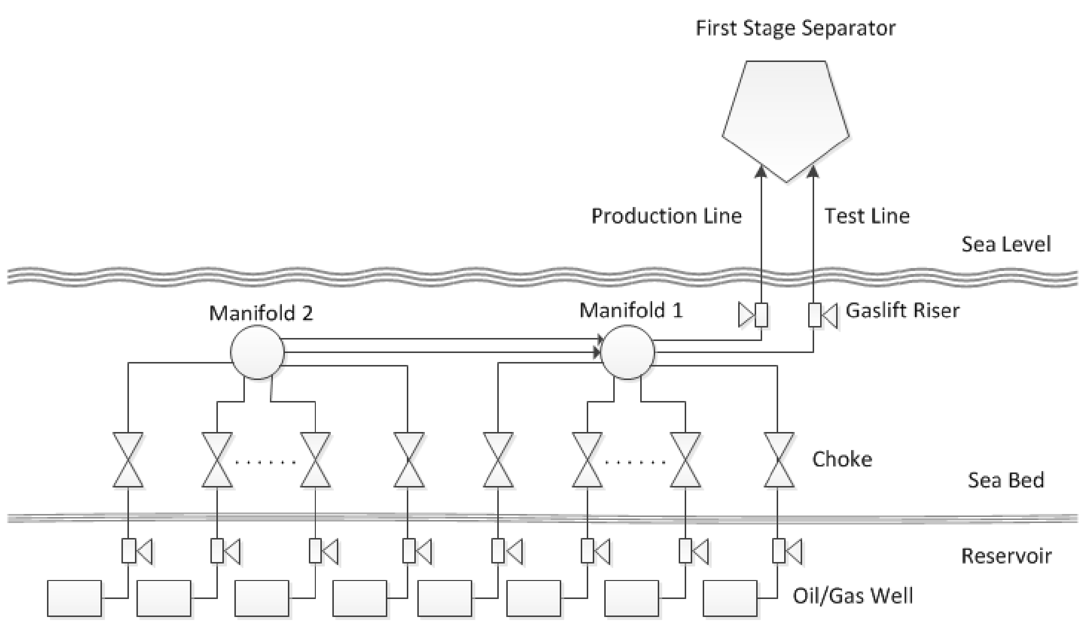
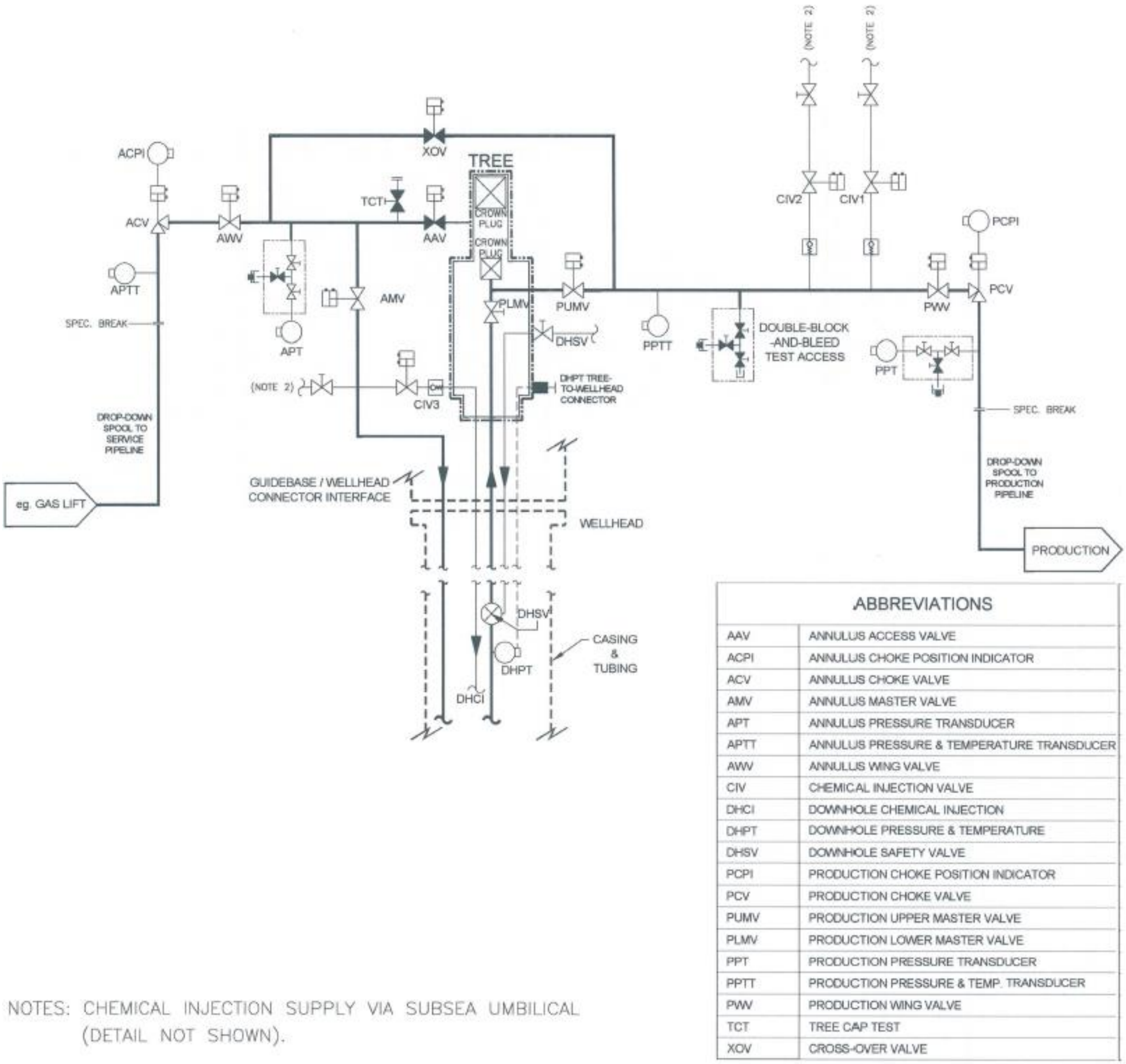


Figure 2: Topology for a Typical Oil and Gas Production System

The system may be larger, with several clusters. Each production well consists of three parts: the well tubing, the choke, and the well flow line. The well flow may be routed to one of two flow lines. The production from a well is controlled by the choke valve. An oil and gas field typically consists of a large number of production systems of the kind described here. These systems connect to one or more reservoirs.

An oil and gas production tree typically consists of a choke, multiple valves, and multiple transmitters that measure temperature and pressure. Other typical third-party devices include downhole pressure and temperature transmitters (DHPTT), chemical injection metering valves (CIMV), sand monitors, and multiphase flow meters. A production manifold usually contains a Pipeline Inspection Gauge (PIG) detector, which monitors the PIGs or plugs from the outside of the pipe. The sensor is clamped onto the pipe and does not need to be welded or drilled during installation. Figure 3 shows a typical subsea tree piping and Instrumentation diagram (P&ID), and figure 4 shows a typical manifold and flow line P&ID.



ABBREVIATIONS	
AAV	ANNULUS ACCESS VALVE
ACPI	ANNULUS CHOKE POSITION INDICATOR
ACV	ANNULUS CHOKE VALVE
AMV	ANNULUS MASTER VALVE
APT	ANNULUS PRESSURE TRANSDUCER
APTT	ANNULUS PRESSURE & TEMPERATURE TRANSDUCER
AWV	ANNULUS WING VALVE
CIV	CHEMICAL INJECTION VALVE
DHCI	DOWNHOLE CHEMICAL INJECTION
DHPT	DOWNHOLE PRESSURE & TEMPERATURE
DHSV	DOWNHOLE SAFETY VALVE
PCPI	PRODUCTION CHOKE POSITION INDICATOR
PCV	PRODUCTION CHOKE VALVE
PUMV	PRODUCTION UPPER MASTER VALVE
PLMV	PRODUCTION LOWER MASTER VALVE
PPT	PRODUCTION PRESSURE TRANSDUCER
PPTT	PRODUCTION PRESSURE & TEMP. TRANSDUCER
PWV	PRODUCTION WING VALVE
TCT	TREE CAP TEST
XOV	CROSS-OVER VALVE

NOTES: CHEMICAL INJECTION SUPPLY VIA SUBSEA UMBILICAL (DETAIL NOT SHOWN).

Figure 3: Typical Subsea Tree P&ID

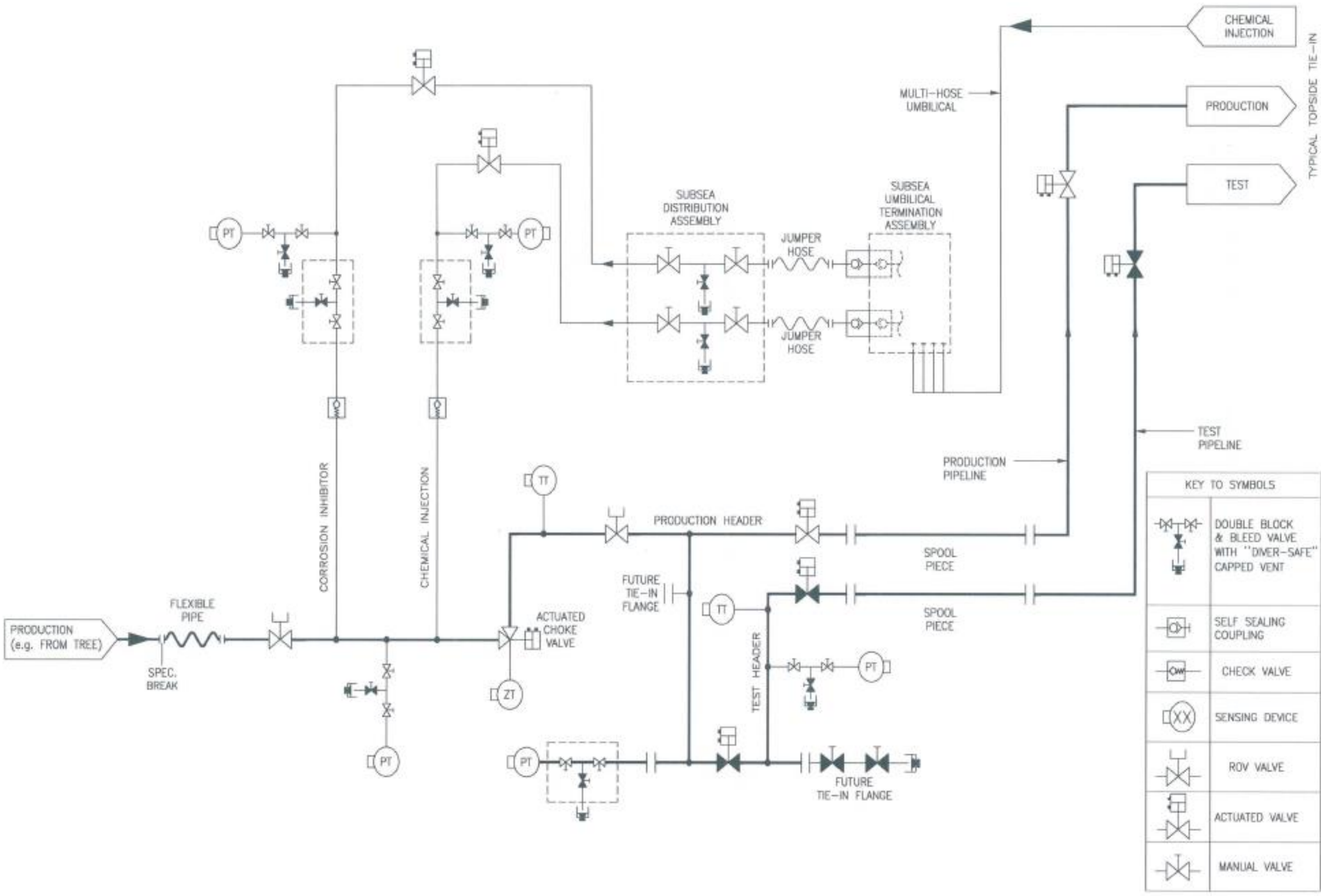


Figure 4: Typical Manifold and Flowline P&ID

3. Multiplexed Electro-Hydraulic Control System

The multiplexed electro-hydraulic system allows many subsea control modules (SCMs, discussed in section 4) to be connected to the same communications, electrical, and hydraulic supply lines, which are bundled in the multiplexed electro-hydraulic umbilical. Therefore, many wells can be controlled via one simple umbilical, which terminates at a subsea distribution unit (SDU, discussed in section 9). From the SDU, the connections to the individual wells and SCMs are made with jumper assemblies.

A multiplexed electro-hydraulic umbilical, as shown in figure 5, typically contains:

- Steel tubes
- Hydraulic supply lines
- Chemical injection lines
- Fiber-optic and copper signal conductors
- Power conductors

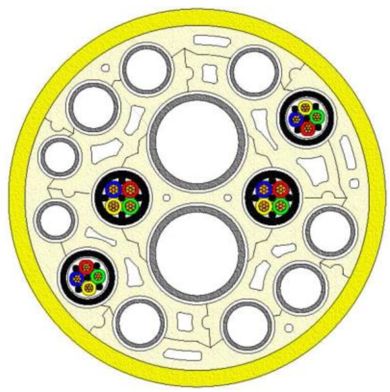


Figure 5: Multiplexed Electro-Hydraulic Umbilical (Cross Section)

The cost of a multiplexed electro-hydraulic system is high due to the complex electronics contained within the subsea electronics modules (SEMs) inside the SCM, additional topside control stations, and required computer software. These costs, however, are offset by the smaller, less complex umbilicals and advanced technology, both of which have reduced the cost of the electronics. Table 1 shows the advantages and disadvantages of the multiplexed electro-hydraulic control system. Figure 6 shows the principle of a multiplexed electro-hydraulic control system. The system is typically used in complex subsea fields of long distances (more than three miles).

Table 1: Advantages and Disadvantages of Multiplexed Electro-Hydraulic Control System

Advantages	Disadvantages
• Reach deeper water • Faster response • Simplified umbilical • Capable of complex control • Improved surveillance	• Increased number of subsea electrical connections • Higher voltage connections • More complex subsea components • More difficult to support

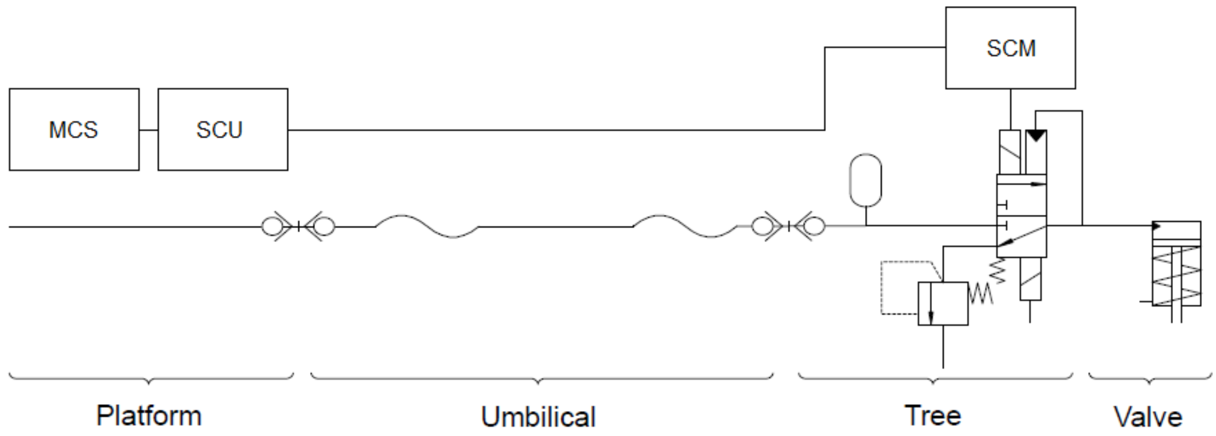


Figure 6: Multiplexed Electro-Hydraulic Control System

When a communication signal is sent to the SEM, it excites the target solenoid valve, directing hydraulic fluid from the supply umbilical to the associated actuator. Subsea line pressure and temperature, flow rate, and valve positions are sent to a topside monitoring station, such as the master control system (MCS) on the platform, through the umbilical. Data are also logged on the MCS or by other data historians for diagnostic purposes.

4. Subsea Control Module (SCM)

The main component of the tree-mounted control system is the subsea control module (SCM). The SCM provides reliable control and monitoring of subsea valves and instrumentation. It consists of electronics, instrumentation, and hydraulics that allow for the safe and efficient operation of subsea tree valves, chokes, and downhole valves. Other tree-mounted equipment includes numerous sensors and electrical and hydraulic connectors. Figure 7 shows a typical SCM.

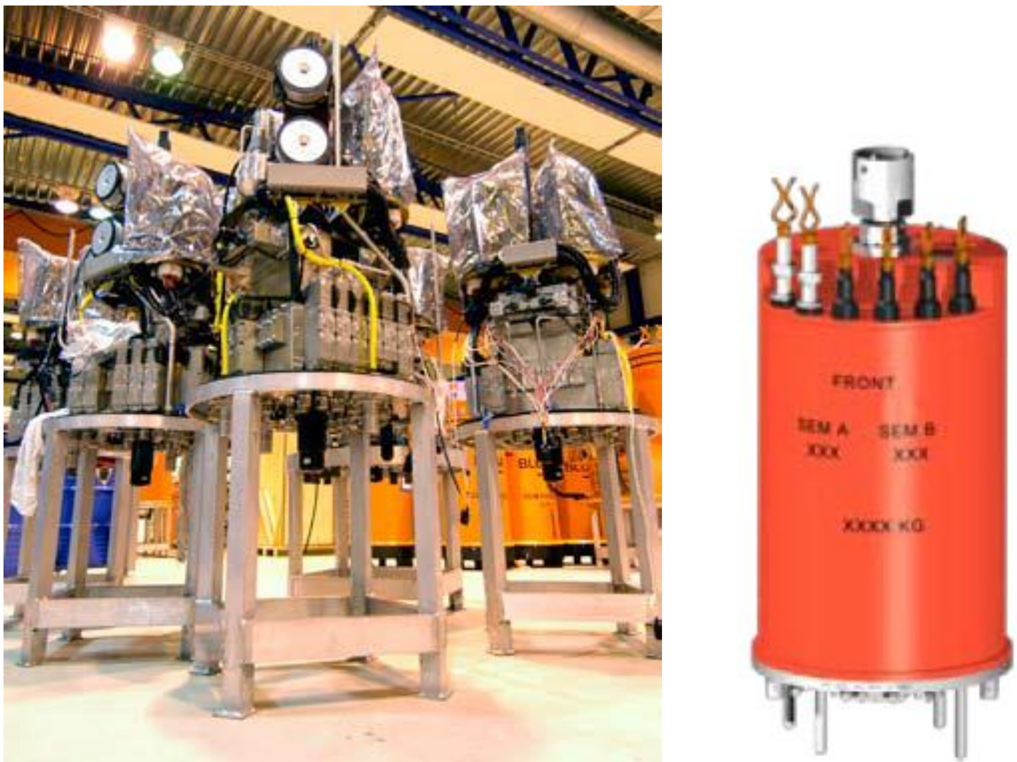


Figure 7: Subsea Control Module

The SCM receives redundant electrical power, communication signals, and hydraulic power from surface control equipment through umbilical hoses and cables. A pair of redundant subsea electronics modules (SEMs) inside the SCM conditions the electrical power, processes communications signals, transmits status, and distributes power to solenoid piloting valves, pressure transducers, and temperature transducers. The SEM typically supports various communication protocols and is intelligent enough to perform local control. Many new SEM manufacturers have utilized open and nonproprietary protocols, such as CAN (Controller Area Network) Bus. CAN Bus was developed and used by the automotive industry for communication between electronic components.

The SEM receives AC power from the electrical power unit (EPU, discussed in section 15) through the subsea power and communication unit (SPCU, discussed in section 16). The SEM normally incorporates two AC-DC converters and outputs to DC bus bars (typically 24V and 5V). Actuation of the electro-hydraulic valves is tapped into the 24V bus bar, and the sensors are tapped into the 5V bus bar. Figure 8 shows an example of an SEM.

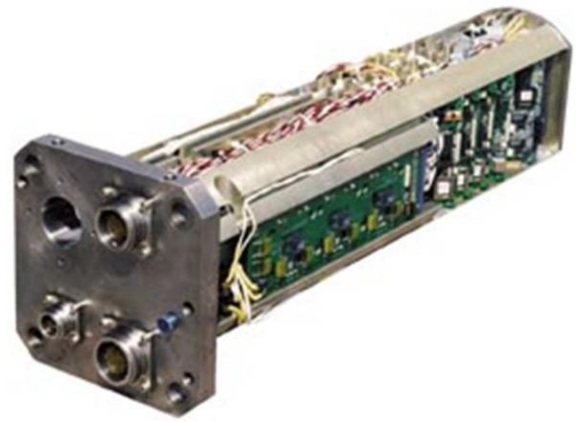


Figure 8: Subsea Electronics Module

The new generation of SEMs provide open architecture communication access, a reduced number of internal wiring interconnections, a modular Ethernet backplane, and support for industry standard interfaces. They also provide an additional single-board computer (SBC) to increase processing capability.

5. Electric Submersible Pump (ESP)

There is less than a fourth of producing oil wells flow naturally. When a reservoir lacks sufficient energy for oil, gas and water to flow from wells at desired rates, supplemental production methods can be considered. Gas and water injection for pressure support or secondary recovery maintain well productivity, but artificial lift is necessary when reservoir drives do not sustain acceptable rates or cause fluids to flow at all in some cases. Artificial lift also improves recovery by reducing the bottomhole pressure at which wells become uneconomic and are abandoned.

Submersible pumps are used in subsea oil production to provide a relatively efficient way of creating artificial lift. Submersible pumps operate across a broad range of flow rates and depths. By decreasing the pressure at the bottom of the well (by either lowering bottomhole flowing pressure or increasing drawdown), significantly more oil can be produced from the well. The pumps are typically electrically powered and referred to as electric submersible pumps (ESPs). An ESP is a device that has a hermetically sealed motor close coupled to the pump body.

Subsea ESP systems are designed to be immersed in the fluid to be pumped. They can be located either in a well or on the seabed. The ESP motors are pressure balanced with the environment, whether that is downhole pressure or water pressure in subsea conditions.

The ESP's main advantage is that the system prevents pump cavitation, a problem associated with the high elevation difference between the pump and fluid surface. Submersible pumps push fluid to the surface rather than pull fluid like jet pumps do. Submersible pumps are also more efficient than jet pumps are. Although an ESP system requires a large supply of electricity, it is less complex and more efficient than gas lift systems are.

A typical ESP system includes the following components:

- A three-phase electric motor
- A seal assembly
- A rotary gas separator
- A multistage centrifugal pump
- An electrical power cable
- A motor controller
- Transformers

Optional ESP system components may include tubing joints, a check valve, a drain valve, and downhole pressure and temperature transmitters (DHPTT), among others. Figure 9 shows a typical downhole ESP configuration.

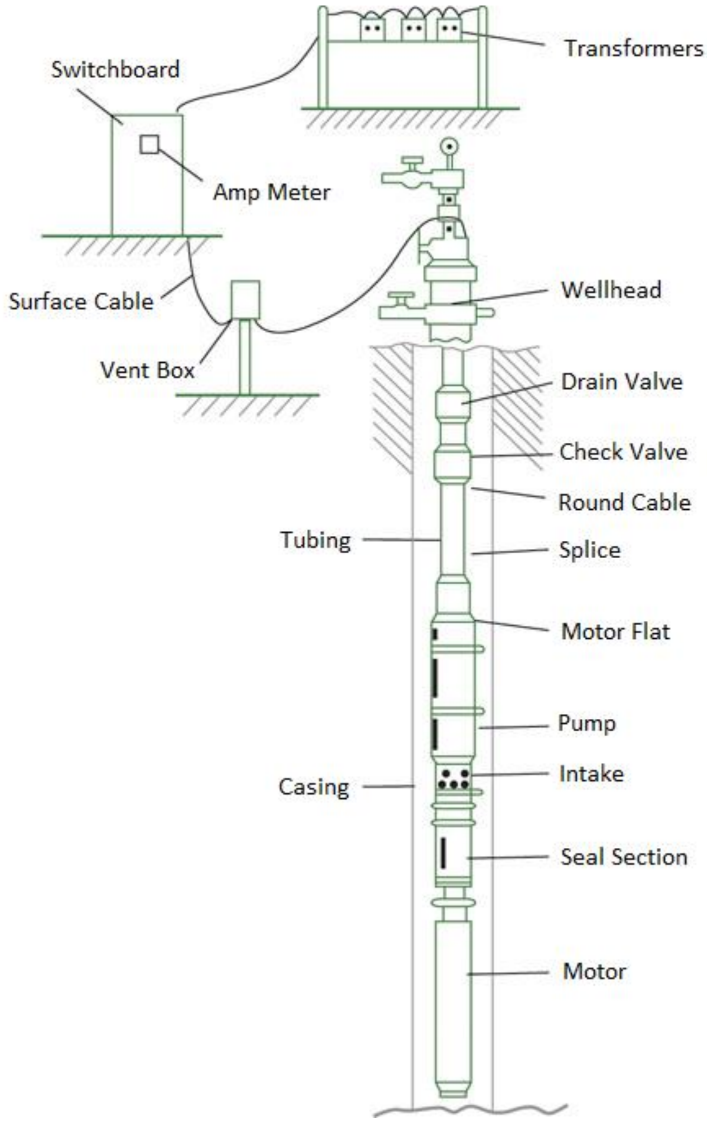


Figure 9: Typical Downhole ESP configuration

The submersible pumps used in ESP installations are multistage centrifugal pumps operating in a vertical position. Although their constructional and operational features have undergone continual evolution over the years, their basic operating principle has remained the same. After being subjected to great centrifugal forces caused by the high rotational speed of the impeller, produced liquids lose their kinetic energy in the diffuser, where a conversion of kinetic to pressure energy takes place. This is the main operational mechanism of the radial-flow and mixed-flow pumps.

The pump shaft is connected to the gas separator or the protector by a mechanical coupling at the bottom of the pump. Well fluids enter the pump through an intake screen and are lifted by the pump stages. The pump itself is a multi-stage unit with the number of stages being determined by the operating requirements. Each stage consists of a driven impeller and a diffuser which directs flow to the next stage of the pump. Other parts include the radial bearings (bushings), distributed along the length of the shaft, which provide radial support to the pump shaft as it turns at high rotational speeds. An optional thrust bearing takes up part of the axial forces arising in the pump, but most of those forces are absorbed by the protector's thrust bearing.

The selection of ESP types mainly depends on the well's fluid properties. There are three major types of ESP applications:

- High water-cut wells, which produce fresh- or seawater
- Multiphase flow wells with high gas–oil ratios
- Highly viscous fluid wells

The pump rate is a function of the rotational speed, the number of stages, the dynamic head acting against the ESP, and the pumped fluid viscosity. These factors dictate the differential pressure across a pump system and, therefore, the flow rate. However, there is an optimal design flow rate that maximizes pump efficiency and run life for a given pump. Figure 10 shows the operating range recommended by ESP manufacturers.

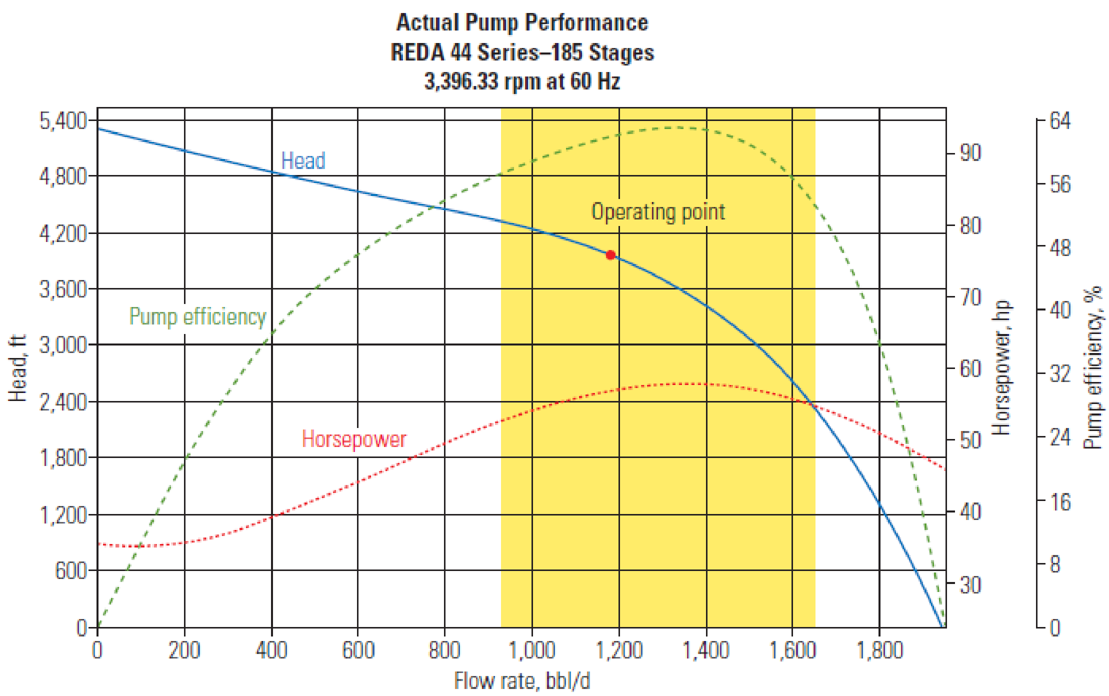


Figure 10: Pump Performance Curve

ESP sizing is based on the flow rate, or predicted completion performance. This usually involves the examination of the well's inflow performance relationship (IPR), which describes the production response to changes in bottomhole pressure, or BHP.

Required data for calculation of the size of an ESP include well data, production data, well-fluid conditions, power sources, and potential problems. Calculations for designing an ESP system include:

- Determination of pump intake pressure
- Calculation of total dynamic head
- Selection of pump type
- Check of load limits
- Selection of accessory and optional equipment

6. Subsea Electrical Connectors

Subsea electrical connectors connect flying leads to subsea structures, such as manifolds, trees, and termination units. Therefore, subsea electrical connectors must be designed to handle the toughest conditions, such as deep water with a hydrostatic pressure of 20,000 psi.

Subsea electrical connectors must meet the following basic requirements:

- Must provide a termination for electrical cables used to transmit low-voltage electrical power and communication signals between subsea production control system components.
- At the very minimum, must meet all requirements as stated in the latest revisions of ISO 13628-4 and ISO 13628-6.
- Should be wet and dry mateable at subsea.
- Can handle low voltage for signal and high voltage for power supplies.
- The number of electrical connectors in series is kept to a minimum. Redundant routing should follow different routes. Consideration should be given to keeping voltage levels as low as practical to minimize electrical stress on the conductive connectors.
- Be either Tronic or ODI.
- Be capable of making wet mateable electrical connections utilizing an ROV. The connectors are designed and constructed for normal and incidental loads imparted by ROVs during critical operations.
- It is important to confirm the type of connector half—whether it is the “cable end” or “bulkhead connector” type.
- The Christmas tree side has male (pin) connectors, and the flying leads have female (socket) connectors.
- Configured to ensure that no male pins are powered up while exposed. Electrical distribution systems should be designed so that “live disconnect” is not required during normal maintenance or, if possible, during failure mode operations or recovery periods.
- Furnished with the necessary equipment to protect them from being unmated while in service and to prevent calcareous buildup and marine growth.
- Optical connectors for any fiber-optic line are fitted with long-term protective caps.

Figure 11 demonstrates some examples of subsea electrical connectors.

Figure 11: Subsea Electrical Connectors

7. Electrical Flying Leads (EFL)

Electrical flying leads (EFLs), shown in figure 12, are also known as jumpers. EFLs serve as support connections between subsea structures, such as manifolds, trees, and termination units. The leads are flown into place using ROVs, as demonstrated in figure 13. The EFL connects the SDU to the SCM on the tree. Each SCM utilizes two independent EFLs from the SDU for the redundant power and communication on power circuits.

Figure 12: Electrical Flying Leads (Jumpers)

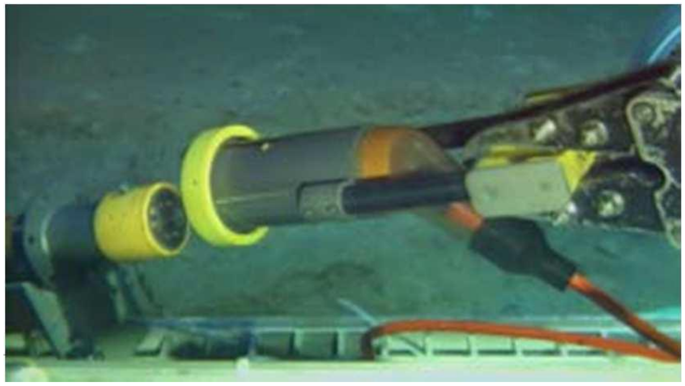


Figure 13: Leads are flown into place using ROV

The EFL connects communication on power circuits between various pieces of subsea distribution equipment. The EFL has different configurations, such as four way (with four wires), eight way, or twelve way. The connectors at the end of the flying lead should be female. EFLs contain ROV-type connectors at each end to allow for subsea installation and retrieval.

The EFL assembly is composed of a pair of electrical wires enclosed in a thermoplastic hose, fitted at both ends with soldered electrical connectors. The assembly constitutes an oil-filled, pressure-compensated enclosure for all wires and their connections bonded to ROV-mateable connectors. Hybrid flying leads may contain both fiber and electrical conductors. Cable may be extruded (shallow water), or individual conductors can be placed in a pressure-balanced oil-filled hose (deep water).

7.1 Construction

During EFL construction, wires are continuous and, at minimum, 16 AWG. A twisted-pair configuration is often used. Voltage and current ratings for the wires are chosen to not significantly degrade the circuit's overall performance based on results from the electrical analysis of the EFL.

Wires are soldered to the connector pins and protected by boot seals. Pin assignment must match the system requirements. A hose with low-collapse resistance, specifically selected for subsea use and with titanium or equivalent end fittings, connects both electrical connectors of the flying lead to ensure the compatibility of materials used. The length of the wire within the hose is sized to allow for any stretching of the hose up to the failure of the hose or up to the end fittings.

Hose stretching does not allow for any pull load on the soldered connections. Hoses are of a continuous length, with no splices or fittings for lengths under 300 feet. Any use of splices or fittings would be considered on a case-by-case basis. Hoses are filled with Dow Corning 200 dielectric fluid, which is used for foam control. The hoses, boot seals, and wire insulation must be compatible with the compensating fluid and seawater.

The wire insulation is a single-pass extrusion and suitable for direct high potential, or hipot. Connectors are appropriately marked to simplify ROV identification and operation. In addition, an alignment key or other device is incorporated to ensure proper orientation. The electrical connectors must be chosen correctly and capable of making and breaking at worst-case angles, before and after course alignment, without failure. They must be capable of making and breaking 100 times under power without any sign of damage to the pins or sockets and still remain capable of excluding seawater.

7.2 Installation

During installation, connectors are provided with shipping protection covers. All EFL assemblies are identified with tags on both ends. Tags must be designed so that they do not come off during severe handling either onshore or offshore during installation and must be visible to ROVs at working-water depth.

The color of the hose must be visible to ROVs when in subsea use. Acceptable colors include yellow or orange. To be easily seen and identified by ROVs, the ROV handles and bottom plastic sleeves of the flying leads should be painted with colorful marks according to standards and codes. These marks should be recognizable for the life of the system. All EFL assemblies are filled with compensating fluid to a slight positive pressure (10 psi) prior to deployment.

Subsea-installed flying leads are protected with mating connectors when not in use. These EFLs are temporarily located in parking positions on the subsea umbilical termination assembly (SUTA), at the tree, or on a specialized parking stand.

The offshore oil and gas industry is investing in simulators to conduct virtual system integration tests (SIT) to quickly find and rectify design weaknesses and to find the limits of safe operation under a wide range of environmental conditions. Simulators enable the rapid construction and evaluation of field development and tool ideas in a virtual world that resembles the real world. In virtual SITs, different solution scenarios can be quickly generated, compared, and tested for feasibility by both subsea engineers and offshore teams. This mitigates risk earlier in projects and leads to greater savings and more confidence when the solutions are deployed offshore. Figure 14 shows a simulation of an ROV performing a tooling intervention from a flying lead on a subsea production system.

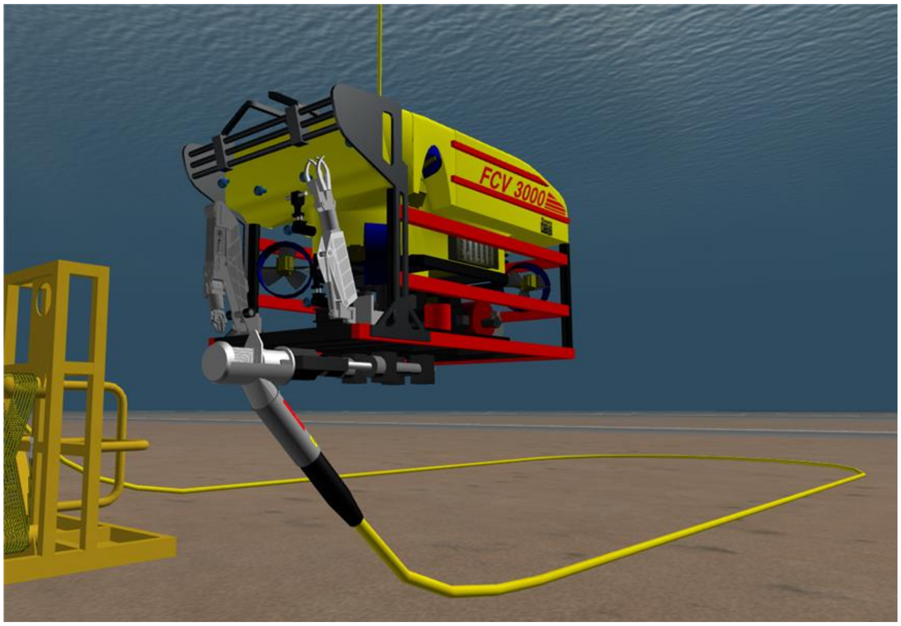


Figure 14: Simulation of ROV Performing Tooling Intervention

8. Subsea Electrical Power Distribution

A subsea electrical distribution system distributes electrical power and signals from the umbilical termination head to each well. Electrical power—as well as hydraulic pressure, chemical supply, and communications—is provided to a subsea system through an electro-hydraulic umbilical.

The SUTA is the main distribution point for the electrical (also hydraulic and chemical) 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 be shared between multiple subsea trees, manifolds, or flow line sleds. Similarly, electrical cables from the umbilical also can have dedicated destinations to electrical components of the subsea production system or may be shared by multiple SCMs or other subsea devices.

The electrical connection is made through electrical connectors on 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 15 demonstrates the typical electrical and hydraulic power distributions in a subsea production system.

For a template system, the electrical distribution system consists of jumper cables between the umbilical termination head and the control modules. For a single satellite system, the electrical distribution system is defined as the jumper cables between the umbilical termination head and the control module. For a manifold/satellite system, the electrical distribution system comprises manifold jumper cables, infield jumper umbilicals, and satellite jumper cables.

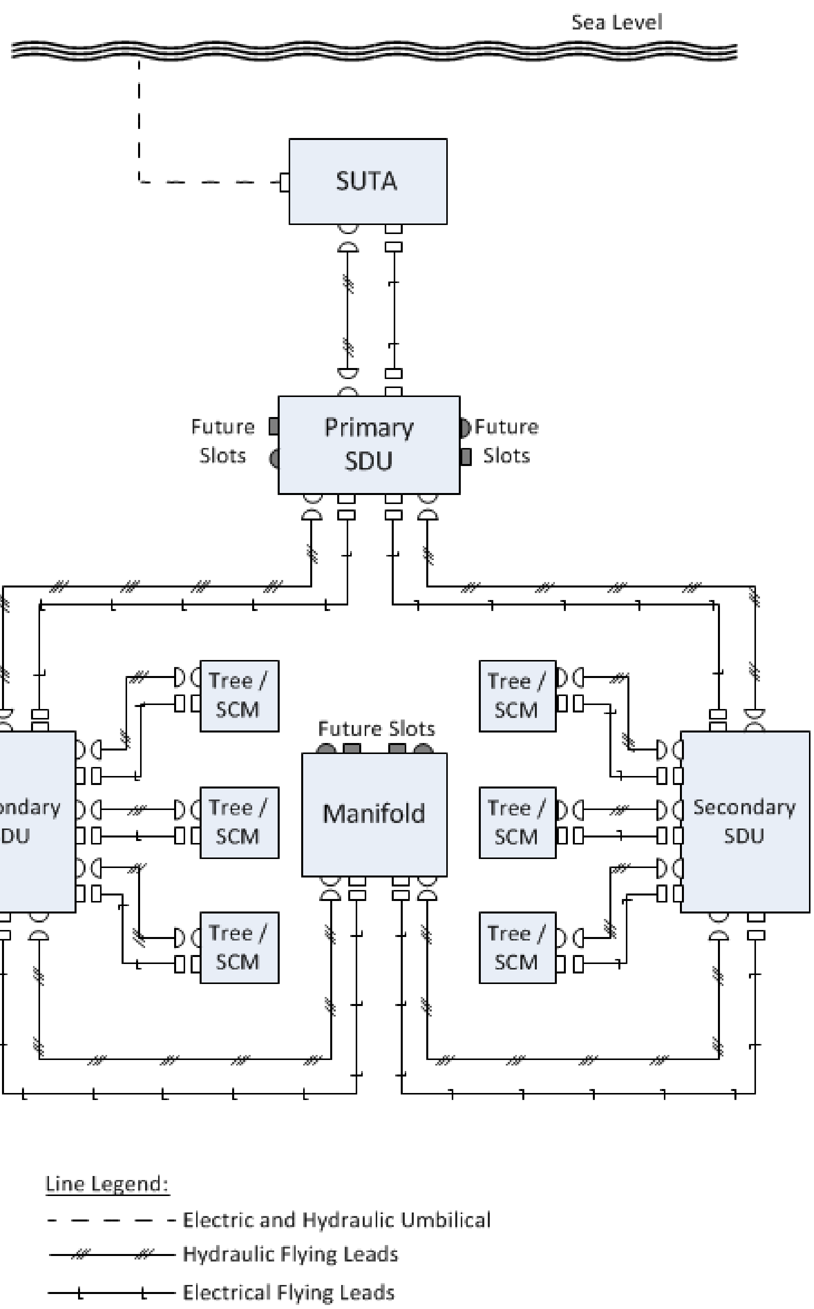


Figure 15: Electrical and Hydraulic Distributions in Subsea Production System

Connections of electrical distribution cabling and electrical jumpers should be made by an ROV or a 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 the required flexibility. Detailed electrical calculations and simulations are mandatory to ensure the proper operation/transmission of the high-voltage distribution network under all load possibilities (full load, no load, rapid change in load, and short circuits).

The following are general requirements of electrical power distribution in a subsea production system. Specific requirements vary based on different standards and the geographic location of the production system.

- The number of electrical connectors in series should be kept to a minimum. Redundant routing to the module connectors should, if possible, follow different paths.
- The cables must be installed into self-pressure–compensated fluid-filled hoses. The fluid should be dielectric. Dual barriers must be provided between seawater and the conductor. Both barriers should be designed for operation in seawater.
- Manifold electrical distribution cabling and jumper cables from umbilical termination to the subsea control module (SCM) should be replaceable by the ROV. Removal of the faulty cable is not necessary.
- In case of a failure in the distribution system, it should be possible to run several SEMs on one pair of cable after using an ROV for reconfiguration.
- If one electrical line supplies power to more than two SEMs, the distribution and isolation units should be located in a separate, retrievable distribution module.
- The connection of electrical distribution cabling and electrical jumpers should be made by an ROV using simple tools, with minimum intervention time.
- The cable assemblies should be designed and installed so that any seawater entering the compensated hoses will move away from the end terminations by gravity. They should be shielded to avoid cross talk and other interferences.

9. Subsea Distribution Unit (SDU)

The subsea distribution unit (SDU), as shown in figure 16, receives electrical power and communications, fiber-optic communications, and hydraulic and chemical services from the SUTA and distributes them to multiple points, including trees, manifolds, pumping and boosting stations, and infield tie-ins. It is necessary that the number of electrical connectors in series are kept to a minimum. Redundant routing to the module connectors should follow different paths if possible. The cables are installed into self-pressure–compensated fluid-filled hoses. The fluid should be dielectric to prevent foaming. Dual barriers are provided between water and the conductor. The barriers are designed for operation in seawater.

Figure 16: Subsea Distribution Unit (SDU)

Manifold electrical distribution cabling and jumper cables from umbilical termination to the subsea control module (SCM) can be replaced by an ROV. In the case of a failure in the distribution system, such as a faulty cable, it should be possible to run several SEMs on one pair of cable after being reconfigured using an ROV. If one electrical line is supplying power to more than two SEMs, the distribution and isolation units can be located in a separate, retrievable distribution module.

Hydraulic/chemical services terminate to a multiple quick-connect (MQC) junction plate. Electrical quad cables are terminated to an electrical termination assembly, which splits the service into a group of bulkhead electrical connectors. The connection of the electrical distribution cabling and electrical jumpers is made by an ROV using simple tools with minimum implications for rig/vessel time. The cable assemblies should be designed and installed so that any seawater entering the compensated hoses will move away from the end terminations by gravity.

The SDU handles and removes utility distribution from the SUTA, reducing the size of the SUTA and simplifying installation. Since SDUs are easier to reconfigure than SUTAs are, upgrades can be done easily without disturbing the umbilical. Flying leads between the SUTA and SDU can perform the same function as logic plates, allowing simple system reconfiguration. SDUs can be designed to land on the same foundation structure as the SUTA does or on an independent foundation. They are typically designed to be independently recovered from their foundations.

10. Subsea Power Supply

A multiplexed electro-hydraulic subsea control system typically requires a topside unit to control and provide the necessary power to the subsea equipment. There are two types of power systems used: an electrical power system or a hydraulic power system.

The electrical power system supplies power to the subsea equipment, including the valves and actuators on subsea trees/manifolds, transducers and sensors, SCMs, SEMs, pumps, and motors. The power sources can come from an onshore facility, as shown in figure 17, offshore wind farms, or directly from the site through offshore rigs or subsea generators.

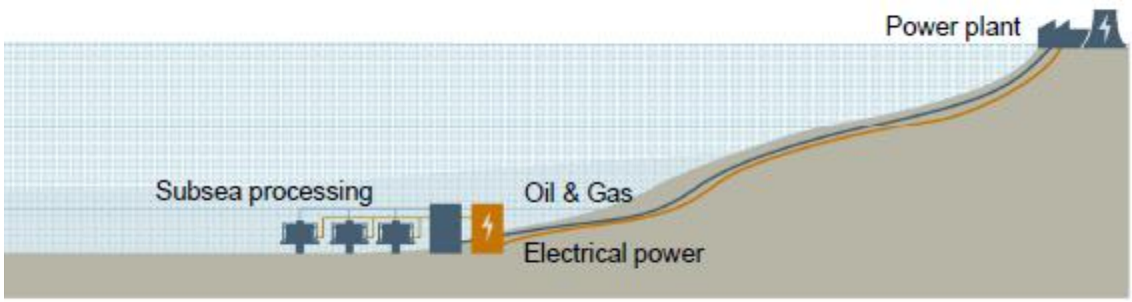


Figure 17: Power Supply from Onshore to Subsea

Offshore rig generators are designed for operation within a division/zone 2 hazardous area, providing safe shutdown and removal of all ignition sources in the event of a platform-confirmed combustible gas release. Typical generators offer the following:

- Up to 2,000 kW of electricity
- 60 Hz and 50 Hz applications
- Low emissions
- Emergency and auxiliary power

As subsea development advances into deeper water, the cost of bringing power by subsea cable from afar may make it uneconomical. An alternative would be the availability of subsea generators with sufficient payload capacity to generate power for subsea equipment. Although subsea power generation does require a high development cost, it has relatively low construction and operational costs. In addition, high-voltage connectors and inverters are not necessary, and the system has virtually unlimited expansion possibilities.

11. Subsea Power Grid

Oil and gas produced from deepwater fields have been typically brought to the surface and transported to onshore processing facilities. The inherent complexity and cost of bringing offshore oil to the surface, transferring it to an oil tanker, and transporting it to onshore refineries is very high, especially with deepwater oil wells. As a result, subsea processing systems have been increasingly accepted as solutions to enhance field economics by maximizing recovery, increasing production, and reducing costs. Subsea processing enables more cost-efficient development, especially for long step-outs and marginal and dispersed fields, and in deeper waters.

Subsea processing encompasses a number of different processes to help reduce the cost and complexity of developing an offshore field. The main types of subsea processing include subsea water removal and reinjection or disposal, single-phase and multiphase boosting of well fluids, sand and solid separation, gas/liquid separation and boosting, and gas treatment and compression.

Subsea processing facilities include many electrically driven pumps and gas compressors to transport oil and gas over very long distances. Therefore, subsea processing relies on an industrial, heavy-duty, high-reliability power grid located on the seabed. Today's subsea technology offers a robust subsea power grid for variable-speed drives supplied from an onshore power plant or platform. A subsea power grid is designed to operate at a depth of 10,000 feet and to withstand extreme pressure and harsh temperatures. Figure 18 shows an example of a subsea power grid.

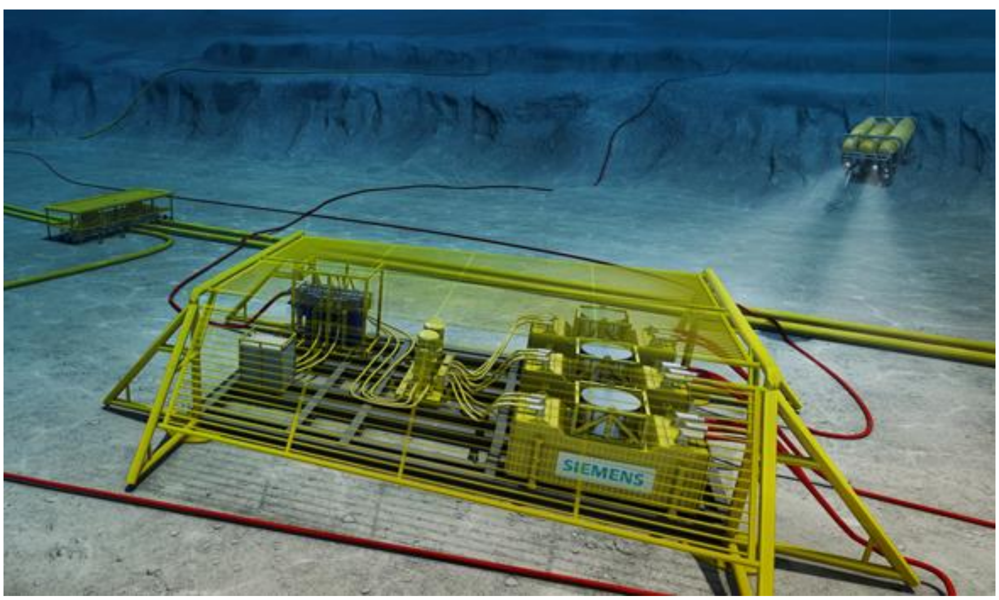


Figure 18: Subsea Power Grid

The subsea power grid contains components such as switchgears, step-down transformers, and variable-speed drives. The transformer is used to step down power to a suitable voltage and distribute power to the variable-speed drive and other subsea equipment. The variable-speed drive is used to control and run subsea engines, such as pumps, compressors, and water-injection systems. The power components can be installed on a common base frame on the seabed. All components within the grid are retrievable. A typical subsea power grid configuration is provided in figure 19.

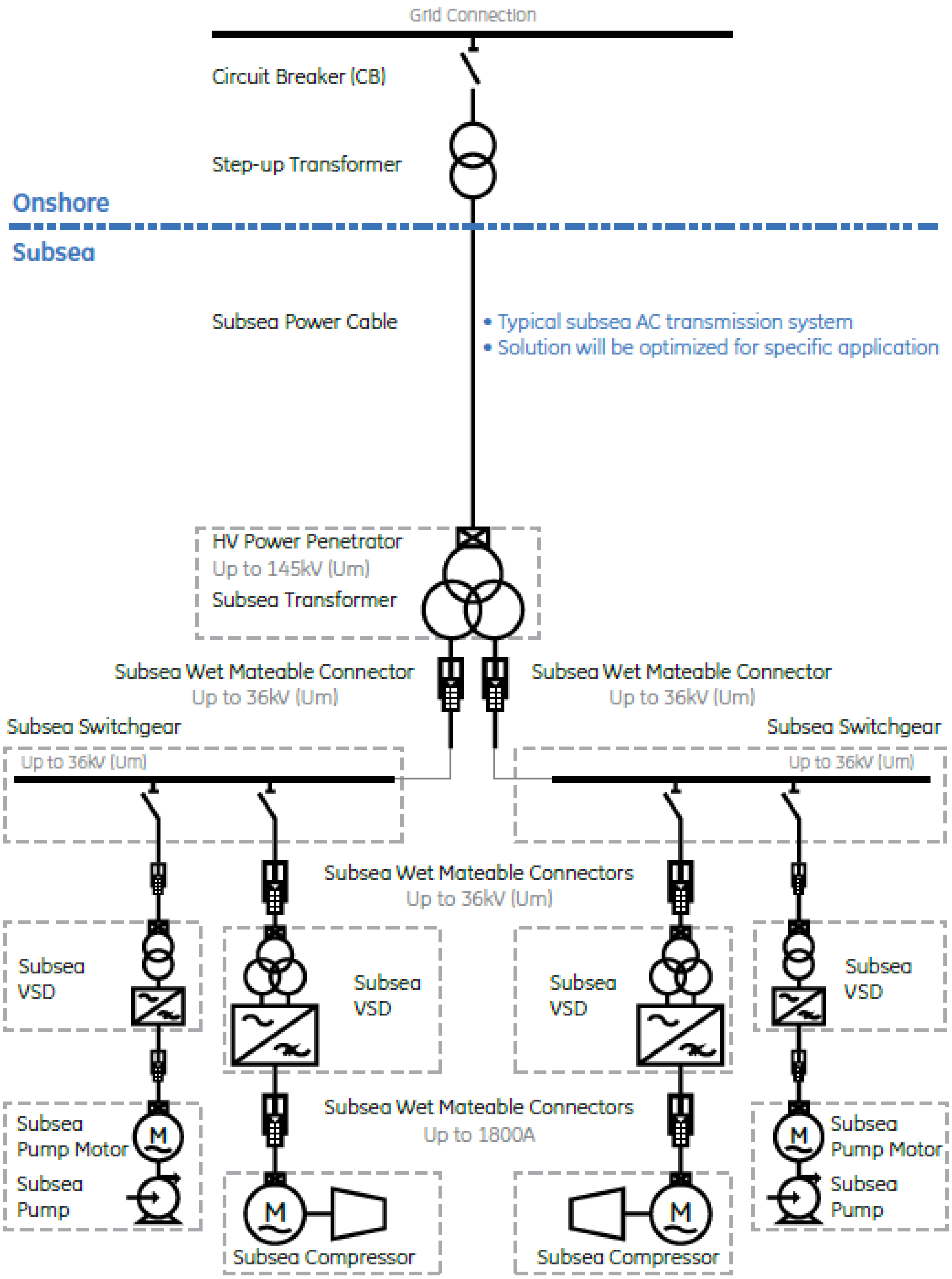


Figure 19: Typical Subsea Power Grid Configuration

The subsea switchgear, as shown in figure 20, utilizes a modular mechanical design with four breaker units mounted in two atmospheric canisters. Its main bus bars, wet-mate connectors, and measuring transformers are housed in a fluid-filled, pressurized base module.

Figure 20: Subsea Switchgear

12. Electrical Power System

In a typical subsea production system, the electrical power system provides power generation, power distribution, power transmission, and electricity from electric motors. To ensure continuous production from a subsea field, it is important that the subsea system's associated electrical power system be designed well. Figure 21 illustrates the design process for an electrical power system.

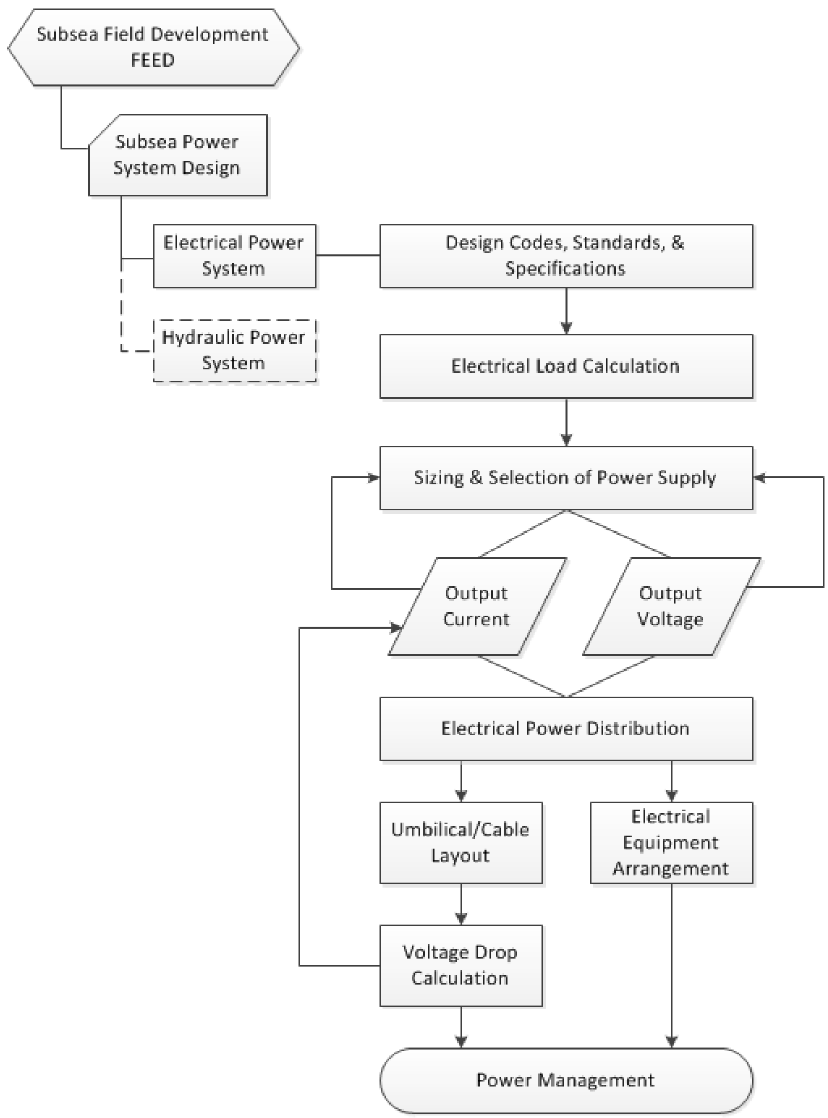


Figure 21: Electrical Power System Design Process

12.1 Design Codes, Standards, and Specifications

Several organizations have developed electrical codes and standards, which are accepted by various industries around the world. These codes and standards specify the rules and guidelines for the design and installation of electrical systems. Tables 2 through 5 list some of the major international codes and standards used for subsea field development.

Table 2: American Petroleum Institute (API)

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 System
API RP 17H	Remotely Operated Tools and Interfaces on Subsea Production Systems
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 3: International Electrotechnical Commission (IEC)

IEC 50 (426)	International Electrotechnical Vocabulary (IEV) – Chapter 426 – Electrical Apparatus for Explosive Atmosphere

Table 4: Institute of Electrical and Electronics Engineers (IEEE)

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 5: International Standards Organization (ISO)

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 Control Systems

12.2 Electrical Load Calculation

Electrical load calculation is one of the earliest tasks during the design of an electrical power system. Engineers must calculate the required electrical load of all topside and subsea equipment so that an adequate power supply can be selected.

Each electrical load can be classified into several categories, such as vital, essential, and nonessential. There are methods of considering a load or group of loads, and these may be expressed in the form of questions, as shown in Table 6.

Table 6: Typical Electrical Load Categories

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

All of the vital, essential, and nonessential loads are typically divided into three duty categories:

- Continuous duty (*C*)
- Momentary duty (*M*)
- Standby duty (*S*) (those that are not out of service)

Switchboard that redirects electricity (for example, from the EPU) usually covers all three categories. The total amounts of each category at the switchboard are C_{sum}, M_{sum}, and S_{sum}. Each total 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); therefore,

$$\text{TPRL} = \sum^{n} (D_c \times C_{sum} + D_m \times M_{sum}) \text{ kW}$$

$$\text{TPPL} = \sum^{n} (D_c \times C_{sum} + D_m \times M_{sum} + D_s \times S_{sum}) \text{ kW}$$

where

n = number of switchboards
D_c = diversity factor for sum of continuous duty (C_{sum})
D_m = diversity factor for sum of momentary duty (M_{sum})
D_s = diversity factor for sum of standby duty (S_{sum})

Different oil companies use different values for the diversity factors, which are based on experience gained over years of designing oil fields. Also, different kinds of host facilities may require different diversity factors. Normally, D_c ranges from 1.0 through 1.1, D_m ranges from 0.0 through 0.2, and D_s ranges from 0.3 through 0.5.

The continuous loads are associated with power consumption, which remains constant during the life of the system regardless of the operations taking place. Such consumers would include the SPCU and the monitoring sensors. Momentary loads are the loads that depend on the system's operational state. An 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 momentary loads, it is important to identify the duration and frequency of such operations as well as to have a statistical description of operating occurrences in a specified time period.

A subsea power system cannot run idle, or without load, at any time except during temporary production shutdowns or maintenance. In tables 7 and 8, typical electrical loads are provided for continuous and momentary loads during the operation of electro-hydraulic and all-electric production systems. Note that the use of a choke valve can be either continuous or momentary, depending on the field requirements.

Table 7: Load Schedule for Electro-Hydraulic Production System

Operation	**Type**	**Power Requirement**	**Frequency (per day)**	**Duration**
HPU	Momentary	11 kW/pump	2	2 minutes
Single valve actuation	Momentary	10W	1–3	2 seconds
Choke valve actuation	Momentary or continuous	10W (momentary)	N/A	2 seconds (momentary)
SEM	Continuous	Maximum 80W	N/A	N/A
Sensors	Continuous	Maximum 50W	N/A	N/A

Table 8: Load Schedule for All-Electric Production System

Operation	**Type**	**Power Requirement**	**Frequency (per day)**	**Duration**
Single valve actuation	Momentary	3–5 KW	1–3	40–60 seconds
Single valve normal operation	Continuous	20–50W	N/A	N/A
Choke valve actuation	Momentary or continuous	1–2 KW (momentary) 60W (continuous)	N/A	2 seconds (momentary)
SEM	Continuous	Maximum 80W	N/A	N/A
Sensors	Continuous	Maximum 50W	N/A	N/A

13. Master Control Station (MCS)

In the topside facilities of offshore oil and gas platforms, a master control station (MCS) is a dedicated system that controls and retrieves data from subsea equipment on the ocean floor. As shown in figure 22, the MCS consists of a computer, programmable logic controller (PLC), and hardwired inputs and outputs. The MCS provides the operators with complete control and monitoring of subsea-installed equipment as well as surface electrical and hydraulic power units through the computer graphical interface. The MCS communicates with the microprocessor in the subsea electronics module (SEM), which receives commands from the MCS and provides data to the MCS.

Figure 22: Master Control Station

The PLC is a logic solver and contains a pre-programmed controller logic, such as ladder logic, which provides the necessary intelligence to operate subsea equipment, system interlocks, and shutdown sequences among other components. The hardwired inputs and outputs are usually wired to push buttons and lamps or LED displays for the emergency shutdown (ESD) of the subsea production system.

14. Topside Umbilical Termination Assembly (TUTA)

The topside umbilical termination assembly (TUTA), as shown in figure 23, provides the interface between the main umbilical and topside control equipment, such as the HPU and EPU. The unit is a freestanding enclosure that can be bolted or welded in a location adjacent to the umbilical hang off in a hazardous exposed environment on the topside facility. These units are usually tailor made to meet specific facility requirements with various materials and hydraulic and pneumatic equipment as well as power and communication cables.

Figure 23: Topside Umbilical Termination Assembly (TUTA)

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. The TUTA includes an electrical enclosure in a lockable stainless steel cabinet certified for its area of classification with ingress protection to fit its location. In addition, the valves in the TUTA comply with the requirements for valves in flammable services, as stated in the fire testing standards.

The termination unit at the topside end of the umbilical is designed for hang off and includes a bull nose that is suitable for pulling the umbilical up through the host guide tube onto a termination support. For a free-flooded umbilical, it is sufficient to seal off the individual ends of the conductors and tubes and use an open bull nose. Tubes must be individually sealed to prevent hydraulic oil loss and water ingress during the pulling operations. Electrical conductors must be sealed to prevent water ingress within the insulation.

Typical TUTA functions include:

- Hydraulic, chemical, and electrical terminations

- A bulkhead plate interface for hydraulic and chemical terminations
- Isolation, block, and bleed valves provided for all hydraulic and chemical lines
- Connections for power and communication electric quads
- Connections for hydraulic/chemical circuit lines that are pressurized up to 15,000 psi

15. Electrical Power Unit (EPU)

The electrical power unit (EPU), shown in figure 24, provides conditioned electrical power to the topside and subsea system components. The EPU receives input power from a topside universal power supply (UPS) and utility power supply. The EPU supplies dual, isolated, single-phase power for the subsea system through the composite service umbilical. The EPU also supplies power to the MCS, SPCU, and instrumentation on the HPU.

Figure 24: Electrical Power Unit

The EPU should be designed to operate safely on the topside facility and allow for individual pair connection/disconnection and easy access to individual power systems for maintenance and repair. The EPU supplies electrical power at the desired voltage and frequency to topside and subsea equipment. Subsea power transmission is performed via the electrical umbilical and the subsea electrical distribution system.

The EPU usually has two outputs: a DC bus bar and an AC line. The energy storage units are tapped to the DC bus bar, whereas the AC output is connected to the SEM. Figure 25 shows an electrical schematic for the EPU.

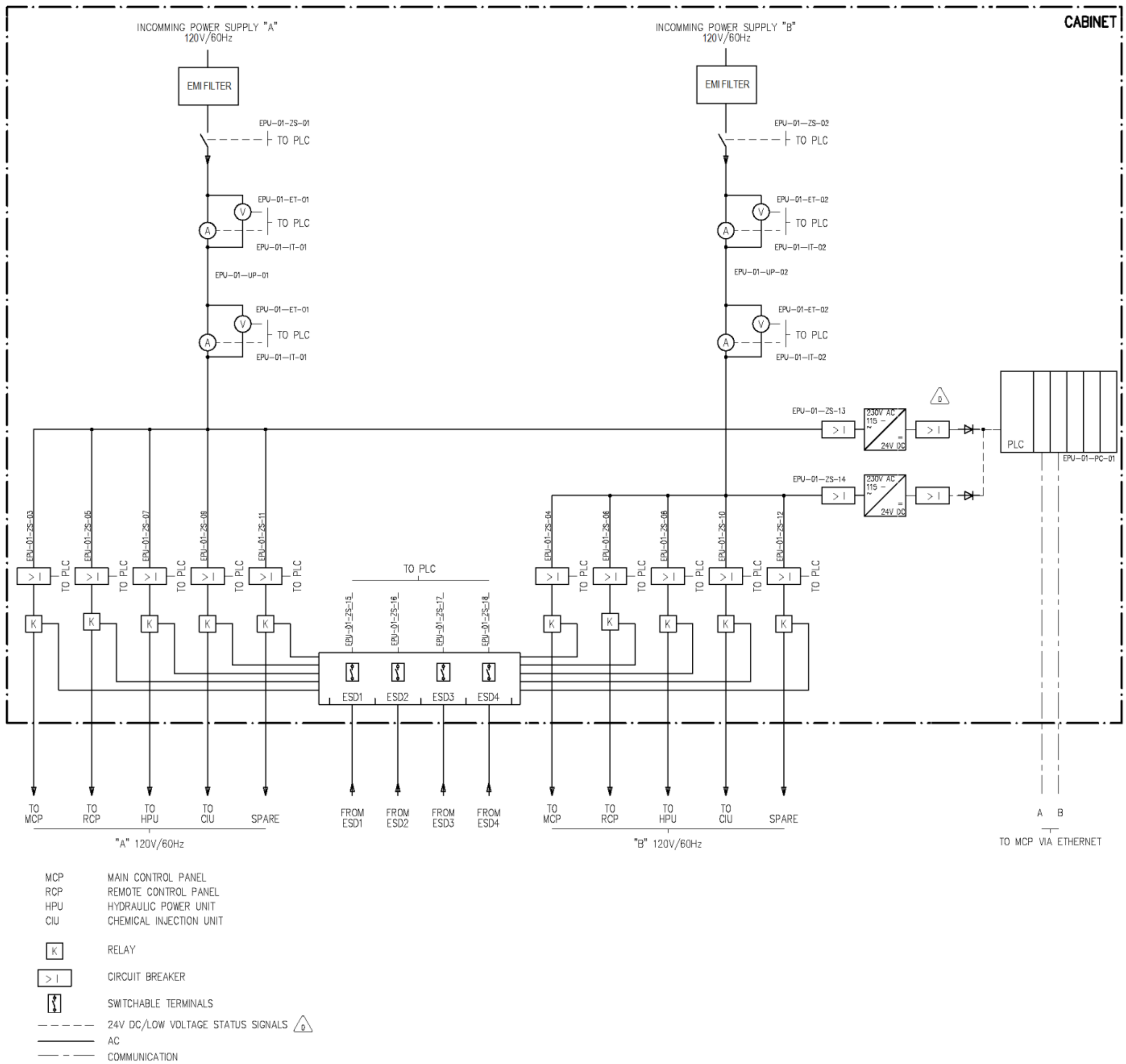


Figure 25: EPU Electrical Schematic

Typical features of the EPU include:

- A proprietary, fully enclosed, powder-coated steel enclosure with front and rear access
- Standard design suitable for safe areas, i.e., nonhazardous gas areas and air-conditioned environments
- Dedicated dual-channel power supplies, including fault detection to the subsea electronics module (SEM)
- Modems and signal isolation to effect the “Communications on Power” transmission system

- Capability of transferring monitoring signals to the MCS
- An electrical power backup input terminal in the event of a power supply outage to both the MCS and EPU

The EPU's status is usually displayed on the MCS for operators to monitor. Figure 26 shows a typical display of the EPU status on the MCS.

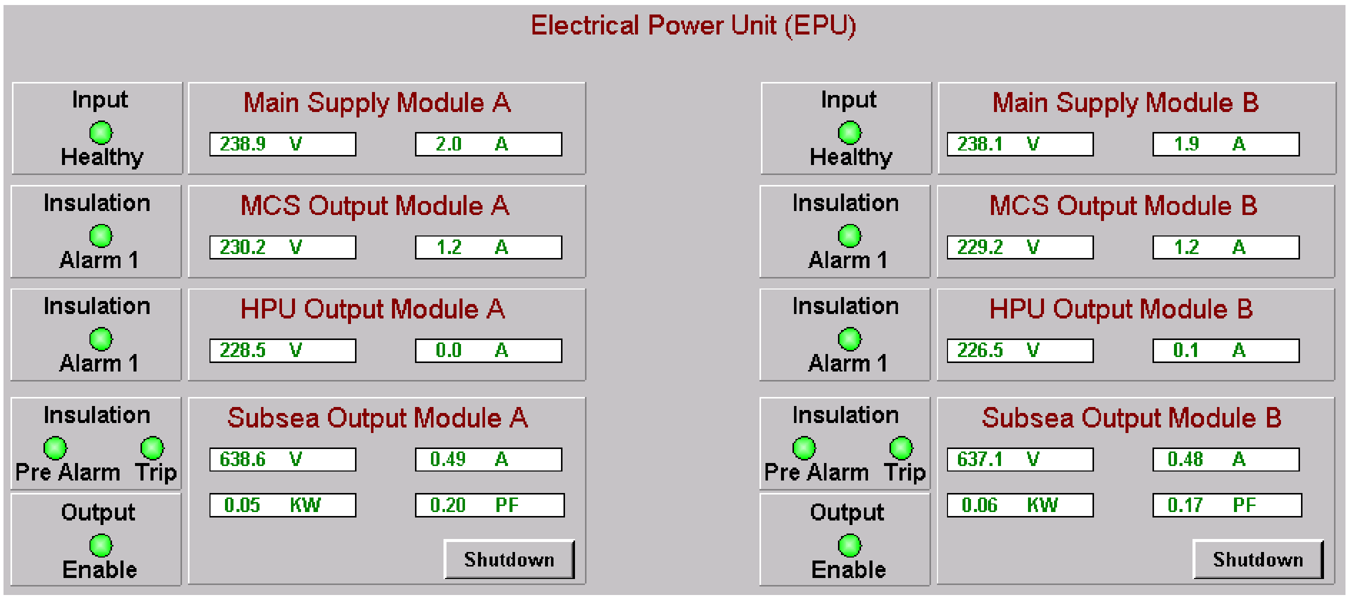


Figure 26: EPU Display on the MCS

16. Subsea Power and Communication Unit (SPCU)

The subsea power and communication unit (SPCU) supplies electrical power to the subsea control and monitoring equipment. The SPCU combines power from the EPU and communications from the MCS for transmission to the subsea SCM and equipment. The SPCU contains redundant communication modems to allow system monitoring, operation, and reconfiguration. The modems have a serial or fiber-optic link to the subsea communication unit (SCU), which transmits and receives signals from the SCM. The SPCU must contain an EMI filter to prevent potential damage to subsea control modules caused by voltage spikes and fluctuations.

Redundant power and communication are provided to each SCM from modular and redundant umbilical line modules (ULMs). Each ULM drives one umbilical line that provides the communication interface to subsea equipment and delivers power over a pair of wires. The voltage must be individually adjustable for each pair of wires. Each pair should be galvanically segregated from the rest of the system. This design allows for individual pair connection/disconnection without the need to shut down the SPCU. The design also allows for easy access to individual power/communication systems for maintenance and repair.

The following parameters of the SPCU are monitored from the MCS:

- Input current and voltage
- Output current and voltage
- Umbilical voltage
- Circuit breaker status
- System alarms

Circuit breakers in the SPCU should meet the requirement of IEC 60947-2.

17. Uninterruptible Power Supply (UPS)

17.1 Topside UPS

The main function of the topside uninterruptible power supply (UPS), shown in figure 27, is to provide a continuous filtered electrical power supply to the subsea control system regardless of the status of the platform electrical power system. The UPS can be daisy-chained to add flexibility. As shown in figure 28, the UPS delivers power to the EPU and, in turn, provides power to the MCS, SPCU, HPU, and TUTA. The UPS battery backup should be capable of running the system for at least thirty minutes after loss of platform power to allow adequate time for the proper shutdown of equipment.

Figure 27: Topside UPS

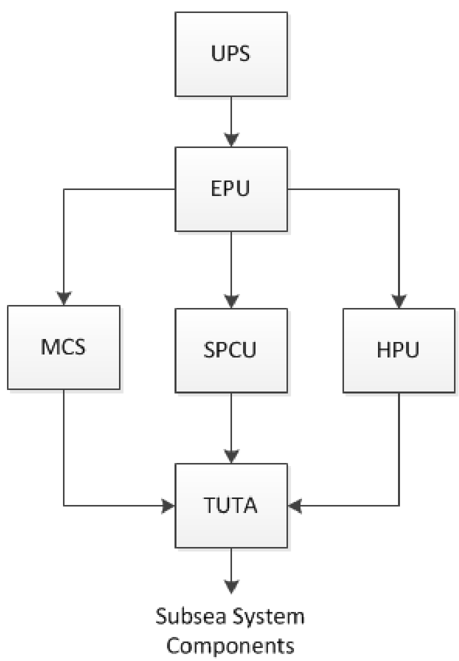


Figure 28: Power Supply from UPS

The following parameters of the UPS should be monitored from the safety automation system (SAS):

- Main voltage
- System current
- System frequency
- UPS bypass mode
- UPS battery mode
- UPS failure

Typically, the power delivered from the UPS to the EPU should be 120VAC or 230VAC +/–10%, 50 or 60 +/–1Hz, single phase, with a maximum of 5% harmonic distortion. Each UPS should have a capacity of 100% of the total load, including future, indicated, or planned expansion of the production control system. Only components necessary for operation of the production control system should be connected to the UPS battery modules through the EPU. For example, HPU electrical pumps should not be regarded as critical.

17.2 Subsea UPS

To enhance production and maximize reliability of offshore fields, focus has increased on replacing some traditional topside equipment with subsea versions. Some of these applications have led to the deployment of large battery and UPS modules for subsea deployment. Applications include the recent development of 165 kWh battery modules to allow subsea pumping.

Subsea UPS also provides uninterrupted power to production shutdown systems. Power is ensured for active magnetic levitating bearings common on subsea compressor systems, electric-actuated valves, and motors on subsea production systems. By providing a localized UPS system to the magnetic levitating bearing controllers, it is possible to provide a redundant power source, which mitigates the risk from failure of the primary subsea power supply. Downtimes for the magnetic bearings are typically a few minutes and fit well within the UPS's voltage, current, and power supply levels. A distributed subsea UPS system utilizes a modular design that can be configured to allow for expansion and enhanced redundancy of the subsea system. Figure 29 is an example of a subsea UPS.

Figure 29: Subsea UPS

18. All Electric Subsea Control System

All electric subsea control systems are an attractive addition and an alternative to existing electro-hydraulic systems.

Benefits of all electric control systems include:

- Zero hydraulic fluid discharge
- Reduced umbilical costs
- Deepwater capability
- Very long offset capability
- Fast and accurate operational response

New electric subsea technology utilizes standard low-power/-voltage umbilical and connector technology, which provides a safer operating environment and minimizes the corrosion risk from stray high-voltage currents. Rechargeable subsea batteries power valve and actuator operations. Subsea batteries require only a low-power and low-voltage supply from the topside, which is typically less than 150W. Actuator electric motors can produce a high amount of power, typically up to 3,000W or more for valve operation, when powered locally by batteries.

A plug-and-play philosophy has been adopted in all electric systems so that actuators can be added and/or retrieved by an ROV during the engineering, testing, and operational phases without requiring any additional engineering study and design. This also means that valve actuators can be repaired using an ROV. The electric system's redundant control modules are individually retrievable so that the system can be repaired without shutting down the well. This improves on traditional electro-hydraulic systems, which normally contain the redundancy within one large control module and require well shutdowns during repair and retrieval.

Process shutdown is different from an electro-hydraulic system, where the bleed off of hydraulic power causes a spring in the actuator to close the valve. In an electric system, the typical approach is to use redundancy and a safety-certified controller plus the batteries for shutdowns, which eliminates large subsea actuator springs. High-reliability lithium-ion batteries developed for space applications are used in subsea operations. These batteries are small, easy to integrate, have long life cycles, and are maintenance free, all of which mean lower costs. For some systems, such as those with rapid closure requirements, an electrically latched spring may be required to power the shutdown function.

All electric subsea controls reduce the cost of topside power generation and subsea umbilicals. Configurable electric-hydraulic systems are available to upgrade existing hydraulic systems. Arctic conditions make oil and gas operations a huge challenge. With an estimated 25% of the world's undiscovered offshore hydrocarbons to be found in the arctic, it will continue to attract operators regardless of the obstacles. Electric solutions have advantages in arctic regions. For one, there is no fluid discharge to the sea. Elimination of hydraulic fluids also removes logistical and expense issues.

Several percentage points of subsea field operating expenditures are related to hydraulic fluid consumption.

Electric technology is also ideal for long standoff distances and ultra-deepwater fields, as supplying hydraulics for these applications is complex and expensive. Electric solutions for subsea applications eliminate topside hydraulic power units as well as control umbilical hydraulic supply lines. The cost savings can be significant, especially for long distances.