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IEEE Guide for the Planning, Design, Installation, and Repair of Submarine Power Cable Systems

IEEE Power Engineering Society

Sponsored by the
Insulated Conductors Committee

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Insulated Conductors Committee
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IEEE Power Engineering Society

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Abstract: This guide presents a list of factors to consider when planning, designing, installing, and repairing a submarine power cable.
Keywords: submarine cable, underwater cable

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Introduction

This introduction is not part of IEEE P1120-2004, IEEE Guide for the Planning, Design, Installation, and Repair of Submarine Power Cable Systems.

This guide has been prepared in the form of a list with brief explanations after each item. This list represents the more important aspects to consider when working on a submarine cable project. As such, this guide should be particularly helpful to the engineer who is occasionally presented with the challenge of working on a submarine cable project.

This approach is used because a comprehensive coverage of the wide variety of subjects involved in a submarine cable project would fill many volumes. Once this list has been used to evaluate a particular project, detailed information can be obtained by searching technical literature and by interviewing experts in the field.

This version of this guide addresses many more topics than the previous version. It also provides brief explanations of these topics to illustrate their relevance.

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IEEE Guide for the Planning, Design, Installation, and Repair of Submarine Power Cable Systems

1. Overview

1.1 Scope

This guide provides a list of factors to consider when planning, designing, permitting, installing, commissioning, and repairing submarine power cable systems. While many factors are common to both power and communication cables, this guide focuses on power cables that cross seas, lakes, and rivers.

1.2 Purpose

The purpose of this guide is to assist engineers in developing knowledge and to assure that important items are not overlooked when dealing with submarine cable systems.

1.3 Preface

Submarine cables are installed in unique environments using specialized installation techniques. Some uncommon characteristics that may be encountered include:

- A variety of environmental conditions, including the transitions between water and land
- Challenges in gathering geophysical information
- High installation and retrieval stresses on the cable
- A potentially hostile marine environment during construction and repair
- Human activities that do not normally threaten land cables

Even with these constraints, submarine cables have successfully served the industry since the 1890s. They sometimes offer a means of delivering energy and communications in a direct route that may provide superior system benefits and higher reliability, and sometimes they cost less than other alternatives.

This guide is broken into a number of clauses that roughly follow the milestones that a submarine cable project goes through. The milestones are commonly not sequential; for example, information will have to be gathered so the route can be evaluated, but one must have chosen a prospective route before a survey can be done.

2. Route selection

A number of factors must be considered when evaluating potential cable routes. Most of these factors influence the cost, constructability, reliability, and reparability of the proposed cable system, and they should be weighed along with the electrical benefits to the power system.

2.1 Natural marine conditions

Below is a list of naturally occurring marine conditions that may influence the evaluation of a prospective submarine cable route. Some of these conditions may vary considerably along the cable route, so an observation at one location may not represent the entire route.

2.1.1 Water depth

As the depth increases, cable-laying tensions will increase, which may influence the design of the cable and the installation method. Route surveys may also be more difficult.

2.1.2 Rock and pinnacles

Laying a cable over a sharp object may kink the cable. Where the cable is suspended between two points on the sea bottom, it may fatigue due to strumming (vortex-shedding vibration) induced by water currents. Where cable touches down, it may abrade on the bottom, especially if the bottom is hard.

2.1.3 Tidal, current, or surf action

Currents may carry silt or gravel that may abrade the cable. Strong tidal currents may wash the cable back and forth across the bottom, thus damaging it.

2.1.4 Shifting bottoms/scour

The soil under the cable may wash out, leaving the cable suspended and under high tension. Alternatively, the cable may become deeply buried (which will affect its ampacity and its ability to be retrieved).

2.1.5 Soil structural stability

The soil composition and consistency affect the stability of the walls of cable trenches. The presence of large boulders, rock outcroppings, and reefs can impede the trenching, plowing, and jetting operations.

2.1.6 Marine slope stability

Underwater landslides can damage a cable system.

2.1.7 Icebergs and pack ice

Icebergs being moved by the wind, river current, or tidal current can scour away soil and damage cables. Icebergs moving ashore can pound on cables in the subtidal and tidal zone.

2.1.8 Soil thermal properties

Soil thermal properties influence the cable design in terms of conductor size and operating temperature. Sediments with high amounts of organic material, oil contamination, or volcanic ash typically have high thermal resistivity. When cables are buried in soft mud by jetting, the sediment composition and its thermal properties may be altered.

2.1.9 Chemical attack/corrosion

Corrosive properties of some soils, or from gas emanation, may affect the cable design.

2.1.10 Sub-bottom material

The material below the surface may be entirely different than the surface material. Rock outcrops may lie just below the surface.

2.1.11 Very soft soils

If the bottom is very soft, the cables may continue to sink into the bottom after they are laid, causing them to be overstressed due to catenary tension. Excessive cable sinking also increases its external thermal resistance, and hence the operating conductor temperature.

2.1.12 Marine borers

Some marine organisms may burrow into the cable.

2.1.13 Storm action

Wave action from storms may result in beach erosion or filling.

2.2 Man-made obstacles

It is common to encounter manmade obstacles in the proposed submarine cable corridor, which may include:

- Other power, communication, submarine cables and petroleum pipelines. Joint installation projects, or integrating power and communications into the same cable, may reduce hazards.
- Pipelines, including sewer, water, and gas lines
- Effluent outfalls
- Sunken ships and debris, especially near docks and bridges
- Piers, docks, boat ramps, roadways, foundations, buildings, etc. These may be abandoned and not visible from the surface of the water.
- Disposal areas, either from dredging or dumping of refuse
- Restricted areas (for example, Naval training or testing areas)
- Future construction

2.3 Hazardous human activities

The most common cause of cable failure is mechanical damage by human activity. The damage may be caused by:

- Dragging anchors and tug boat lines
- Beached marine equipment
- Dock and bridge maintenance
- Dredging
- Dumped debris
- Fishing activity
- Shellfish harvesting
- Aquatic farming
- Pile driving
- Horizontal directional drilling
- Other cable or pipe laying operations
- Maintenance work on adjacent cables or pipelines
- Contamination of the seabed with chemicals, toxins, and heavy metals

2.4 Marine access

A number of factors may influence the desirability of certain routes, including:

- If the water is shallow for a long distance from shore, some marine craft and installation techniques may not be able to be used
- The distances the marine surveying vessels must travel
- The distance installation vessels must travel from dockage, the cable transfer port, and support facilities
- The distance to safe harbors for marine vessels for protection from inclement weather
- The size and length of the submarine cable, and the width of the cable corridor

2.5 Beach conditions

2.5.1 Slope and stability

Steep slopes may make the land portion of the route difficult to construct or unstable.

2.5.2 Beach composition

Poor digging conditions may make it difficult to lay the cable in the beach. Concrete cable chases, cast iron cable protectors, or other forms of protection may be required.

2.5.3 Access by land

It is beneficial to have access to beaches by shore-end marine installation equipment. It is desirable for the cable route from the water to the termination to allow for the cables to be installed and for the simultaneous passage of equipment and traffic.

2.6 Termination sites

The termination site may be as simple as a terminal pole, or a splice to a land cable, or as complex as a cable termination station that includes system protection, metering, transformation, and shunt reactors. The following is a brief list of factors to consider. See 6 for termination station design considerations.

- Access to beach landing of cable
- Equipment and water access to the termination site
- Proximity to power lines on land
- Access to station service power
- Proximity to communications lines or microwave tower sites
- Extent of site preparation
- Room for laydown area, site office, and temporary power
- Aesthetics/screening/landscaping
- Land use zoning
- Cost of land or right-of-way acquisition
- Future development

2.6.1 Elevation differences between terminations stations

When a fluid-filled cable system is used, it is desirable for the two termination stations to be at approximately the same elevation unless the fluid pressurizing will be done from one end only.

2.7 Installation considerations

2.7.1 Installation technique and environmental impacts

Alternative routes may go through various natural environments and different installation techniques may be required to install the cable in each environment. See 3 and 7 for more information.

2.7.2 Public access

Access to beaches, waterways, and boat ramps may be impacted by the installation operation.

2.7.3 Navigation

The cable-laying vessel may temporarily inhibit the free passage of marine traffic. This may require coordination with marine authorities, including local vessel traffic control, the Coast Guard, and the Navy.

2.7.4 Historical/archaeological significance

The preservation of historical or archeological sites may be required. Surveying or sifting through excavated material may be required to identify if archeological artifacts are present.

2.8 System integration

The submarine cable must be integrated into the existing systems on each side of the water. Some routes may provide more overall system benefit than others.

2.9 Length

In general, longer crossings are more expensive than shorter ones. An exception may occur if two route alternatives require different types of cable construction or installation techniques.

2.10 Width

The cable corridor width may vary with alternative cable system designs. For example, a single, three-conductor cable requires less right-of-way width than a system that uses four single-conductor cables (one cable being a spare). See 5 for more information.

2.11 Operating rights and permitting

Operating rights, including easements and leases, may be easier to acquire or less costly for certain routes.

2.12 Monitoring and environmental mitigation

Some routes may go through environmentally sensitive areas that will have to be monitored before and after the cable installation, and any damage may have to be repaired.

3. Permitting and environmental impacts

The route, installation method, termination station siting, and timing of the installation may all be influenced by the potential environmental impacts. Each route may have unique environmental aspects. Permitting agencies may require monitoring, mitigation, or compensation for any damage. In most countries, permitting agencies are located at the federal, state, and local levels. Aboriginal groups may also have jurisdiction. Some considerations are outlined in the following paragraphs.

3.1 Marine vegetation

Marine vegetation, such as eelgrass, kelp, and other macro algae is considered an essential element to the health of many species. It provides food for some species, a breeding ground for others, and shelter for migrating juveniles.

3.2 Marine animal life

Shellfish and other animal life may be injured by some installation methods, either by direct impact or by being covered by excavated materials. Different embedding machines leave different footprints (e.g., skids versus tires).

3.3 Silt and turbidity

Disturbing the soil may cause a plume of sediment and turbidity that may harm marine organisms and migrating fish. Depending on the amount of sediment, it may suffocate certain types of fish, shellfish, and plant life. Seasonal timing of the work may avoid certain migrating fish. Sometimes it is required that the turbidity be monitored during construction.

3.4 Storage and disposal of excavated material

Trenches in the intertidal zone may have to be backfilled prior to inundation by tidal water. The location where excavated material is temporarily stored may be restricted, and may have to be covered to prevent erosion. Disposal areas may be restricted.

3.5 Grain size distribution

Certain fish, such as sand lance and smelt, require a specific composition of beach material to spawn in. The installer may be required to return the beach’s top strata to its pre-installation conditions.

3.6 Beach stability

Erosion and accretion of the beach materials may be affected by the construction activities. The ability of a beach to heal depends on the soil composition and the wave energy. In low-wave energy locations, trenches will take longer to fill on their own, and spoils will take longer to settle back to their original condition. Wave action and a broad tidal range may help to quickly return the beach to its native morphology.

3.7 Topography

The installer may be required to return the beach to its pre-installation topography. Topography changes may be initially caused by the direct impact of heavy equipment or later by erosion (for example, if a beach’s protective armoring of cobbles is disturbed).

3.8 Upland plants and wetlands

Heavy equipment on land may damage certain plants or environments. In tropical areas, mangrove trees prevent shoreline erosion and provide shelter for marine animals.

3.9 Oil, grease, and pH

Some chemicals may be toxic and/or may suffocate certain organisms. Typically, bleed water from concrete or fluidized thermal backfill pours must be contained. Machinery should be in good working order, with all seals inspected to make sure there are no fluid leaks. A spill prevention or clean up plan may be required by permitting agencies. If distressed or dead fish are found, the work may be shut down.

3.10 Contamination

Some sites may be contaminated by debris or toxic chemicals from dumping or previous owners, or may be contaminated by upstream activities.

3.11 Noise

Certain operations may cause objectionable noise levels to wildlife, especially raptors, shorebirds, and waterfowl during breeding season. Humans, too, may find some levels of noise objectionable. There are legislated maximum noise levels in some areas.

4. Information gathering and surveying

One of the keys to a successful installation is to fully understand the environment and the installation process. In general, the more uncertainties that are addressed, the higher the chances are of a successful installation and a long-lived cable system. This clause outlines some sources and methods of gathering information.

4.1 Existing maps

Governmental agencies (National Oceanic and Atmospheric Association, U.S. Geological Survey, National Ocean Service, etc.) can provide maps with the following information:

- Permitting agencies
- Road locations
- Topography and bathymetry
- Utility company maps (power, communications, sewer, gas, telephone, TV, water, etc.)

4.2 Photography and video

Photographs and video may be useful in illustrating and documenting each site for evaluation, route selection, permitting, and installation contractors. Photographs taken from both the air and ground may be useful. Photographs of commonly used fishing gear may provide the design engineer information on the extent of protection a cable will need.

- Intertidal zone at low and high tide
- Cable route on land
- Equipment and material laydown areas
- Local boat ramps

- Nearby moorage
- Termination sites

4.3 Weather data

The environmental conditions that a cable will be subjected to will help determine the most appropriate cable design and installation.

- Atmospheric data (high temp, low temp, wind, precipitation, etc.)
- Water temperature data. Water temperature may vary widely in a crossing. For example, water over a shallow, sun-warmed tide flat may become very warm, which may affect the cable ampacity.
- Maximum wind velocity and direction
- Weather data may vary widely during the seasons.

4.4 Marine Surveys

4.4.1 Bottom profile

Single-beam or multi-beam echosounders may be used. Combining the geo-referenced data from multiple transects helps provide a detailed bathymetry map of the proposed cable corridor.

4.4.2 Side-scan sonar

This method uses sonar to survey a wide strip of the bottom. It is used to search the bottom for hazards, such as rock outcrops, wrecks, and anchor scars, and to characterize the surface texture of the bottom.

4.4.3 Subbottom profile

This method sends out high-energy sound waves that penetrate the bottom and reflect off the layers of bottom materials. The result is a profile of each material layer, which can be used to help assess the suitability of the bottom for excavation and cable burial.

4.4.4 Soil sampling

Soil sampling along the proposed route can provide information for cable laying and determine the soil parameters affecting the cable design and performance. It is also helpful in interpreting subbottom profile results. This activity may follow the other surveys, such as bottom profiling, side scan and subbottom surveys, so that the sampling locations and depths can be strategically planned.

A number of techniques are available for collecting and analyzing soils. These include scooping, vibracoring, drop-sampling, anchor drop test, cone penetration testing, and drilling from platforms or barges. The sampling method chosen depends on the soil conditions encountered, marine conditions, available equipment, and the type of analysis required.

Properties to measure may include:

- Thermal properties
- Chemical properties
- Structural properties

In addition to soil sampling, in-situ measurements of soil temperature and thermal resistivity may be made along the route.

4.4.5 Magnetic obstacle detection

A magnetometer may be used to detect magnetic materials. These may be cables, abandoned towlines, wrecks, car bodies, or mineral deposits.

4.4.6 Remotely operated vehicle (ROV)

These vehicles are unmanned and tethered to a surface vessel. They may carry a variety of instrumentation, including cable-locating equipment. Typically they are used to photograph and videotape objects that are identified by bottom profiles and side-scan surveys. Normally they carry underwater positioning equipment so their location can be determined relative to the geo-referenced position of the surface vessel and objects of interest found with other survey techniques.

4.4.7 Divers

Divers may be used in shallow water to investigate and document conditions.

4.4.8 Submarine

Manned submarines can be used to gather first-hand information. They offer more flexibility in maneuvering than ROVs but cannot send real-time video to the surface to be watched by others.

4.4.9 Locating existing cables and pipelines

Existing cables and pipelines may be located by injecting a tone onto a conductive component of the cable or pipe. A receiver that is integrated with position fixing equipment can make multiple passes over the cable/pipe to make a map of its location.

Sensors that detect the electromagnetic field from energized cables can also be used to locate cables that cannot be de-energized to inject a tone onto them. Underwater metal detectors can also be effective.

4.4.10 Current speed and direction

This information may be retrieved at various depths using tethered instruments or Doppler profiling equipment. It may be used to determine the:

- Size or type of cable-laying vessels to be used
- Minimum weight of the cable necessary for the cable to rest securely on the bottom
- Amount and type of armoring
- Susceptibility of cables to vortex shedding vibration where suspended above the bottom

4.4.11 Wave and tidal height

The height of stormwater surges at extreme high water may be of interest so that facilities are not placed in danger.

4.4.12 Marine habitat

Permitting agencies may require information from marine habitat surveys. Both plant and animal density counts may be required, both in intertidal and subtidal zones.

4.4.13 Marine vessel traffic

The characteristics of vessels operating in an area may influence the type or amount of cable protection. For example, it may be desirable for a cable system to be able to avoid damage from the largest anchor that may be dragged across it, or heavy tow lines, or fishing trawls.

4.4.14 Fishing, marine plant, and shellfish harvesting

These operations may damage a cable during their trawling, staging, anchoring, or harvesting.

4.4.15 Seismic survey

Statistics can be gathered on seismic activity in the region.

4.5 Land surveys

4.5.1 Soil sampling

The land route may be surveyed for the same properties as the marine route. The soil sampling operation may be combined with in-situ thermal resistivity measurements at select locations along the route. The sampling and testing may extend below the cable burial depth to determine the properties of the soil below the cable.

4.5.2 Temperature profile

A temperature profile at various depths and during different seasons may be useful in determining cable ampacity. Installing a thermocouple tree and a data logger at each critical location can monitor and record the seasonal variations in soil temperature.

4.5.3 Other surveys

Other surveys may include:

- Topography
- Habitat
- Wetland delineation
- Archeological and historical sites

4.6 Survey control

Public marine and land survey plans are normally not tied to the same geo-referenced coordinate system. It is important to establish the appropriate vertical and horizontal translation equations between the terrestrial and marine datum.

It is common to tie marine surveys to land survey control monuments that have been located with differential GPS positioning equipment.

4.7 Post-installation surveys

An as-built survey is commonly performed to confirm and document the location of the cable after it is laid. Also, some environmental surveying may be required to document the final condition of the cable field and land portions of the work.

4.8 System studies

Power flow studies and load growth projections may be used to determine the amount of power the cable should be designed to carry. Both the magnitude of the load and seasonal and daily load shape may be required to design the cable system.

In addition, long submarine cables can have relatively high amounts of capacitive charging current, which may limit the real power transfers unless adequately compensated. The additional capacitance can also introduce voltage and transient instability difficulties, which should be thoroughly investigated.

5. Cable systems

5.1 Reliability

5.1.1 Causes of failures

Submarine cables are normally very reliable, but they can fail due to:

- Physical damage caused by human activities
- Forces of nature, such as seismic activity
- Electrical insulation breakdown
- Hydraulic failure (for fluid-filled cables)

5.1.2 Long duration outages

The repair of a submarine cable failure takes much longer than the repair of an equivalent land cable. During some seasons, repairs may have to wait until inclement weather subsides.

5.1.3 Number of cables or circuits

Installing multiple cables can improve reliability, if one or more of the cables are redundant. On AC cable systems, sometimes four single-conductor cables are installed—one being a spare. If two more cables are added, to make six cables, the cable system may be operated as a double circuit. This may double the normal transfer capacity and increase reliability over a single circuit with no spare.

Careful consideration is necessary if a new circuit is planned in parallel with an existing circuit. If the design of the new cables differs from the existing cables, the difference in cable system impedance may result in unbalanced load between the circuits.

5.1.4 Spacing

When multiple cables are installed, the farther they are spaced apart the less likely more than one cable will be damaged by a single external cause. Unfortunately, a dragging anchor or tow line can damage several cables at once.

Cables are commonly spaced far enough apart to allow for a section of bad cable to be cut out, a new section spliced in and then lowered to the seafloor, without the cable laying on top of any of the remaining cables. This is usually a function of water depth. The greater the depth, the farther apart the cables should be laid.

5.1.5 Single-conductor versus three conductor

A three-conductor cable will be heavier and stiffer and normally have heavier armor wires than a single-conductor cable. This makes the three-conductor cable less susceptible to damage, but larger equipment is required to lay and retrieve it. The user may wish to consider whether locally available vessels can be used to make repairs.

A fault on one phase of a three-phase cable may damage one or both of the two unfaulted phases and splicing a three-phase cable is more complicated than splicing a single-phase cable.

Generally, a three-conductor cable will have lower losses than multiple single-conductor cables, and it may be less costly to install a single three-conductor cable than multiple single-conductor cables (which will require a wider corridor if separation will be maintained between the phases).

See 5.6 for grounding issues.

5.1.6 Protection

Physical protection of the cables may be provided by a number of means, as outlined in 7.6.

5.1.7 Repairability

The degree of difficulty in repairing a damaged submarine cable depends on many things, including: the water depth, cable burial depth below the bottom, the length of the crossing, the cable design, sea conditions, and the amount and type of physical protection.

5.1.8 Preparation for repairs

The availability of spare parts, marine vessels, tools, experienced workers, and documentation can influence how quickly a cable system can be repaired.

5.2 Ampacity

The ampacity of a submarine cable is controlled by a number of factors both on the land portion and submerged portion of the route. Unless the cables are lying on a hard bottom, the treatment of ampacity for submarine cables is similar to that for buried cables, except the depth below the bottom is used instead of a land cable’s burial depth. Also, the water temperature is used instead of the ambient air temperature.

5.2.1 Ambient temperatures

The following ambient temperatures are used for rating cables, accessories, and auxiliary equipment.

- Water and sea bottom temperatures in marine section
- Air and soil temperatures in the land sections

5.2.2 Soil thermal properties

The thermal resistance of the soil of both the land and marine portions of a submarine cable should be considered when determining the ampacity rating of a cable. The soil around a cable that is buried in a sea bottom can dry out if the cable produces a significant amount of heat, so the thermal stability of the soil should also be considered.

The soil characteristics may change along the path of the cable.

5.2.3 Cable burial depth

The deeper the cables are buried, the higher the soil thermal resistance will be. The soil temperature will also vary with depth and the season. The cable burial depth in the marine section may change due to the cable sinking, littoral drifts, sedimentation, and dredging operations.

5.2.4 Cable spacing

When on land, the spacing of a multi-cable system influences the mutual heating and circulating currents. Commonly the cables are spaced far enough apart when in the water that mutual heating is insignificant, although the wide spacing increases the circulating current.

5.2.5 Shore ends

The shore ends of a submarine cable commonly limit the amount of power that may be transferred due to close conductor spacing and higher soil thermal resistance. Sometimes larger conductors are spliced onto the shore ends to eliminate these bottlenecks.

5.2.6 Bonding

The method of bonding the metallic components that are outside of the cable core will influence the ampacity of the cable system. See 5.6 for more information.

5.3 Hydraulic limitations

Sometimes the allowable rate of change of load may be limited by excessive fluid pressure in the fluid channel of a cable. Typically the most pressure develops when a cable is de-energized and then full load is applied.

Conversely, it is desirable to always have positive pressure on the fluid. The worst-case condition is when the cable is operating at maximum temperature and then the cable is de-energized.

5.3.1 Hydraulic limitations during failures

If a fluid-filled cable fails hydraulically, either due to electrical failure or mechanical damage, the fluid pressure may be lost. If this happens water may enter the cable, which may make a significant portion of the cable unrepairable.

Hydraulic systems are commonly designed to provide positive pressure to the entire cable for a period of time after a cable is severed. This may be accomplished through reservoir systems or pumping plants or a combination.

5.4 Cable components

5.4.1 Conductors

Stranded conductors in cables with extruded insulation can be longitudinally water-blocked to keep water from migrating down the conductor if it is damaged.

5.4.2 Insulation system

The insulation systems used in submarine cables are the same as those systems used in land cables. Submarine cables are commonly made in lengths long enough that no field splices are required, but special arrangements for transportation may be required.

An insulation material with low permitivity and dissipation factor may be advantageous in long crossings to lower the capacitance and charging current.

5.4.3 Sheaths

Lead is commonly used in high-voltage cables to provide a flexible, conductive, water-impervious barrier. Lead also adds weight to the cable, which helps hold it on the bottom in strong water currents, but increases laying tensions, which can be an important factor in deep water.

5.4.4 Sheath reinforcement

If the dielectric fluid pressure is high enough on a self-contained, fluid-filled cable, the sheath may require reinforcing. The hydraulic pressures on submarine cables can be high due to their long length or large depth, although the internal pressure due to water depth is somewhat equalized by the head of the insulating fluid for self-contained, fluid-filled cables. Metallic tapes are commonly used to reinforce sheaths.

5.4.5 Return conductors

Single-conductor cables typically contain a return conductor to carry circulating current, charging current, unbalance current and return fault current. This conductor is typically the parallel combination of metallic shields, armoring, and lead sheath.

5.4.6 Jackets

Submarine cables commonly include either insulating or semiconducting plastic jackets. If the cable is a multiconductor cable, the jacket may be installed over each individual cable or over the laid-up bundle of individual conductors, including a neutral conductor and/or a fiber optic cable. For the latter case, caution should be exercised to ensure that the compression due to water pressure can be accommodated.

5.4.7 Anti-marine borer tape

Some marine organisms may burrow into cables. To discourage this, a copper or bronze tape is sometimes installed over the cable core.

5.4.8 Bedding

A bedding layer is commonly installed under the armor wires to provide a cushion between them and the underlying cable core.

5.4.9 Armor

5.4.9.1 Purpose

Armoring serves multiple purposes, including:

- Providing a partial path for return current
- Carrying tension during laying and retrieval
- Providing some physical protection against impacts, such as a dragging anchor or fishing gear
- Controlling the bending radius to avoid kinking if laid over a sharp object
- Providing abrasion resistance
- Adding weight to the cable so it is less likely to wash back and forth on the bottom
- The return conductor to carry circulating current and fault current

Some submarine cables may not require armoring, depending on the natural and manmade hazards, and environmental conditions.

5.4.9.2 Construction

A single layer of armor is common, but two layers of armoring may be used where there is a significant amount of abrasion or where rock or debris is placed that may fall onto the cable. If two layers are used, the layers may be laid in the same or in opposite directions, depending on the desired coiling characteristics of the cable. The pitch of armor wires may vary depending on the desired bending, stiffness, and coiling characteristics of the cable. Round, flat, or tape armoring may be used.

Double armor in opposite directions, also called “double-cross armor,” is recommended for deep-water projects because it allows building a “torque balanced” cable whose elongation under high tension is reduced to its minimum.

5.4.9.3 Materials

Armor wires are made of various metals, including: aluminum, bronze, copper, and galvanized steel. Magnetic armoring materials will develop higher losses.

5.4.9.4 Corrosion

Some armoring materials are more resistant to corrosion than others. Both galvanic and AC corrosion may have an effect on cable armor life. Sacrificial anodes and/or active cathodic protection systems may be used to prolong armor life.

Cathodic protection systems tend to protect only the shore ends and not the middle of long crossings.

5.4.9.5 Jacketed armor wires

Sometimes each armor wire is jacketed with plastic material to protect it from corrosion. If a single-phase cable is long, this may not be practical due to excessively high induced voltage.

5.4.10 Serving and finishing

Polypropylene, nylon, or jute serving materials are common materials used to reduce abrasion to the armor wires and to contain them when reeling and unreeling the cable.

5.4.10.1 Asphalt

An asphalt compound is commonly slushed over the armor and the serving. It provides some cohesion between the armor wires and may help reduce corrosion of the armor.

5.4.10.2 Chalk

Chalk may cover the outer serving to keep the cables from sticking together in storage and transportation.

5.5 Cable weight

The cable should have significant negative buoyancy if it will be exposed to water currents.

5.6 Sheath voltages and bonding

The phase current on a *single-conductor* AC submarine cable will induce a voltage onto all other metallic components of the cable that are not continuously grounded. These ungrounded **metallic components** may be reinforcing tapes, a metallic sheath (commonly a lead sheath), or armor wires (if jacketed). This voltage will accumulate linearly with the cable length.

If the cable length is long enough, this voltage may be sufficient to break down a **non-conducting layer** in the cable, such as a polyethylene jacket. This may allow seawater to enter the cable and can result in corrosion that will seriously damage the cable, possibly leading to phase-to-ground failure.

The normal load current will induce a standing AC voltage on the metallic components and fault current will induce a transient voltage (even if the fault is on a land-based portion of the circuit). Lightning impulses and switching surges will also induce transient overvoltages.

On some single-conductor submarine cables, nearly 100 percent of the phase current returns on a combination of the armor and concentric shield/sheath.

5.6.1 Mitigation

A number of methods are available to mitigate high voltages on metallic components on cables.

5.6.1.1 Withstand

The non-conducting layers may be designed to withstand the standing AC and transient overvoltages. The design should consider the steep-front electric waves created by faults, lightning, and switching surges.

5.6.1.2 Bonding

To eliminate circulating currents and increase the cable ampacity rating on very short submarine cables, the sheath may be grounded at only one location (single-point bonding). This may be done if the non-conducting layers are designed to withstand the maximum induced voltage.

On medium-length cables, a common scheme is to bond the metallic components together at both termination stations.

On longer cables, the metallic components are bonded together at a number of places along the cable run.

Exceptional care must be taken when designing and installing mid-run bonds to prevent water intrusion and corrosion.

One occasionally used scheme is to install bonding boxes at the low water line and then single-point ground the cables that run onto land. This eliminates the circulating current on the metallic sheath from the bonding box to the cable termination, thus increasing the ampacity of the cable on land where the thermal properties of the soil may be inferior to those properties under water.

It is impractical to deploy cross-bonding to reduce the circulating currents.

5.6.1.3 Semiconducting material

Using semiconducting materials, such as a semiconducting overall jacket, may eliminate the need to periodically bond and ground the metallic components of the return current path.

5.6.1.4 Three-conductor cable

Voltage buildup is much less of a problem on a three-conductor cable due to the cancellation of induced voltages due to the close proximity of the three phases. Still, a voltage can build up if:

- The metallic components of the three phases are insulated from each other. This is commonly the case when jacketed cables are triplexed and then armored to form a three-conductor cable.
- The return path for fault current or unbalance current is on an insulated conductor.

5.7 DC systems

DC systems are configured as either monopolar or bipolar. The monopolar system uses a single, high-voltage cable with an integrated return on a dedicated low-voltage cable or a sea return through electrode beds. The bipolar system uses two high-voltage cables, one positive and one negative. Bipolar systems are frequently favored, in which case they still need a metallic or sea return path. DC systems are typically used where:

- The charging current of an AC system would be so high that it significantly limits the power transfer capacity of the cable system.
- The two interconnected electrical systems operate at different frequencies or where an AC tie would be too weak to keep the systems stable.
- The amount and direction of power transfer needs to be closely controlled.

The operation of sea return systems may introduce environmental, corrosion, and compass-based navigation concerns.

5.8 Joints

5.8.1 Factory

These joints are made at the manufacturing plant under controlled conditions. They reconstitute the cables, and are made prior to armoring.

5.8.2 Flexible

These joints are made on the job site. They attempt to reconstitute the cable, including all its mechanical properties.

5.8.3 Rigid

These joints are made on the job site and are typically enclosed in a rigid cylindrical casing. Typically they cannot be wound on a reel as can the cable, a factory joint, or a flexible joint.

5.8.4 Desirability of joints

Some people consider joints to be weak spots in cables, so they avoid them when possible, although for some manufacturers it may be less costly to manufacturer a cable with joints.

5.9 Armor anchors

Armor anchors are sometimes installed to secure the submarine cable where it is spliced to an unarmored land cable or to protect the cable termination from damage if a dragging anchor snags the cable. Particular attention should be paid to the strength of these anchoring devices when the submarine cable is laid on a steeply sloping profile.

5.10 Optical fiber

Optical fibers may be placed in the interstices of multiconductor cables, incorporated into the armoring, or lashed to the outside of a cable. The fibers may be used for:

- Temperature sensing
- Damage detection
- System protection (pilot wire)
- Communications for utility or commercial use

5.11 Reparability

When choosing a cable design, the user should consider how easily repairs can be made.

6. Termination stations

Many submarine cables are simply terminated on poles. Others are terminated inside fenced stations. Below are a number of factors to consider when terminating a cable inside a station. Many considerations are the same as those related to normal substations or switching stations, so only those components that are somewhat unique to cable termination stations are discussed in the following paragraphs.

6.1 Terminations

6.1.1 Foundation design

6.1.1.1 Seismic

The cable termination and termination stand should be designed to withstand the expected seismic activity.

6.1.1.2 Cable bending radius

The submarine cable may have a long bending radius, which should not be violated at the base of the termination stand.

6.1.1.3 Cable expansion and clamping

Room for the cable to expand and contract due to cyclic heating should be considered.

6.1.2 Protection from damage

Barriers are sometimes installed to protect the terminations from vandalism or from collateral damage if a neighboring termination or other piece of equipment fails catastrophically.

6.1.3 Creepage distance of insulator

If the terminations will be located near salt water, additional creepage distance may be needed.

6.2 Station grounding

The induced circulating currents of single-conductor cables commonly are about the same magnitude as the phase current. The station ground system, including the conductors that connect the sheaths and armor wires of cables together must be sized appropriately to handle both steady-state currents and fault current.

Commonly, the grounds for the armor wires and metallic sheath are brought to a common, substantial grounding pad or bar. If a ground becomes disconnected, a standing voltage will develop that may be unsafe. This pad also provides a point at which the magnitude of current flowing in each return path can be measured and the integrity of the non-conducting layers of the cable may be tested.

6.3 Slack cable

Slack cable may be laid in or near the station to form an S- or a horseshoe shape to allow for the replacement of a termination without splicing in new cable.

6.4 Spare cable storage

Due to the large weight and size, spare cable sometimes cannot be transported over land routes, so it must be stored where marine access is available. Spare cable is sometimes stored in the termination station on a reel, on a turntable, or simply as a coil. Because this spare cable may not be needed for many years, if ever, the storage equipment should be designed to last for many years without rotting or corroding. Note that if cable is stored for many years, some of its electrical characteristics may degrade if it is improperly stored or if it is damaged in storage. Consideration may be given to electrically testing cable that has been stored for long periods of time to confirm its electrical integrity before it is installed.

6.5 Fluid handling

Fluid pressure and room for fluid expansion are required for self-contained, fluid-filled cables. Either a pressurized reservoir system or a pumping plant, or a combination of the two, may provide these requirements. These systems may be located at one or both cable terminations.

Reservoir systems are either pressurized by compressed gas or by elevating the reservoir tank.

Fluid systems are commonly designed to be able to supply enough volume and pressure to prevent water from entering into the cable through any breach in the sheath. The capacity may be designed to allow for emergency action to be taken to address the situation before the fluid supply is depleted.

In anticipation that the cable may be operating at a high temperature when it fails, some fluid systems initially provide high volumes of fluid, and then step the flow rate down as the cable cools and the fluid is contracting less rapidly.

6.6 Spare fluid storage

Spare fluid may be stored in the cable termination station or offsite.

6.7 Fluid containment system

A fluid containment system may be required around cable fluid–handling systems and fluid storage area.

6.8 Degasifier

A cable cable-fluid degasifier may be mobile or built into the station.

6.9 Instrumentation and metering

6.9.1 Fault detection

Submarine cables commonly have very low impedance compared to overhead lines, so it is sometimes difficult to determine the location of a fault on a segment of line that contains a submarine cable. As a result, system protection systems, including breakers, are sometimes installed in cable termination stations.

- Current transformers
- Potential transformers
- Directional relays
- Distance relays
- Pilot wire relaying

6.9.2 Temperature sensing

The temperature of a cable may be measured by attaching thermocouples to the outside of the cable, by constructing the cable with fiber optic strand(s) built into the cable, or by laying a fiber optic cable in close proximity to the power cable.

The temperatures of motor bearings, dielectric fluid, the air, and the ground may also be measured.

6.9.3 Hydraulics

The pressure of the dielectric fluid, its flow rate, and its volume may be measured. Calculating changes in the difference between reservoir volumes or differences in fluid flow rates may give an early warning to a problem with one cable of a multi-cable system.

6.9.4 Alarms

Sensing a problem as early as possible may buy time to diagnose and remedy the situation before a small problem turns into a major failure. A number of parameters may be measured and used to trigger alarms, including:

- Loss of vacuum
- Fluid pressure
- Fluid volume
- Fluid flow rates
- Cable temperature (fiber optic or thermocouple)
- Cable damage (fiber optic)

6.10 System protection equipment

Cable systems commonly have high levels of charging current and at times may experience higher than normal voltage due to the cable's capacitance. The substation equipment, including switches, should be rated to handle these currents and voltages.

6.11 Communications

A communications system installed with a submarine power cable may be used for damage detection, system protection, internal company communications, and commercial use.

6.12 Backup generation and pressure pumps

Backup generation may be desirable to operate fluid handling systems in case of an outage on the station service. Sometimes compressed nitrogen pumps are used to power backup pumps.

6.13 Laydown area

An area for storing equipment and materials may be required. Also, room for a construction shack may be needed.

6.14 Future expansion

Future additions to the stations should be considered in the original design.

7. Installation techniques

After a cable design, route, and termination facilities have been determined, a number of constraints may influence the installation methods and the timing of the installation.

7.1 Schedule and timing

The following factors may influence what equipment is used and when a cable may be installed.

7.1.1 Tidal velocity

Some marine vessels or embedment equipment may have a difficult time operating in strong currents.

7.1.2 Tide height

- Trenching in the intertidal zone may be limited by high water during daylight hours
- Dredging may be limited by low water.
- Time to install splices, bonding boxes, or armor anchors may be limited.

7.1.3 Wind velocity

- Marine vessels may not hold a steady course in high winds.
- Anchors may drag.

7.1.4 Wave action

A heaving vessel may introduce excessive strains on the cable during the laying operation or when anchored.

7.1.5 Fog

Limited visibility may curtail a cable-laying operation.

7.1.6 Precipitation/snow/ice

- Working conditions may become dangerous.
- Access roads may become unpassable.
- Soil erosion may be excessive during some times of the year.

7.1.7 Marine traffic

Commercial or armed forces traffic may hold precedence in certain waterways.

7.1.8 Fishing seasons

Commercial fishing operations may conflict with the cable-laying operation.

7.1.9 Environmental constraints

The installer may be required to avoid certain fish migrations or spawning seasons.

7.2 Removal of obstacles

The chosen route may be littered with natural or manmade debris that may have to be removed before the cable can be installed. If a cable will be buried, it may be necessary to remove obstacles submerged in the seabed.

Sometimes obstacles are not identified until the cable is being installed, such as buried logs, abandoned wire ropes, and abandoned utility cables. In general, it is much less expensive to deal with these obstacles before a cable-embedding machine is entangled in them.

7.2.1 Identification

A number of methods may be used to discover obstacles, as outlined in Clause 4.

If a cable will be buried, a pass may be made along the cable route with a grapple, knife, or with the burial equipment (without the cable) to “proof” the route.

Thorough surveys are commonly made as part of the route selection. In some cases a sidescan or precision multibeam bathymetry survey is run just prior to installation to assure that no new obstacles have appeared since the initial route surveys.

7.2.2 Location record

Once an obstacle is found, its location must be recorded. This may be done with a number of instruments, some of which are more accurate than others.

- Global Positioning System (GPS)
- Microwave positioning system
- Laser range finder
- Survey triangulation
- Acoustic positioning on remotely operated vehicle

7.2.3 Obstacle removal

Obstacle removal is normally done by grappling the debris and loading it onto a barge for disposal. Notches may be cut through buried logs. Bridges may be built over existing cables or pipes. In some cases it may be easier to alter the cable route around the obstacle.

7.3 Transportation

Small short cables may be delivered over land routes, larger cables may be delivered by rail, and still larger cables may be delivered only by sea. Depending on the delivery method, the user may need to make special accommodations to receive the cable. Cables may be delivered to a staging area in a nearby port or directly to the job site.

7.4 Reel handling

If the cable is delivered on a reel, the reel may be large and heavy, and the user’s normal reel-handling equipment may be inadequate to unload it. Commonly, either a crane with a large spreader bar is used or two cranes (one for each end of the cable reel).

Unspooling cable off the delivery reels may require a motorized reel-turning stand.

7.5 Laying equipment

7.5.1 Vessel

The following items are things to consider when evaluating a cable-laying vessel.

- Anchoring equipment
- Availability for installation and repair
- Cable-coiling facilities (turntable for large cables or cables with anti-twist double-layer armor)
- Cable-tensioning machines (linear engine or capstan with adequate braking capability)
- Draft
- Dynamic positioning with interface with GPS
- Lay control equipment (tension dynamometers, lay angle devices, etc.) integrated with the vessel positioning system
- Laying sheave or sheaves with adequate diameters
- Propulsion system (on-board or tugs)
- Response to wave and wind action
- Weight limitations

7.5.2 Navigation/communications

- Ability to follow a route within a given tolerance
- Available communication frequencies
- Communication system
- Required bottom position accuracy
- Survey control system

7.5.3 Minimum bending radius

Care should be taken that all equipment and installation methods do not violate the minimum bending radius of the cable. This includes:

- Reels and coils
- Sheaves, rollers, and fantail
- Tensioning equipment
- Turntables

7.6 Cable protection

In a submarine project, the cost of the cable protection is commonly significant. Thus, the protection specification (burial depth, type of aggression it has to withstand, etc.) should be considered as early as possible in the project implementation. This clause outlines a number of ways to protect a cable from physical damage.

7.6.1 Cable spacing

If multiple cables are installed, they may be spaced with the hope that if one cable is damaged, the others will be spared. Also, adequate space should be left between adjoining runs so that a cable may be repaired and relaid without crossing over an adjoining cable.

7.6.2 Cable embedment

To prevent damage from most mechanical threats, a cable may be buried along its route.

7.6.3 Burial depth

The depth of burial depends on what is being protected against. For example, a cable may be buried deeper than the deepest expected dredging activity, deeper than an anchor will penetrate into the bottom when dropped, deep enough to avoid the flukes of a dragging anchor, or deep enough to avoid the abrasion of high tidal currents or surf. Cables have been embedded to depths exceeding six meters.

7.6.4 Embedment techniques

A number of embedment techniques may be used. These include specially built machines that insert the cable into the bottom, either as the cable is being laid or after the cable is laid ("post-embedment"). Some machines can cut through rock. Most are pulled along the bottom with lines attached to a surface vessel.

7.6.4.1 Cable embedment

These machines can simultaneously dig a trench and embed the cable:

- Water jet plow
- Vibratory plow
- High-force plow

7.6.4.2 Footprints

Embedment machines have different footprints, which may cause different environmental impacts.

- Sled skids
- Tracks
- Rubber tires

7.6.5 Trench excavation

These techniques dig a trench in which the cable is laid:

- Hand jetting
- Clamshell bucket
- Suction or air-lift dredges
- Cutterhead and ladder dredges
- Chain saw trencher
- Milling drum saw
- Trackhoe mounted on a barge
- Explosive charges

7.6.6 Conduit

The cable may be pulled into preinstalled conduit for the shore ends. Alternatively, split conduit may be placed around the installed cable.

7.6.7 Cable protectors

In shallow water and on shore, interlocking, articulated sections of split conduit may be bolted together or banded over the cable to form a barrier against physical damage. The split conduit may be made of cast iron or plastic.

7.6.8 Cable chases

Cable chases may be installed on land and in the water. These may provide both protection and future access to the cables. After the cables are installed the chase is commonly filled with select backfill or fluidized thermal backfill and a lid is placed on top for added protection. They may be either poured-in-place or precast.

7.6.9 Concrete tile

Near shore and on land, concrete half-tiles are sometimes laid over the cable before it is backfilled to protect the cable from being dug into.

7.6.10 Mattresses, blankets and scour mats

Specially made bags (“mattresses”) may be set over the cable and filled with concrete or gravel. Blankets or scour mats can be made of either tires or precast concrete blocks that are lashed together and laid over the cable. When heavy mattresses or blankets are used, the soil should be firm enough to support the mattress without settling and care should be taken to prevent the cables from being compressed by the mattresses.

Another option is to install soil stabilization blankets or mats. These are intended to trap sediment by slowing the water flow, thus giving the solids an opportunity to settle to the bottom and cover the cable.

7.6.11 Rock dumping

Covering the cable with rock that is carefully placed from a barge can provide mechanical protection for the cable when cable burial is impractical.

7.6.12 Horizontal directional drilling

Horizontal directional drilling may be used to install a conduit under part or all of a waterway. Commonly, this method is used to install conduit for the shore ends of a cable installation. Directional drilling may require a large laydown area.

7.6.13 Bridges and free spans

Mattresses, or bags of sand or concrete, may be used to form a bridge over uneven terrain to support the cable where it would otherwise be suspended. A longitudinal depression in the top of the bridge may be made that will cradle the cable and allow anchors to be deflected over the cable without catching it.

Sometimes active utility cables or pipes may have to be crossed by other submarine cables. In general, it is desirable not to be trapped under another cable because this limits repair and retrieval options. When crossing other utilities, a bridge may be installed that allows the trapped cable to be removed without having to pick up the overriding cable.

7.6.14 Cable crossing warning signs

Large, highly-visible signs placed on the shores are commonly used to inform mariners of the presence of a cable crossing. These signs may include graphics that illustrate that vessels should not anchor in the cable corridor (such as an anchor with a slash through it). They may be written in highly reflective lettering, and they may be illuminated at night to provide greater visibility.

7.6.15 Navigation maps

Navigation charts, such as National Oceanic & Atmospheric Administration (NOAA) charts, may be updated to show the location of the cable corridor.

7.7 Intertidal installation

The installation method used to install the cable in the shore ends may be different than that used in the mid-channel crossing. Sometimes a combination of methods is used.

7.7.1 Trackhoe

Trackhoe trenching is limited in how far it can trench into the water and may be limited in very soft soils.

7.7.2 Dredging

Clam shovel, air-lift dredging, or suction dredging is limited to the cable route that is accessible from the water.

7.7.3 Jetting

Hand jetting may be used to excavate a trench. This is only done under water.

7.7.4 Embedding machines

Some embedding machines may be started on dry land and continue into the water.

7.7.5 Horizontal directional drilling

Drilling under the intertidal zone will avoid trenching.

7.8 Mid-channel crossing installation

7.8.1 Floating

In protected waters and short crossings, the cable may be supported by floats and winched across the waterway. Once across, the floats are removed.

If access is limited to one shore, a “clothes line” approach may be used by placing a turning block on the far shore and setting the cable trailer and winch side by side on the near shore.

7.8.2 Winched barge

The cable may be paid off a barge that is winched across the waterway. Typically, a buoy tender vessel places the anchors in a leap-frogging sequence while the winches on the barge control the barge’s position.

7.8.3 Free barge or free boat

The cable may be paid off a vessel whose position is controlled by tugboats or by thrusters on the vessel. Some vessels are specially built to lay cables. Typically these are used in long crossings or to lay large cables.

7.8.4 Cable tension

The cable must be designed to withstand the tension resulting from the catenary that forms between the laying vessel and the bottom, plus the dynamic forces of a heaving laying vessel.

The maximum tension will occur at the laying vessel. This is where the tension will want to straighten the armoring (if the cable has a single layer of armoring). Near the bottom the cable tension will be less, so the armoring will tend to loosen. If the cable tension on the bottom is inadequate, the cable will twist a loop into itself, which can easily become a kink.

On the other hand, it is desirable to lay the cable with a minimum of remaining tension so the cable will conform to the bottom and not become suspended.

Linear tensioning machines or capstans are commonly used to maintain tension on the cables during laying. On smaller cable installations a powered payout reel may be used.

7.8.5 Coiling cable and turntables

It is undesirable to coil some cables on the deck of a vessel because each revolution requires the cable to twist 360 degrees, which the cable (especially its armor) may not be designed to withstand. To eliminate this twisting, some cables are spooled off reels or turntables rather than being coiled on the vessel. Short sections of cable may be coiled in “figure-eights” to relieve the 360-degree twisting.

7.9 Installing cable on land

7.9.1 Methods

- Winches may be used to pull the cable ashore.
- Rollers may be used to reduce pulling tension and to eliminate abrasion of the cable. Vertical rollers placed on the side of a gently curved trench may help the cable make turns.
- Large sheaves or sectors may be used to turn corners if they are securely anchored.
- Motorized rollers or linear machines may be placed midway on long runs to reduce the pulling tension.
- The cable may be pulled through a conduit system that has been installed by directional drilling or laid in a trench.

7.9.2 Constraints

- Sidewall pressure
- Pulling tension
- Tidal currents, wind, vessel maneuvering ability, and anchoring restrictions may limit the ability to uncoil, cut, and float slack cable off the laying vessel at the receiving end of the cable installation.

7.10 Cable handling and storage

Handling and storage of the cable in the cable plant, the laying vessel, and in storage at the owner’s property is important, particularly in the case of large diameter cables with thin paper tapes in the insulation wall. Some cables should not be coiled, but instead be spooled on turntables.

The purchaser and the manufacturer may need to agree on how the cable will be handled during storage, transferring, and transporting.

8. Quality assurance and testing

8.1 Plant audit/vendor selection

Auditing manufacturing plants and installation companies, along with investigating their past installations, may provide insight into their qualifications to provide a quality installation.

8.2 Qualification testing

Some cable designs are tested both mechanically and electrically prior to manufacturing to demonstrate they are suitable for use. These tests are sometimes referred to as “prototype tests.”

8.2.1 Mechanical

The April 1997, edition #171, of *Electra* includes a paper titled “Recommendation for Mechanical Tests on Sub-Marine Cables” [B13].[1] This paper describes testing submarine cable for coiling, bending, internal pressure withstand. It also describes a sea-trial test.

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[1] The numbers in brackets correspond to those of the bibliography in Annex A.

8.2.2 Electrical

Some electrical tests that may be performed during qualification testing are described in the documents listed in Annex A

8.3 Production testing

A cable may be tested after it is produced to demonstrate it is electrically and mechanically suitable for use. The same organizations mentioned in the previous clause provide testing protocol. These tests are sometimes referred to as “factory tests.”

8.4 Pre-installation testing

Electrical tests are normally performed prior to installation to assure that the cable was not damaged during transportation.

8.5 Witnessing

A buyer of submarine cable may choose to observe one or more of the following:

- Qualification testing
- Manufacturing process
- Production testing
- Commissioning tests

8.6 Commissioning and maintenance tests

8.6.1 Inspection

A post-installation survey may be done to assure the cable is lying properly on the bottom and/or adequately buried. An as-built survey may be useful if the cable has to be repaired or retrieved, another cable laid over or near it, or construction work done around it. The following techniques may be used to locate or observe the cable:

- Cable locating (toning, electromagnetic field detection, metal detector)
- Sidescan
- Precision multibeam bathymetry
- Video or still photography via diver or ROV

8.6.2 High voltage electrical

A number of electrical tests are available to assure the cable has been installed without damage:

- AC testing (AC tests are not always practical due to excessive charging current of some long cables.)
- DC testing
- Jacket integrity testing indicates if the cable has sustained significant mechanical impact that damaged the jacket. This test is not possible if the jacket is semiconducting.

- Dissipation factor
- Sheath and armor current measurements

8.6.3 Hydraulic

A number of tests of the hydraulic system are available to ensure that the system is working properly:

- Leakdown pressure test of cable system
- Dissolved gas analysis
- Piping/pump leak testing
- Insulation impregnation test
- Fluid flow test

8.6.4 Calibration of instrumentation

The calibration of the instrumentation is critical to providing accurate and credible readings. If there is an alarm, and the instrumentation is not properly calibrated, the response may be confused by misinformation.

8.6.5 Time domain reflectometer (TDR)

A "picture" of the cable taken with TDR equipment may be useful in locating faults in the future, especially if the cable has multiple splices. It also helps confirm the cable length or the impulse propagation velocity.

9. Spare material

9.1 Spare cable

9.1.1 Loop at termination

A spare loop of cable may be buried near the base of each termination structure. In case of termination failure or cable failure near the termination, this loop can be excavated and used to make up for the damaged cable or the preparation length of a replacement termination.

9.1.2 Stored cable

See 6.4.

9.1.3 Length

A minimum of two times the water depth of spare cable is commonly needed to repair a cable. Additional spare cable may be kept on hand in case multiple cables are damaged, a length of cable is damaged, or a cable is damaged multiple times.

If a land cable is spliced onto the submarine cable, a spare portion of the land cable equal to the length of the longest distance between manholes or splices, plus cutting waste, may be kept on hand.

9.2 Fluid

Spare fluid for fluid-filled cable systems can be stored in drums or in a storage tank, depending on the volume required. Drums should be stored in an environment where they will not rust.

9.3 Splices and terminations

Spare splices and terminations should be packaged for long-term storage and stored in an area that protects them from the environment. A given project may have rigid, flexible, or both types of splices. The shelf life of some parts may be limited, so these parts may need to be periodically replaced.

The number of spare items an owner keeps on hand may be influenced by many factors, including:

- Probability of failure or damage
- Time to obtain spare parts
- The required reliability of the circuit

9.4 Tools and equipment

Specialized tools or equipment may be required to make repairs to certain components or to perform certain maintenance. These items may not be readily available in the market. Whether the user purchases these items may also depend on whether the user intends to perform repairs and maintenance with in-house workers.

9.5 Degasifier

Critical parts for the degasifier, or a spare degasifier, may be purchased for fluid-filled cable systems.

10. Documentation and operation

Submarine cable systems commonly operate for many years without requiring any repairs. When a component requires repairing, replacement, or calibrating, there may not be workers readily available who are intimately familiar with the workings of the system. Therefore, it is important to have complete documentation of the cable system.

10.1 As-built documentation

Below are some factors to consider including in the documentation.

- Plan and profile of where the cable was laid, both in the water and on land, including survey control points and landmarks
- Location of obstructions
- Locations of splices
- Complete termination station drawings
- Photographs

10.2 Operating manual

An operating manual that describes the complete system is highly desirable, especially for fluid-filled systems. The manual should include the following:

- A description of the system and how it works
- Instructions on how to operate the system under normal and contingency conditions
- Instructions on how to respond to alarms and emergencies

10.3 Description of system components

If a component must be replaced, the owner should have adequate information available either to order a replacement part or one that is similar enough or to have one made.

- Description of each part
- Drawing
- Dimensions
- Performance specifications
- Manufacturer’s name and catalog number
- Description of how the system works

10.4 Operating limits

10.4.1 Electrical ratings

- Steady-state load current
- Emergency load current
- Transient or short-term current
- Fault current
- Line-to-line voltage rating
- BIL
- Switching surge

10.4.2 Hydraulic limits

- Pressure
- Flow rates
- Pressure-volume curves

10.4.3 Other design criteria

- Soil thermal properties
- Seismic
- Operating temperatures

10.5 Routine operating, inspection, and maintenance procedures

- Schedule
- Procedure
- Calibration instructions
- Fluid testing
- Acceptable and unacceptable findings
- Cleaning termination insulators
- Location and condition of spare parts, special equipment, and tools
- Shelf life of spare parts
- Inspection of spare cable
- List of suppliers

10.5.1 Testing of jackets

The integrity of the non-high voltage, non-conducting layers of a cable are critical. For example, if a jacket fails, water may enter the cable and corrode the underlying metallic components, thus leading to an electrical failure. Maintenance testing is a way to detect a failure of the insulating layers of cables that do not have midpoint bonding. The discovery and repair of a pinhole in an insulating layer may prevent an unscheduled phase-to-ground failure of the submarine cable.

10.6 Re-surveying

The bottom conditions may significantly change after a significant weather event or natural disaster (e.g., earthquake, tropical cyclone, and severe flooding), which may leave the cable suspended, deeply buried, or highly stressed. A bottom survey after such an event may reveal these conditions.

10.7 Repair strategy

Cable repair can be expensive and time consuming, especially where the cable is remote from manufacturers, laying/repair vessels, and trained workers. In such cases a repair strategy may be developed and included in the documentation. See 11 for additional information.

10.8 Emergency maintenance procedures

This may describe the means to address each of the following situations, including how to isolate and locate problems. It may include a discussion of temporary repair methods and damage mitigation.

- Response plan for each alarm
- Fluid leak detection and location
- Electrical fault location and damage control
- Location of spare parts, special equipment, and tools
- A list of contractors and manufacturers who can help in case of an emergency

10.9 Installation of replacement components

- Drawings
- Instructions
- Material list
- Tools
- Equipment
- Location of spare parts, special equipment, and tools

10.10 Safety and hazards

Hazards may exist in or around a submarine cable system. An operating manual may include a discussion of the hazards, the precautions that may be taken to minimize these hazards, and describe procedures that may be followed in the case of a hazardous event. Fire, electrical failures, and electrical shock are examples of some hazards.

10.10.1 Fluid leak

Commonly, a fluid spill response kit is located inside every station containing insulating fluid, along with instructions and drawings. These drawings show such things as drainage systems and fluid retention systems.

10.10.2 Chemicals

Consult Material Safety Data Sheets for hazardous chemicals.

10.11 Notification of authorities

A list may be kept of officials and/or agencies that need to be contacted in the event of an incident requiring work on the water or on the shoreline.

11. Repair

11.1 Locating faults

Faults in the cable may be electrical or hydraulic (if the cable is self-contained, fluid-filled). The following are some techniques to consider when dealing with a failure.

11.1.1 Search for evidence

- Anchored vessels, fishing vessels, dredges, pile driving, backhoes, etc.
- Dielectric fluid on the water
- Diver or ROV with video camera
- Underrunning the cable and examining it as it passes over the vessel deck

11.1.2 Electronic locating techniques

- Time Domain Reflectometry
- Murray Loop
- Sidescan or precision multibeam bathymetry may be useful:
    - If a dragging anchor is suspected of damaging the cable because the cables may form a “V” where the anchor dragged the cable.
    - In identifying pinnacles the cable is laid over, or locations where the cable is suspended.
- Once a fault is located, record its location with GPS or by survey triangulation from shore.

11.2 Locating dielectric fluid leaks in SCFF cable

- Check the metering for malfunctions and calibration
- Pressure-drop test individual cables
- Air surveillance: Look for an oil sheen on the water
- Diver or ROV with video camera

11.3 Evidence

Video taping and photographing the cable may be useful in confirming the extent of the damage, providing evidence for analysis of the cause of the problem, and recording evidence for damage claims against an offending party.

11.4 Containing dielectric fluid from a cable

An open-bottomed, metal doghouse may be placed over the leaking cable to catch the escaping fluid. The dielectric fluid may be pumped out through a chimney in the top of the roof.

Special clamps may be installed over a break in the cable to stop the leak.

The cable may be cut, brought to the surface, and capped.

The fluid pressure may be reduced to reduce the fluid flow rate. Caution: If the fluid pressure is reduced below the water pressure at the failure, water will enter the cable.

11.5 Retrieval

There are many methods and variations to retrieve and repair a failed cable. Which method is used depends on a number of factors, such as the distance from shore where the cable failed, the depth of the water, the type of cable, its age, and condition.

One method is to grapple the cable, cut it, bring one end to the surface, cut out the damaged portion of cable, splice on a new piece of cable, partially lower the new cable and splice, pick up the other end of the old cable, splice it to the remaining end of the new cable, and overboard the splice (without getting a twist in the cable or without trapping a neighboring cable).

Another method is to cut the cable on both shores and reel it onto a vessel. The repair is made back in port after the cable is unreeled. Afterwards the cable is spliced at one shore and then relaid and spliced at the other shore.

In shallow water there may be enough slack in the cable to raise the cable onto a repair barge without cutting the cable.

If the water is shallow enough and there is sufficient slack, the cable can be lifted near the shore and placed in sheaves on the edge of the barge. The barge then underruns the cable out to the fault. The fault is cut out and a spare length of cable is spliced in. Then the barge underruns the cable back to the shore where it is laid off into shallow water.

For fault locations near shore, the cable can be cut near shore and reeled up on the barge out to the fault location. After the spare piece of cable is spliced in, the cable is relaid back to the shore where a splice is made to the shore end to complete the repair.

11.6 Cable repair splices

Whether a flexible splice or a rigid splice is used to make the repair depends on the cable retrieval technique.

Annex A

(informative)

Additional information

The documents in the following list may be useful in gathering additional information on submarine cables.

A.1 Standards

[B1] IEC 60060-1, High-voltage test techniques. Part 1: General Definitions and Test Requirements.[2]

[B2] IEC 60229, Tests on Cable Oversheaths Which Have a Special Protective Function and are Applied by Extrusion.

[B3] IEC 60230, Impulse Tests on Cables and Their Accessories.

[B4] IEC 60840, Power Cables With Extruded Insulation and their Accessories for Rated Voltages Above 30 kV (Um=36 kV) up to 150 kV (Um=170 kV) - Test Methods and Requirements.

[B5] IEC 62067, Power Cables With Extruded Insulation and Their Accessories for Rated Voltages Above 150 kV (Um=170 kV) Up To 500 kV (Um=550 kV) - Test Methods and Requirements.

[B6] IEEE 48™-1996, IEEE Standard Test Procedures and Requirements for Alternating-Current Cable Terminations 2.5 kV through 765 kV.[3]

[B7] IEEE 404™-2000, IEEE Standard for Extruded and Laminated Dielectric Shield Cable Joints Rated 2500 V to 500000 V

[B8] IEEE 575™-1988, IEEE Guide for the Application of Sheath-Bonding Methods for Single-Conductor Cables and the Calculations of Induced Voltages and Currents in Cable Sheaths

A.2 Articles in periodicals

[B9] *Electra* 32, “Recommendations for Tests on D.C. Cables for a Rated Voltage up to 550 kV.”

[B10] *Electra* No. 89, “Transient Pressure Variations in Submarine Cables of Self-Contained Oil-Filled Type.”

[B11] *Electra* 151, “Recommendations for Electrical Tests Prequalification and Development on Extruded Cables and Accessories at Voltages Above 150 (170) kV to 400 (420) kV.”

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[2] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[3] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[B12] *Electra* 151, “Recommendations for Electrical Tests Type, Sample and Routine on Extruded Cables and Accessories at Voltages Between 150 (170) kV and 400 (420) kV.”

[B13] *Electra* 171, “Recommendations for Mechanical Tests on Submarine Cables.”

[B14] *Electra* 189, “Recommendations for Tests of Power Transmission DC Cables for a Rated Voltage up to 800 kV” (Electra 72, 1980, revision).

[B15] *Electra* 189, “Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage Above 30 (36) to 150 (170) kV.”

[B16] J.M. Oudin, R.A. Tellier, “Submarine DC Cables,” *IEEE Spectrum*, Vol. 3, July 1966, pp. 75–82.

A.3 Books

[B17] *Accessories for Specially Bonded Extruded-Dielectric Transmission Cable System*, Vol. 1 & 2, EPRI, July 1991, Palo Alto, Publication EL-7259.

[B18] T.B. Bamford, et. al., *Riser Segment Design of Underwater Electric Power Transmission Cables System*, DOE Report ORO-5359-1, 1978.

[B19] Bartnikas, R. and Srivastava, K.D., *Power and Communication Cables—Theory and Applications*, New York: IEEE Press, 2000, pp. 582–623. (The bibliography in this book contains 148 entries that deal with submarine cables.)

[B20] Edison Electric Institute, *Underground Systems Reference Book*, New York, Edison Electric Institute, Pub No. 55-16, 1957, 8-53 – 8-58.

[B21] Electric Power Research Institute, *Underground Transmission Systems Reference Book*, Palo Alto: EPRI, 1992, pp. 101, 243, 292–306.

[B22] Moore, G.F., *Electric Cables Handbook*, 3d ed. London: Blackwell Science, pp. 621–656, 1999. (The bibliography in this book contains 15 entries that deal with submarine cables.)

A.4 CIGRE Proceedings

[B23] G. Maschio, E. Occhini, “Overvoltages on Anti-corrosion sheaths of High Voltage Cables with Particular Reference to Long Submarine Cables,” CIGRE 1964.

[B24] L. Elgh, and B. Sonnerup, “Repair of 400 kV AC Submarine Cable,“ CIGRE 21-05, 1982.

[B25] E. Crowley, J.E. Hardy, L.R. Horne, and B.G. Prior, “Development Programme for the Design, Testing And Sea Trials of the British Columbia Mainland to Vancouver Island 525 kV Alternating Current Submarine Cable Link,” CIGRE 21-10 1982.

[B26] L. Rebuffat, G.M. Lanfranconi, F. Magnani, U. Arnaud, G. Monti, “Installation of Submarine Power Cables in Difficult Environmental Conditions: The Experience with 400kV Messina Cables,” CIGRE SC21-10, 1984.

[B27] “Methods to Prevent Mechanical Damage to Submarine Cables,” CIGRE WG21.06, CIGRE 21-12, 1986.

[B28] R. Arnold, A. Homer, B. Riot, “Seabed Repair Facility of the Cross Channel Cables,” CIGRE 21-05, 1986.

[B29] U.Arnaud, A. Bolza, F. Magnani, E. Ochini, “Long Island Sound Submarine Cable Crossing 345kV, 750MVA,” CIGRE SC21, WG 306, 1992.

[B30] K. Bjorneklett, E. Kaldhussaeter, P.V. Laengen, “Installation of 300 kV HV AC Underground Power Cable – Part of the Main Power Supply for Kollsnes Gas Treatment Plant, Troll Phase 1 Onshore Plant and Troll Phase 1 Power Offshore Cable,” CIGRE 21/22-06, 1996.

[B31] W.S. Sabri, and M.F. Nawara, “The Gulf of Aqaba Submarine Cable Crossing,” CIGRE 21-302, 1998.

A.5 IEEE Proceedings

[B32] G. Barclay, A.L. Verhiel, “Operation and Maintenance of British Columbia Hydro and Power Authority Mainland-Vancouver Island 132kV Submarine Cable Connection,” *Transactions of the IEEE*, Vol. 82, Part 3, PAS, Dec. 1963, pp. 876–884.

[B33] Waldron, R.C., “115 kV Submarine Cable Crossing Puget Sound,” *IEEE Trans Power Apparatus and Systems*, Vol PAS-84, pp. 746–755, 1965.

[B34] D.J. Cowley, R.G. Foxall, “Planning, Design and Construction of a 500kV Transmission System to Vancouver Island Including Long Submarine Cable Links,” *Transactions of the Canadian Electrical Association, Engineering and Operations Division*, Vol. 22, Part 5, 1983.

[B35] J.H. Cooper, M.J. Polasek, “Planning and Installation of the 138kV South Padre Island Submarine Cable,” *IEEE Transactions on Power Delivery*, Vol. 8, No. 4, October 1993.

[B36] J. Grzan, E.I. Hahn, R.V. Casalaina, J.O.C. Kansog, “The 345kV Underground and Underwater Long Island Sound Project,” *IEEE Trans Power Apparatus and Systems*, Vol. 8, No. 3, July 1993.

[B37] E.C. Bascom III, Y. Iossel, A.V. Poliakov, J.F. Troisi, R.J. Schwabe, “Construction Features and Environmental Factors Influencing Corrosion on a Self-Contained Fluid-Filled Submarine Cable Circuit in Long Island Sound,” *IEEE Transactions on Power Delivery*, Vol. 13, No. 3, July 1998.

A.6 IEEE Papers

[B38] P. Gazzana and G. Maschino, “Continuous Long Length AC and DC Submarine HV Power Cables The Present State of the Art,” IEEE Paper T 73 127-8, 1973.

[B39] G. Bazzi, G. Monti, A. Malesani, S. Balli, and G. Porta, “The 132 kV A.C. Power Cables and The Optical Fiber Cable for the Submarine Intertie Italy-Elba Island,” IEEE 88 SM 513-4.

[B40] M. Nakamura, N. Nanayakkara, H. Hatazaki, and K. Tsuji, “Reliability Analysis of Submarine Power Cables and Determination of External Mechanical Protection,” IEEE Paper 0-7803-0219-2/91/0009-003, 1991.

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