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Sea-to-sea Electronic Links: A Study of Subsea Cables as a Support for Global Communications

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ABSTRACT

Subsea cables are essential infrastructure for supporting global digital communication and energy distribution across continents. This article reviews the structural and transmission characteristics of subsea fiber optic and power cables, including their key components, protection mechanisms, and performance under deep-sea conditions. It highlights the evolution of optical technologies such as DWDM and advanced modulation schemes, as well as the fabrication processes and materials used to withstand hydrostatic pressure, corrosion, and electromagnetic disturbances. Furthermore, the paper compares single-core and three-core cables, explores the environmental impacts of cable deployment, and evaluates the maintenance strategies needed to ensure system longevity. Special attention is given to the relevance of these systems for archipelagic nations like Indonesia, which depend heavily on reliable inter-island connectivity. The review aims to provide a comprehensive technical perspective to support future development and deployment of subsea networks worldwide.

1. INTRODUCTION

In today's digital era, the importance of fast and reliable global connectivity is increasingly felt. The rapid growth of information and communication technology drives the need for a strong digital infrastructure as the main foundation to support data exchange between countries and continents. One crucial component of this infrastructure is the submarine cable system, which functions as the backbone of the international communication network. Around 99% of total international data traffic is transmitted via submarine cables, not via satellite as is often misunderstood (International Telecommunication Union, 2024). These cables stretch thousands of kilometers on the seabed, connecting countries on different continents and enabling data exchange in milliseconds. With this very strategic role, submarine cables are an irreplaceable element in the global digital ecosystem.

However, behind the importance of this role, submarine cables also have significant vulnerabilities. Physical disturbances due to ship activities, earthquakes, and even sabotage have repeatedly caused disruptions to internet services in various parts of the world. One example is the cable severance incident in the Red Sea in 2024, which had a direct impact on connectivity in several countries in East Africa (The Guardian, 2024). This shows how vulnerable the infrastructure is if not properly protected and managed.

In addition to technical challenges, geopolitical aspects are also an important dimension that must be considered in the development and management of submarine cables. Strategic projects such as the PEACE Cable connecting Asia, Africa, and Europe not only affect technical and economic aspects, but also reflect the dynamics of global politics among major powers (Carnegie Endowment for International Peace, 2022). Countries are increasingly aware that control over digital communication lines can function as a tool of diplomacy and even domination. For Indonesia, which is an archipelagic country with more than 17,000 islands, submarine cables are vital to ensuring connectivity between regions. However, geographical challenges, extreme sea depths, and limitations of local technology often become obstacles in the construction and maintenance of these cables (Le Monde, 2024). There are still many remote areas in Indonesia that are not optimally connected due to the lack of basic digital infrastructure, including submarine cables.

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2. METHODS

This research is based on a literature review collected from secondary data sources. A literature review is a systematic, explicit, and reliable procedure for identifying, analyzing, and summarizing research works and ideas developed by academics and practitioners. The researcher obtained data and information indirectly from various credible sources, including literature studies, scientific publications, and previous research.

3. RESULT

3.1 Definition of Subsea Cable

3.1.1 History of Subsea Cable

For more than a century, undersea communications relied on copper cables to transmit telecommunication signals between continents. However, in the 1980s, submarine fiber optic cable technology began to replace the old system due to its ability to transmit large volumes of data at high speeds and minimal interference. In the last decade, the utilization of submarine optical cables has seen a rapid surge due to the increasing global need for data connectivity across continents. One significant advancement is the use of Dense Wavelength Division Multiplexing (DWDM) optical systems that enable thousands of communication channels through a single optical cable (Han, Li, Qi, Peng, & Chen, 2025). On the other hand, the development of optical sensors integrated in cables is also starting to be used for marine environment monitoring, such as seismic detection and ocean temperature, as developed in fiber optic projects for geothermal activity monitoring (Ou & Sharma, 2025).

This system provides dual-use capabilities, as both a communication network and a subsea sensing system. Another study showed that fiber optic-based sensors embedded in submarine cables can provide real-time data for submarine seismicity and seafloor geotechnical conditions (Jurick, Reynolds, & Sharma, 2025). With the growing trend of global digital networks, submarine optical communication systems such as SEA-ME-WE 5 and MAREA can now transfer data on the scale of terabits per second, connecting Asia, Africa and Europe with the Americas in very low latency. Historically, the transition from copper cables to submarine optical fiber marked a revolution in global digital infrastructure,

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and innovations in the past decade have strengthened optical cables' position as the backbone of the global internet.

3.1.2 Submarine Cable for Communication in General

Submarine cables are fiber optic cables installed on the seabed to connect communication networks between continents or between regions separated by oceans. These cables enable high-speed data transmission over very long distances, such as between continents, with large capacity and low latency. As the installation of new cables is very expensive and complex, the use of technologies such as spatial division multiplexing (SDM) in submarine cables can increase efficiency and capacity without the need to install massive new cables. These submarine systems can also utilize parallel integration of components to reduce costs and energy consumption (Winzer & Neilson, 2017). Fiber optic cables function as dielectric waveguides that guide light through total internal reflection within a core surrounded by a cladding layer with a lower refractive index. These cables are capable of transmitting light in the visible, ultraviolet, or infrared spectrum, making them ideal for high-bandwidth communication systems (Huerta-Cuellar, 2021). Optical fibers also exhibit high resistance to electromagnetic interference, which makes them superior to conventional copper cables. Recent innovations such as Dense Wavelength Division Multiplexing (DWDM) allow hundreds of communication channels to run simultaneously in a single fiber, significantly increasing spectrum efficiency up to terabits per second capacity(Han, Li, Qi, Peng, & Chen, 2025).

3.2 Specification of Fiber Optic Cable

3.2.1 Based on Fiber Type

Based on the Fiber Type, it can be divided into 2 types, namely Single-Mode Fiber (SMF) and Multi-Mode Fiber (MMF).

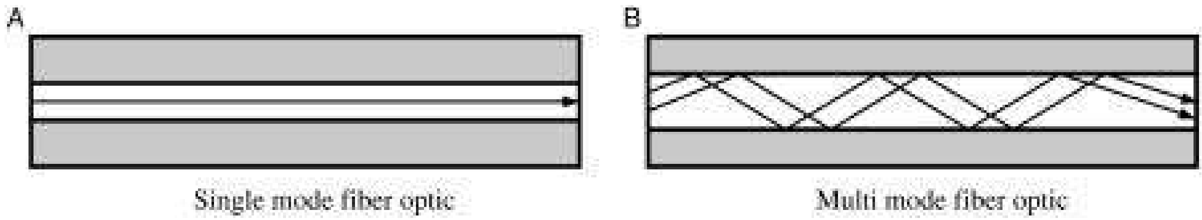

Figure 2. SMF and MMF Optic Cable (Mohamed, 2023).

a. SMF, is a type of optical fiber that has a large transmission bandwidth and can be used for long-distance communication at high speeds. SMF has advantages such as the absence of modal noise, low attenuation, compatibility with integrated optical technologies, and good durability. SMF usually uses thin films in its manufacture so that it has a high mass density and a good elastic modulus, so it does not break easily. SMFs also have characteristics based on propagation constants or birefringence that affect the quality of light transmission in them (Hairi et al., 2022).
b. MMF, is a type of optical fiber that can carry multiple modes of light simultaneously through its relatively large fiber core. This allows multiple light paths to propagate in parallel, which is typically used for shorter transmission distances due to higher modal

dispersion compared to single mode fiber. Multimode fibers are often used in communication and sensor applications, including microstructured optical fibers (MOFs) or photonic crystal fibers (PCFs) that have special structures to regulate the propagation characteristics of light (Drljača et al., 2025).

3.2.2 Based on Fiber Core Material

In its application, it can be distinguished based on its constituent materials, which greatly affect its physical characteristics and transmission performance. In general, there are two main types of fiber optic cables that are widely used, namely Glass Optical Fiber (GOF) and Polymer Optical Fiber (POF).

a. Glass Optical Fiber (GOF), is an optical fiber made of pure quartz or silica glass, which is capable of transmitting light with very low attenuation and high bandwidth capacity, making it ideal for long-distance communication systems such as internet backbone networks, undersea communications, and data center connectivity. GOF's ability to support light transmission in the infrared spectrum with minimal signal loss makes it a top choice in modern telecommunications (Huerta-Cuellar, 2021).
b. Polymer Optical Fiber (POF), are made from polymeric materials such as PMMA (Polymethyl methacrylate), which despite having higher attenuation and limited bandwidth than GOFs, offer advantages in terms of flexibility, lower cost, and ease of installation. POF is widely applied in short-range network systems such as in homes, vehicles, or consumer electronic devices. POF's main advantage is that it is flexible and bend-resistant, making it suitable for dynamic installation environments that do not require long-distance transmission performance (Huerta-Cuellar, 2021).However, POF has significant limitations in subsea applications. Polymeric materials tend to absorb water, which can lead to material degradation and increased signal attenuation. In addition, POF has higher intrinsic attenuation than GOF, limiting its effectiveness in long-distance transmission in marine environments. Therefore, POF is not recommended for undersea communications that require high reliability and long transmission distance (Min et al., 2022).

3.2.3 Specification Based on ITU-T Standard

Based on ITU-T standards, SMF type G.652.D has a maximum attenuation of 0.35 dB/km at 1310 nm and a maximum dispersion of 18 ps/nm-km at 1550 nm. Type G.655 (Non-Zero Dispersion Shifted Fiber) supports DWDM with attenuation of 0.25 dB/km and dispersion between 4-8 ps/nm-km. G.657.A1, which is bend-insensitive, is ideal for FTTH installations as it has high tolerance to bends with low fixed attenuation.

3.2.4 Based on Construction

Fiber optic cables are available in indoor, outdoor, and hybrid forms. Indoor cables use tight-buffered construction and are suitable for indoor applications such as simplex, duplex, and breakout cables, as per the IEC 60794-2-21 standard. Meanwhile, outdoor cables use a gel-filled loose-tube structure and often feature armor protection (steel) as well as anti-rodent coating, following the IEC 60794-3-10 standard. Hybrid cables combine optical and copper fibers for simultaneous data and power transmission, commonly used in FTTH installations and 5G networks.

3.3 Working Mechanism Of Subsea Cables

3.3.1 Digital data

Submarine cables are a very important infrastructure in the world's communication system that connects various continents and countries with fast internet networks. Around 99% of all international data traffic including banking transactions, social media, and communication between countries is sent via optical cables that stretch thousands of kilometers on the ocean floor. To ensure that data can be transmitted through this system, the first step is to digitize and process the signals very carefully.

The initial process begins by converting analog data (such as sound and moving images) into digital bits, which are a series of binary numbers 0 and 1. This process includes sampling, which is recording analog signal snippets periodically, and quantization, which is rounding signal values to discrete numbers so that they can be processed by electronic devices. The resulting digital signal is then compressed to reduce its size without losing important information, thus optimizing the use of transmission lines with limited capacity. In addition, data is also encrypted using certain algorithms to protect the security and confidentiality of information while on the submarine network which is at risk of illegal access.

In order to maintain accurate data transmission even through routes of thousands of kilometers that are susceptible to interference, channel coding techniques are used, a method to add additional information (redundancy) to detect and correct errors in the transmission process. One very efficient method is Low-Density Parity-Check (LDPC), a coding system based on a sparse matrix (low-density matrix) that is able to correct errors without greatly reducing transmission capacity (Guo et al., 2023).

In order to support the transmission of large volumes of data, submarine cable systems also utilize multiplexing techniques, namely the combination of several signals in one transmission channel. One method that is often used is Orthogonal Frequency Division Multiplexing (OFDM). In this approach, the signal is divided into many orthogonal sub-carriers, allowing simultaneous transmission and increasing resistance to interference, such as signal attenuation in deep ocean environments (Lian et al., 2019).

Furthermore, this system also uses an adaptive Modulation and Coding Scheme (MCS). This scheme facilitates the system to automatically adjust the modulation type (signal coding method) and coding level according to the transmission channel conditions. For example, when the channel is in good condition, the system will use 16-QAM (a complex modulation that allows more bits to be delivered per symbol), while in unfavorable conditions, the system will switch to QPSK (a simpler modulation that is more resistant to interference) (Guo et al., 2023).

Overall, submarine cable communication technology relies on the combination of data digitization, compression, encryption, channel coding, multiplexing, and modulation adjustment to ensure efficient, secure, and reliable data transmission. Without this system, the rapid and massive global information exchange like today would not be possible.

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3.3.2 Optical Fiber Transmission

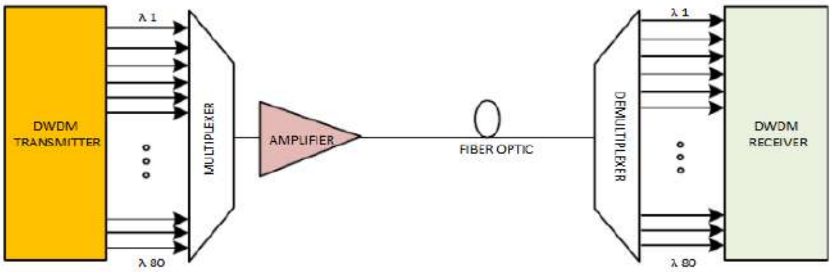

Figure 3.3.2 Dense Wavelength Division Multiplexing (DWDM) system block diagram (Saputra, G. N. A. A., & Firdausi, A. (2022)

Today's long-distance international data transmission relies heavily on submarine cables that utilize optical fibers as a means of transmitting signals. The core of these fibers is made of very pure glass with a high refractive index, while being coated with a cladding with a lower refractive index. This combination allows light to travel within the fiber core through a process of total internal reflection, which helps to keep signals from being lost even though they travel thousands of kilometers underwater (Senior et al., 2016). To increase transmission capacity, Wavelength Division Multiplexing (WDM) technology is applied, a method that divides light signals into several different wavelengths so that they can be sent simultaneously using a single optical fiber. A more sophisticated version of this technology is Dense Wavelength Division Multiplexing (DWDM), where the distance between wavelengths is made closer, allowing hundreds of communication channels to be processed simultaneously on a single fiber. With DWDM, transmission capacity can reach terabits per second, which is one trillion bits in one second, which is a very large volume to meet global communication demands (Qiu et al., 2021). On the other hand, optical fiber also has other advantages compared to traditional media, such as its resistance to electromagnetic interference and very low signal attenuation levels. This is the reason why optical fiber is the main choice in the construction of intercontinental infrastructure networks that require high stability and reliability in the long term.

3.3.2 Repeater

Along the submarine cable route, light flowing in optical fiber experiences a decrease in intensity (attenuation) due to the effects of absorption and scattering caused by the glass material. To overcome this problem and maintain good and strong signal quality, a device called a repeater is needed, which functions as a signal amplifier that is installed periodically. Generally, repeaters are placed every 50–100 km, depending on the quality of the fiber and the type of amplifier used. This distance is the result of a technical compromise between how efficient the amplification is and the installation cost, considering that the optical signal begins to decrease significantly after a distance of 80–100 km due to the accumulation of attenuation of around 0.2 dB/km.

The latest optical repeaters rely on two main technologies:

a. Erbium Doped Fiber Amplifier (EDFA), which is an optical amplifier that uses fiber that has been doped with erbium and is activated by its pump laser. EDFA functions by amplifying the light signal directly without converting it into an electrical signal, thereby reducing delays in transmission.

b. Raman Amplifier, which utilizes the Raman scattering effect in optical fibers to enhance the signal by adding its pump laser into the fiber path. This provides more flexible amplification and more even power distribution (Zhang et al., 2024).

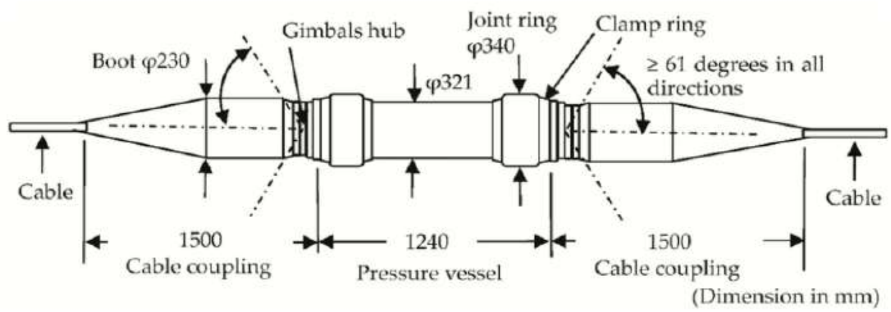

Figure 3.3.2 Schematic construction of OS-560M submarine optical repeater (Ogasawara et al., 2021).

In its design, the repeater must be designed to withstand extreme conditions on the seabed, such as high hydrostatic pressure (can reach thousands of atmospheres), low temperatures, and the risk of corrosion. Therefore, the repeater casing is usually made of corrosion-resistant metals such as titanium or stainless steel alloys coated with additional protection. Titanium, for example, is chosen because it has a high strength-to-weight ratio, resistance to seawater corrosion, and resistance to changes in temperature and pressure, making it suitable for lasting for more than 25 years (Tang et al., 2023).

3.4 Type Of Subsea Cables

3.4.1 Submarine Telecommunication

Undersea telecommunications cables serve as the foundation for global connectivity, carrying more than 95% of international data through fiber-optic systems that connect continents and countries (AAE-1, 2025). Dense Wavelength-Division Multiplexing (DWDM) technology allows hundreds of data lines to be transmitted simultaneously at different wavelengths of light over a single fiber, increasing capacity without the need for new cables (Papapavlou et al., 2022). The physical structure of these cables is equipped with a high-density polyethylene (HDPE) sheath, which is resistant to environmental conditions. In extreme situations, these components are also enriched with polyurethane to increase flexibility and resistance to abrasion and physical hazards such as ship anchors and underwater landslides (Okolo et al., 2020). To ensure network reliability, the redundant design uses a ring topology that can automatically repair the path in the event of a disruption, allowing service to continue without relying on satellite technology as an alternative (Papapavlou et al., 2022). One example of the application of this technology is the Asia-Africa-Europe 1 (AAE-1) cable which is 25,000 km long and has a capacity of 100 Tbps, indicating the increasing demand for bandwidth triggered by global internet growth (AAE-1, 2025). In the face of technological advances and materials that continue to innovate, submarine cables remain an important element in a reliable and durable global communications system (Jill C, G., 022).

3.4.2 Subsea Power Cable

Submarine power cables are essential for delivering electricity over long distances in the ocean, linking various islands and nations. These cables usually contain optical fibers, which support communication and monitoring alongside the electrical transmission.

3.4.2.1 Optical Fiber Integration and Material Considerations

Advanced submarine telecommunications cables now utilize fiber optics to support real-time communications and monitoring. These fiber optics are placed adjacent to power conductors, allowing data and electrical current to flow simultaneously. The presence of fiber optics greatly improves the efficiency and reliability of submarine power systems (Zhang, 2017).

There are two main categories of insulating materials used in submarine power cables:

a. Mass Impregnated (MI): This traditional insulation method consists of a layer of paper dipped in a viscous oil material. MI provides excellent thermal and dielectric stability, making it suitable for high-voltage applications. However, its greater weight and wider size can make it difficult to install and manage (Zhang, 2017).
b. Cross-Linked Polyethylene (XLPE): XLPE is a type of thermoplastic polymer that is chemically linked to improve its thermal and mechanical properties. Cables with XLPE insulation are lighter, have a smaller diameter, and can withstand higher operating temperatures than cables with MI insulation. These characteristics make XLPE insulated cables more suitable for complex underwater installations and in conditions with limited space (Zhang, 2017).

3.4.2.2 Environmental Impact and Mitigation Measures

The deployment and functioning of submarine power cables may affect marine ecosystems. During the installation process, tasks like trenching the seabed and laying the cables can disrupt sediments, which may harm benthic organisms and their habitats. Moreover, the electromagnetic fields (EMFs) emitted by the cables can affect the behaviors of some marine species, including their migratory patterns and navigation abilities (Leadvent Group, 2023).

3.5 Characteristics of Subsea Cables

To better understand the performance and reliability of submarine cables, it is crucial to examine their structural characteristics, materials, and electromagnetic behavior under marine conditions. Submarine cables are essential infrastructure used to transmit electrical energy and data signals across inter-regional routes beneath the seabed (Livadariu et al., 2024). This type of cable consists of several layers of sequential protection, starting from the main conductor made of copper or aluminum (Worzyk, 2019). Copper is more commonly used because of its high electrical conductivity and corrosion resistance, although it is more expensive than aluminum (Zhang et al., 2023). These conductors are coated with XLPE (cross-linked polyethylene) insulation and a semiconductive layer for controlling voltage distribution. Beyond insulation, additional barriers are implemented to protect the cable from seawater ingress and physical disturbances. To avoid damage due to seawater infiltration, these cables often have a lead sheath as a radial water barrier, which is then wrapped in a waterproof polymer such as polyethylene (PE) or high-density polyethylene (HDPE) (TAO

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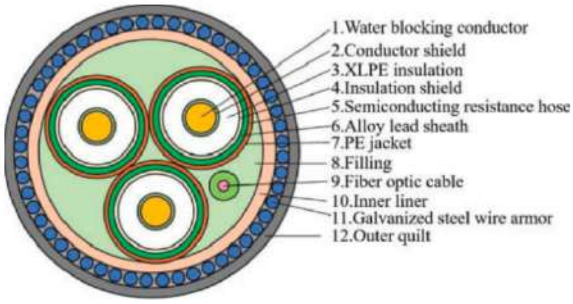
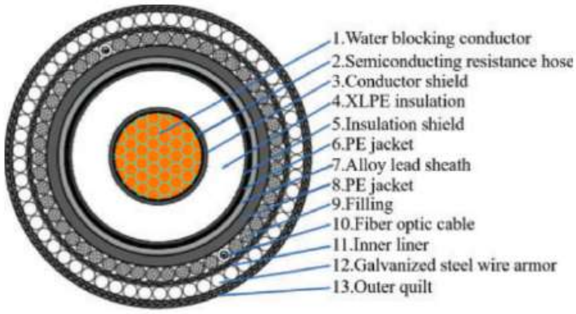
ZHANG et al., 2017). Galvanized steel armor is wrapped around the outside as a mechanical protection against hydrostatic pressure and external disturbances such as ship anchors or friction from seabed rocks (Li et al., 2023). Some submarine cables are also equipped with optical fibers inserted between the cores or in the armor layer for data communication needs and real-time cable monitoring. Depending on the intended application, submarine cables come in various configurations. The two most common are single-core and three-core types, each with unique construction and use cases.



(a)Three-core subsea cable



(b) Single-core Subsea Cable

Figure 3. Structure of Subsea Cable (L. Wang et al., 2023)

The structural differences between three-core and single-core subsea cables. The three-core cable (Figure 3a) is typically used for high-voltage AC transmission and contains three individually insulated conductors bundled within a common armor sheath. In contrast, the single-core cable(TAO ZHANG et al., 2017) (Figure 3b) is often used in DC transmission systems and consists of a single conductor with surrounding insulation and armor (Tao et al., 2024). The structural complexity of three-core cables makes them bulkier and less flexible, but suitable for AC grid integration and redundancy, while single-core cables are more efficient for long-distance, high-capacity transmission with lower reactive power losses (Zamani et al., 2021).

Because power cables generate magnetic fields during operation, understanding their electromagnetic properties is essential for both performance and environmental monitoring. The commonly analyzed cable structure is the single-core AC type, which has five main layers: conductor, XLPE insulation, waterproof protective layer, non-magnetic metal armor, and polymer outer sheath (He et al., 2024). This cable produces a magnetic field due to the electric current flowing through it, and the strength of this field can be detected up to a radius of 1 km in the sea using sensitive sensors such as the Superconducting Quantum Interference Device (SQUID). Therefore, armor material should be selected that is non-ferromagnetic to prevent magnetic field distortion. The ability of the cable to maintain performance in high conductivity seawater is also a design focus, because salt water can accelerate the attenuation of electromagnetic signals.

Aside from dry designs, a newer type of cable known as the wet-design has emerged to simplify construction while addressing specific environmental challenges. The non-impermeable (wet-design) type of submarine cable does not use a metal layer as a waterproof protector, but instead relies on XLPE insulation which is resistant to “water tree” degradation (Ida et al., 2023). This type of cable is easier to manufacture and install, and

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has a lower cost, but poses new challenges in the form of susceptibility to long-term dielectric breakdown due to moisture infiltration into the insulating layer (Ida et al., 2023).

Table 1. Parameters of a Single-Core Subsea Cable (Li & Guo, 2022)

No	Structure	Thickness	Outside Diameter	Material Property	Volume Resistivity
1	Conductor		17.1 mm	Copper	1.7241x10−8 Ω·m
				Semiconducting	<1000 Ω·m
2	Conductive Package	2 x 0.25 mm	17.6 mm	polyethylene (PE)	<1000 Ω·m
3	Conductor shielding	1.5 mm	19.1 mm	Semiconducting PE	
4	Insulation	25 mm	44.1 mm	Cross-Linked	
				Polyethylene	<500 Ω·m
5	Insulative shielding	1.2 mm	45.3 mm	Semiconducting PE	<500 Ω·m
6	Aquiclude layer	2 x 0.5 mm	46.3 mm	Semiconducting PE	2.14x10-7 Ω·m
7	Sheath	3.9 mm	50.2 mm	Lead Alloy	<1000 Ω·m
8	Sheath outer layer	3.4 mm	53.6 mm	Semiconducting PE	-
9	Packing Layer	5.0 ± 0.5 mm	58.6 mm	-	-
10	Optical fiber unit	-	-	-	-
11	Armoring cushion layer	1.5 ± 0.2 mm	60.1	Polypropylene	1.38x10-7 Ω·m
12	Armoring	(66±2)xΦ6.0 mm	66.1 mm	Galvanized SteelWire	-
13	PP outer serving	4.0 ± 0.5 mm	70.1 mm	Polypropylene	1.7241x10-8 Ω·m
14	Armoring	6xΦ6.0 mm	-	Copper	

In addition, there is also a composite photoelectric cable, which is a submarine cable that can transmit electrical power and optical signals (González-Cagigal et al., 2021). This cable consists of 12 physical layers, including copper conductors, XLPE insulation, semiconductive layers, lead sheaths, PE jackets,polypropylene fillers, silica fiber optics, to galvanized steel wire armor and outer jackets (L. Wang et al., 2023). Electromagnetic losses (EM losses) that occur in the metal protective layer and armor directly increase the temperature of the cable, thereby reducing the current carrying capacity or ampacity. Thus, in the design of single-core cables, it is recommended to use armor with high conductivity and low magnetic permeability (Livadariu et al., 2024). The distance between cables also affects the distribution of temperature and magnetic fields. In addition, in a mesh-type submarine cable network, The characteristics of the cable are influenced by the resistance parameters (0.825 mΩ/m), capacitance (0.254 nF/m), and inductance (0.53 μH/m), as well as the topology configuration of the constant current electrical system for long-term marine monitoring (X. Wang et al., 2023). In conclusion, the structural and material characteristics of submarine cables determine not only their durability and conductivity but also their ability to adapt to the harsh and dynamic conditions of the deep sea.

3.6 Fabrication and Manufacture

The manufacturing process of submarine cables is a critical determinant of their operational lifespan and integrity in underwater applications. The manufacturing process of submarine cables is a critical determinant of their operational lifespan and integrity in underwater applications. The submarine cable fabrication process is a critical stage that affects the integrity, efficiency, and service life of the cable for decades in the marine environment (Hae Won, 2025). The fabrication process begins with winding copper wire as a conductor core, then coated gradually using a thermal extrusion process with semiconductive materials and XLPE insulation (L. Wang et al., 2023). This layer must be applied precisely to prevent the formation of voids or gas bubbles that can cause local electrical discharges under high voltage. The lead layer as a water barrier is applied under high pressure using a special extruder, and the polyethylene layer as an outer jacket is added through a thermoplastic extrusion process. For optoelectronic cables, fabrication requires the insertion of silica glass optical fibers into the cable cavity, which is protected from mechanical stress and tension.

The fabrication process for wet-design type cables is simpler because it does not require the installation of an impermeable metal layer, but requires the formulation of insulating materials that are resistant to long-term saturated moisture absorption (Ida et al., 2023). This process was tested through a 30-year operational simulation in a 90-day accelerated test using a high humidity environment. From the system side, although it does not explain the physical fabrication, the cable fabrication process also includes the integration of electrical components such as CCBE (Constant-Current Branch Equipment) and CCVE (Constant-Current to Constant-Voltage Equipment), thus requiring high precision assembly and testing at the system module level (X. Wang et al., 2023). Apart from the physical structure, the choice of materials such as armor also greatly determines the performance of the cable. Galvanized steel armor can be replaced with other metals that have a combination of high conductivity and low permeability to reduce inductive losses (L. Wang et al., 2023).

Submarine cable manufacturing is carried out in large-scale factories with turntable facilities and storage drums with capacities of up to thousands of tons. The manufacturing process includes conductor manufacturing, conductor splicing, XLPE insulation extrusion, degassing, lead coating installation, temporary storage, cable core laying process, armoring, and final storage (Worzyk, 2019). Lay-up is done horizontally for short cables or vertically using large turntables for long cables (up to 40 km). The armoring process uses planetary or rigid movement machines synchronized with the cable pulling speed, and sometimes double armoring (two winding directions) is performed (Li et al., 2023). For corrosion protection, hot bitumen spray can be added before the final sheath is applied. Installation of the lead sheath is carried out with a Hansson-Robertson extruder that allows continuous production of up to 50 km without joints (X. Wang et al., 2023).

The manufacturing process involves the implementation and design of an optimal power supply system. The cable and network design is prepared using the Invasive Weed Optimization (IWO) algorithm that considers the number of nodes, the probability of failure, and the reliability of the subsea monitoring unit (X. Wang et al., 2023). Thus, submarine cable manufacturing involves not only material production techniques, but also systemic aspects, such as power distribution redundancy, cost control, and system reliability calculations. In this case, manufacturing becomes an integral part of the design process of a comprehensive and sustainable marine electrical system.

3.7 Advantages and Disadvantages of Fiber Optic Cables

Using fiber optic has several advantages and disadvantages. Among the advantages is having a very large data transmission capacity because this cable can transmit large amounts of data effectively, cannot be affected by electromagnetic and radio frequency, not easily flammable (Puti 2023), can transmit data from a distance because it has a small size and is also slim so it can save space, will not cause an electrical short circuit because it has a main material of glass fiber and does not involve an electric current, has a very good signal and will not be affected by the weather, has a stable and fast speed (Telkomsel 2022). In addition to having advantages, using fiber optics also has disadvantages. Fiber optics have a relatively expensive price (Arkadiantika et al. 2020), this type of cable is susceptible to damage if bent or bent at a sharp angle (Max Ki. 2024).

3.8 Fiber Optic Cable Maintenance

An underwater communication system using cables buried in the seabed to connect communications between islands and countries (Yoggi 2019). This cable is a cable that is placed on the seabed, the installation process of which uses special ships that have been modified so that they can reach the seabed (Dan Swinhoe 2021). Due to its location on the seabed, routine maintenance and repairs are essential to ensure that the fiber optic cable does not experience interference which will later affect the cable's performance. Optical fiber is well known for its ability to transmit information with large capacity and high speed. Inaccuracy in the transferred data can occur due to damage in the Fiber Optic communication network (Imansyah et al. 2025), The presence of attenuation is also highly avoided because it will cause the optical fiber to lose power, which can then slow down data transmission and cause the quality of the internet produced to decrease (Nurul & Irwanto 2024). Fiber optic cable maintenance is useful to ensure optimal cable performance, long-term cable service life without having to be replaced frequently, reducing repair costs (Dian 2024). How to care for it by reducing contaminated cables (Fiberplus 2022), installing cables properly such as the specified paths and routes must be appropriate, avoiding excessive pressure and also chemicals, carrying out routine checks and maintenance, not carelessly rolling up cables, avoiding radiation exposure, and the most important thing is if you experience a slight disturbance, immediately make repairs so that later it does not cause major damage.

4. CONCLUSION

Submarine cables serve as the backbone of global digital infrastructure, supporting over 99% of international communications, including internet connectivity, telecommunication services, and transcontinental power transmission. Based on the literature review, submarine cable systems have demonstrated significant technological advancements in materials, structural design, signal transmission mechanisms, as well as maintenance strategies and environmental mitigation. Technologically, the implementation of DWDM systems, optical repeaters such as EDFA and Raman amplifiers, and the use of materials like XLPE and galvanized steel have enhanced the reliability of data and power transmission under extreme subsea conditions. The comparison between three-core and single-core cables highlights their specialized functions in AC and DC transmission systems respectively. Additionally, the precision and standardization in the manufacturing process are crucial in ensuring the durability and service life of these cables over several decades.

For archipelagic countries like Indonesia, submarine cables play a vital role in overcoming regional isolation and strengthening inter-island connectivity. However, geographical challenges, physical damage risks, and geopolitical issues remain key considerations in the planning and management of this infrastructure. Therefore, the development of submarine cable networks must holistically address technical, economic, security, and environmental sustainability aspects. With ongoing technological progress, submarine cables are expected to remain an irreplaceable component of global communications infrastructure while offering new research opportunities in subsea sensing, smart cable systems, and real-time geophysical monitoring.

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