The floaters for submarine-cable landing and its engineering applications

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Abstract. The floater can be employed to provide additional buoyancy to the submarine cable during its landing to ensure its routing and connection with the onshore connectors. With the update of the voltage-class of the submarine cable, to ensure the efficiency and quality of the landing operations, the floater has been changed from the traditional waste tires to the new types of pre-fabricated floaters. In this paper, the characteristics of different floaters will be introduced and compared with the engineering applications. The development trends of the floaters for submarine-cable landing are proposed.

1. Introduction
The application of submarine cables has lasted for over one hundred years. In the early period, the cables were mostly used to transmit the electricity to the nearshore devices, such as the beacons [1]. As the technologies were developed, the submarine cables were employed for the power supply to the islands. With the successes in the high-capacity cables, it has been used to connect the national grids between different countries. Recently, the offshore wind farms and the ocean renewable energy became the hot spots in ocean developments. The submarine cables should transmit the green electricity to the onshore substations [2, 3, and 4]. In the last forty years, the manufacturing technologies, the laying technologies, and the laying vessel construction technologies of the submarine cables have been developed rapidly [5]. In the meantime, the floaters for cable landing also made a fast development, and various types of floaters have been proposed and manufactured for engineering applications.

Although the floater for cable landing has become more professional and specialized, it still faces some problems because of the increase in the cable-landing difficulties caused by the enhancement of the length and the unit quality of the submarine cable and the change from the shallow water with the flat seabed to the deep water with complicated bathymetries. Therefore, a reasonable choice of existing floaters or a new design of the floater will be a hard challenge to solve all possible problems during
cable landing in the future. In this paper, it is first to summarize the development of the floater for cable landing, and some trends will be predicted and proposed for reference.

2. Key characteristics and operation mode of the floater

2.1. Key characteristics
Although different new-type floaters have been designed and developed, there are two common key characteristics among them:

1. Material. The material is one of the most important indicators for the normal us-age of the floaters. Currently, almost all the new-type floaters use the high-strength PVC coated fabric material, which has excellent abrasive resistance, anti-ultraviolet performance, and puncture resistance. The floater made of this material could be employed in severe sea conditions and used repeatedly.

2. Tying. As the floaters should guarantee a limited submerged depth of the submarine cable during its landing, they should be fixed with cable along its length by tying with the ropes. First, the typing should be intense, which ensures the individual floaters not to gather under the actions of the winds, currents, and waves. On the other hand, the typing ropes should be released easily for the cable laying down to the seabed following the routing accurately, and the floaters are easy to be recovered from the engineering site.

2.2. Operation mode
The cable-laying operation can be divided into three parts: the initial end landing, the middle part laying, and the tail end landing [6]. During the landing of two ends, the water depth becomes smaller as the shoal changes to the shoreline. The cable-laying vessels cannot operate in shallow water with very limited depth. Furthermore, the pulling operation of the submarine cable over the seabed may cause unpredictable damages to the cable because of the seabed frictions. Therefore, during the cable landing in the shallow water, the cable should be floating around the sea surface using the floater to provide additional buoyancy [7]. The winch on the shore could pull the hauling rope with the cable head to the shore; as the different sections of the cable arrive at the shore, the floaters could be removed rapidly. Finally, as all the floaters were removed, the submarine cable could lay down on the seabed following the pre-designed routing. All the floaters could be pulled back to the shore using another hauling rope to realize the floater recovery [8]. In the former operations, the engineers always applied the waste tires to provide additional buoyancy. As the relative technologies have been developed, the gasbag floaters have re-placed the cumbersome tires to enhance the cable laying efficiency.

3. Typical types of the floater and the engineering applications

3.1. Abroad types and engineering applications
In the 1980s, a barge was first launched using the airbags. At present, the airbag products have been active in ship launching, caisson floating transportation and underwater salvaging. Currently, the new-type floaters have many advantages, such as low cost, less resource requirement, short operation period, reusage, et al… These floaters have been widely used for laying operations of the high-voltage and large cross-sectional cables. The abroad technologies on the floaters have been mature, and the waste tires for cable landing used one hundred years ago have been eliminated. The present floaters could be divided into different types based on their shapes. The inflation and deflation of the airbags could realize the buoyancy change and cable support [9, 10].

3.1.1. Empty barrel in the early stage. In 1950, the electricity transmission line between the mainland and the Gotland is-land was constructed. The total length of the transmission line was 96 km, and it was the first high-voltage direct-current submarine line in the world. During the cable landing, the empty barrels were used for floating support, as shown in Figure 1 [11].
3.1.2. Parachute airbags. The parachute has a drop-shaped design as a large floater, as shown in Figure 2, which was mainly used in underwater salvaging and could also be used for cable laying. Its single-point design is suitable for buoyancy supporting to the light tube, and its open design of the bottom is safer for relative operations. The parachute air-bags produced by the Unique Group Company can change the buoyancy by adjusting the inflation discharge. Some pressure reducing valves installed on the airbag can deflate the air at the flow rate of 2 m$^3$/min [12].

3.1.3. Single sealed barrel. The single sealed barrel utilizes a single cylinder barrel design, which is suitable for the cable laying, the buoyancy support for the bridge and platform, and sunken salvaging. The single sealed barrel has a simple structure, which can be considered as a perfect cable supporting device. The single sealed barrel can be fixed on the floating structures by a single-point connection. Compared to the multi-point connection, it needs less fabrication time. Figure 3 presents the tube landing operation with the assistance of the single sealed barrels [13].

3.1.4. Double inflated pillow-airbags (DIPA). The DIPAs use two pillow-shaped airbags connected by a supporting slice with the lock on the airbag bottom and the heavy-duty fabric fixed with the cable. The floater has the overpressure valve, the ball valve, and the locking device. The weight of a single floater is relatively larger, which can be applied for the buoyancy support for laying the cables with large cross-section areas or the tubes. In the KIKLADDES project of Greek, the Nexans engineering company participated in the routing survey, cable design, manufacturing, and laying of the 150 kV submarine cable. The cable length is 108 km, and the maximum water depth is 300 m. The cable-laying vessel Nexans Skagerrak conducted the cable laying operation, and the DIPAs were used for buoyancy support during the cable landing process, as shown in Figure 4 [14]. In the grid connection project between Ras Laffan and Halul Island in Qatar, the Jan De Nul Company used the DIPAs during the cable landing for the 132 kV cable with a length of 101 km, as shown in Figure 5 [15].

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Figure 1. Empty barrels for cable floating.

Figure 2. Parachute airbag.

Figure 3. Single sealed barrel.
3.1.5. Single-point floating ball (SPFB). The SPFB is a sealed spherical floater, which only has a hoisting point and can endure some swaying. The design concept of this floater is similar to that of the para-chute floater. Each floating ball has a pressure releasing valve and an inflation/deflation ball valve. The size of the floating ball is relatively small, which is mainly used for the lighter cables. If the cable needs larger buoyancy, the parachute floater is preferred. In the project of the cable laying project between Sicily and Tunisia, the Global Marine Company used the SPFB to provide additional buoyancy during the cable landing, as shown in Figure 6 [16]. In November 2014, the OUOCI union also used the SPFB to assist the cable landing in the project of Chocolate-Margarita submarine cable for Venezuela, as shown in Figure 7 [17].

3.1.6. Double inflated floating barrel (DIFB). The DIFB can be employed in the cable landing and the installation of the submarine tube. The airbag of the DIFB consists of two individual operating floating barrels. The maximum buoyancy is 600 kg. The cable or the tube could be put on the sup-porting slice and be stuck between two airbags. The ropes on the barrels can be used to fix the DIFBs on the cable, as shown in Figure 8 [18].

3.1.7. Floating tube. The floating tube can be considered as an individual and continuous inflated air tube. The tube has no limits on the diameter and the length, which can be fixed based on the project demands. The floating tube can be employed in cable laying, sunk ship salvaging, and caisson transportation. The ropes can fix the floating tube and the cable together. As the cable arrives at the desired routing, the ropes can be re-leased by continuously inflating the airbags to snap the ropes. Subsequently, the cable sinks down to the seabed following the routing. In the cable laying project between the Channel Islands Guernsey and Jersey, the Dutch company VDS Cable bv used the floating tube for cable landing, as shown in Figure 9 [19].

For the above introductions, there are all kinds of floaters to provide additional buoyancy during cable landing. Under different landing environments, the floaters can be used for different cross-section areas and weights of the submarine cables. Generally, the floaters can enhance the stability and safety of the cable landing operation with advanced technologies.
3.2. Domestic types and engineering applications

In the domestic projects for cable landing, it has been a long time to use abroad technologies directly or employ the backward plastic foam or the waste tires. For the application of waste tires, the cable should be tied many times to be fixed with the tires. In addition, the foam and the tires are hard to be removed, which significantly restricts the operation efficiency of the cable landing process.

In 2009, the Hainan 500 kV grid connection project used cables with a length of 32 km. During cable landing, the Nexans engineering company employed the DIPAs to provide additional buoyancy, as shown in Figure 10 [20]. In 2015, the 110 kV/AC electricity transmission line project had cables with a length of 38 km from Daishan Island of Zhoushan City to Yangshan Island of Shengsi County. During the cable landing process, the submarine cable was pulled out from the cable-laying vessel “Jianlan 1” and lay down into the seawater with the traditional inflation tires as the buoyancy provider, as shown in Figure 11 [21].

In 2016, the cable landing site of the 110 kV submarine cable project for Hailing Island, Yangjiang City, Guangdong Province, was the estuary. The riverway and estuary are all the shoal, and the cable landing is difficult. The project engineers also used the inflated tires as the floaters, as shown in Figure 12 [22]. In 2019, the 500 kV cross-linked polyethylene insulated submarine cable for Zhoushan city islands on the Dapeng Island, also employing the traditional inflated tires as the floater, as shown in Figure 13 [23].
In 2020, the Zhoushan power supply company of State Grid Corporation of China developed a new-type floater, which can be used for now. The new floaters are made of high-strength PVC coated fabric material with inflation and deflation valves, an automatic releasing device, and tying ropes. The floater has the shape of a flat pillow, and the cable is stuck between to airbags and sit on the supporting slice. The electromagnetic lock forces the ropes and the airbags to clamp the cable. As the cable is pulled to the shore, the engineers could release the lock remotely, and the floaters and the cable are separated. These new floaters will be used for cable laying in the construction of the offshore Wind farms [24].

4. Development trends of the new floater

With the wide applications of submarine cables with high-voltage classes and large cross-section areas, the demands to the floaters become higher and higher. As the innovations of the cable laying technologies have proceeded, some new development trends of the floaters are proposed as the following.

4.1. Automatic trend
Most present floaters should be tied and released artificially, and the automatic level is low. The operation efficiency still has a big space for improvement. In the future design, some automatic technologies should be developed, such as the fast inflation and deflation technology, automatic lock releasing technology, and automatic positioning technology. By remoting control through the computer and realizing these technologies practically, the manpower and material resources will be saved significantly and the operation efficiency will be enhanced.

4.2. Intelligent trend
In the former projects for cable landing, the intervals between the floaters were evaluated roughly, and the errors were always large. If the interval were too small, the number of the floaters would be large,
and it would waste more human resources and reduce the operation efficiency. On the other hand, if the interval was too big, the number of floaters would be small, and the submerged depth of the cable would be too large. Therefore, calculating software to calculate the number of the floaters, and the inflation air volume will be very helpful to the application of the floaters during cable landing.

4.3. Light trend
The design of large cross-section areas and weights per length will cause the floaters larger and larger. The weights of present floaters will increase as their volume increases, which will induce more practical engineering difficulties. Therefore, some new light material should ensure a smaller weight of the floater and enough buoyancy to be provided.

4.4. Environment-friendly trend
The present floaters are mostly made of PVC materials, which cannot be degraded and have a pollution risk to ocean environments. Therefore, the development of new, environment-friendly materials or the improvement of the PVC material will be necessary.

5. Conclusions
With the development of ocean exploration and utilization, the demands for submarine cables will be greater and greater. As the key elements of the cable landing process, the floaters will play a key role in the practical applications. In this paper, different types of floaters and their engineering applications were summarized. The automatic, intelligent, light, and environment-friendly trends are proposed for the future development of the floaters for the service of cable landing.

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