An overview of the vessels for electrical submarine cable laying

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Abstract. The cable laying vessel is a key factor for the submarine laying routing, installation, and layout. The loading and laying capabilities of a submarine cable vessel always determine the speed and costs of corresponding cable construction engineering, which will significantly affect the electricity transmission of the islands, wind farms, and other offshore energy engineering. Therefore, an overview on the recent development of domestic and international cable laying vessels and related construction equipment is conducted with the summarizations of the development trends. Furthermore, a perspective of the cable laying vessels in the future is also proposed.

1. Introduction

The recent rapid developments of the island economics, offshore wind farms, marine renewable energies, and the smart offshore grid proposed a new demand for marine electricity transmission [1]. Currently, as the most widely used marine electricity transmission equipment, the utilization of the submarine cable has last for over one hundred years. The cables are laid on the seabed for electricity carrying and transmission [2, 3, and 4]. In the last forty years, with the domestic and international developments of the electricity transmission and transformation, the manufacturing and processing technologies, the construction technologies, the laying vessel construction technologies, and the long-distance power transmission technologies of the submarine cable have also been improved significantly. Furthermore, as the key factor for submarine cable engineering, the cable-laying vessel also has been developed rapidly. The maritime powers have their own cable-laying vessels, which can satisfy the demands for laying and constructing different kinds of submarine cables under various marine environmental conditions.

Although the technologies of the cable laying with the professional vessels have been developed for over several decades, the difficulty of the submarine cable laying operation still exists. A series of the
cable properties and the vessel selection should be considered carefully for the operations and constructions. For instance, the selection of the vessel should be based on the cable loading capacity, the maneuverability, the specialized laying equipment, the available space on the deck, and other conditions. A detailed construction plan, including the selection of the cable-laying vessel, could significantly reduce the construction period, ensure the construction quality, and enhance the overall safety [5]. In this study, the state-of-art of the domestic and international cable-laying vessels are summarized, and the future trends of this type of specialized ship are also proposed.

2. Brief history of the submarine cable laying vessels and equipment

The cable-laying vessel (CLV) was developed with the submarine cable, which can be divided into three stages: 1) the first stage for the submarine telegraph cable before the 1950s; the second stage for the coaxial cable from 1950s to the middle of 1980s; the third stage for the optical and photoelectric composite cables since 1980s to this day. The CLV can be classified as the CLV for the submarine telegraph cable and the CLV for the submarine electricity cable. Compared to the CLV for the telegraph cable, the CLV for the electricity cable started later and developed more slowly.

In August 1850, the world’s first submarine telegraph cable was laid down in the Strait of Dover by the United Kingdom and France. The construction ships at that time were mostly refitted from the merchant ships, which are lack of the specialized equipment for cable laying. The operation water depth is limited, and most vessels could only work in the shallow water. In the 1960s and 1970s, the trans-oceanic submarine cable constructions began to appear in Europe and North America. As the construction demand for the coaxial cables is high, the professional and specialized cable-laying vessels came into being. In the 1980s, the variable pitch and the side thruster enhanced the vessel maneuverability, resulting in an improvement of the cable-laying technologies. At the end of the 1980s, the massive development of the submarine cables promoted the rapid emerging of more large-tonnage CLVs. At the beginning of the 1990s, the professional 10, 000 ton CLV has emerged in the cable laying field.

In the 21st century, more and more specialized equipment has been installed on the modern CLV, including the dynamic positioning (DP) system, the cable laying machinery, and other automatic controlling and measuring systems. The advanced DP system, the new mode for cable-laying at the stern gate, automatic cable-laying machinery, and the residue controlling system based on the internet of things form the basic elements and characteristics of a modern CLV.

The DP system is an automatic ship maneuvering system controlled by computers. As the accurate positioning, meteorological, tidal current velocity, and other data are gathered, the computer could control the DP system to adjust the thrusts of different thruster (the propeller, the lateral thruster, and the steering engine) automatically and realize the accurate dynamic positioning. The DP system could be classified into three levels: DP-1 level should contain at least one DP system, and could maintain the position and heading of the ship automatically; DP-2 level should contain two individual DP systems, which can operate individually despite the state of the other one; DP-3 level should have at least three DP systems and other additional demands, which could realize the advanced dynamic positioning, record the transient longitude and latitude, and control the vessel speed effectively. The improvement in the vessel maneuverability promoted the revolution of the deck operation mode. The cable laying and burying operations could be conducted at the stern, which saves much space on the deck and influences the general space planning of the CLV to enhance the operational efficiency of the CLV.

The cable-laying machine (CLM) is an important indicator of the modern CLV, which is specialized equipment for the submarine cables. The CLM has two types: the linear-type CLM and the drum-type CLM. The two types of CLM have their own advantages. The drum type CLM occupies less space on the deck with a larger tension and a stable operation state. The linear type CLM is suitable for the long-distance operation and occupies more space with a smaller tension. In addition, the CLM should operate under the automatic tension controlling mode or the laying speed controlling mode. For the latter mode, the length residue of the cable should be considered. The length residue is not only related to the total length of the cable but also to the routing length. As the cable is laid by the CLM, the routing is
simultaneously covered by the movement of the CLV. The synchronization and coordination between
the vessel speed and the cable-laying speed should be controlled and realized by the computer system.

3. Current status of the CLVs

3.1. Domestic status
In China, the domestic submarine cable engineering started relatively later, and the corresponding
technologies are relatively backward. The number of independently built CLVs is less. Furthermore, the
cable loading and laying capabilities of domestic CLVs still have a remarkable gap with the overseas
developed countries, which restrict the operational efficiencies of the submarine cable engineering [6].
Because of the CLV tonnage, the submarine cable engineering was carried out in the nearshore shallow
water. The positioning system is mainly composed of anchors and mooring lines, and the CLM is the
traditional cable burying machine, which cannot satisfy the rising demands of the submarine cables.

The first domestic CLV is called “Youdian 1”, as shown in Figure 1. It was designed and built in
1976 based on the agreement for the construction of the submarine cables between China and Japan.
The length and width of the vessel were 71.4 m and 10.5 m, respectively. Its displacement was 1300
tons, and the cruising speed was 14 knots. The maximum cable loading capacity was 400 tons. Youdian 1 had a special V-type outside cross-section shape to obtain good stability and increase its thrust
efficiency. The linear-type and drum-type CLM and the pulling winch for the cable burying machine.
The CLV went into service in May 1976 and finished the cable laying tasks.

Figure 1. “Youdian 1” CLV.

“Jianlan 1” CLV is the main vessel belonged to Zhejiang Zhoushan Qiming Electricity Company,
which could bury the submarine cable deeply. It went into service in June 2010, as shown in Figure 2.
Jianlan 1 has accomplished the tasks of burying the cable deeply for the Jiangmen 110 kV project of the
China Southern Power Grid Company, Zhoushan-Sijiao 110 kV grid connection project, the Daqu
expansion project for the 110 kV transformer substation, and the Huangze Mountain 110 kV project.
The CLV was an unpowered flat bottom barge, which used the anchors and mooring lines for positioning
and was suitable for the operations in the shallow waters [6]. The Qiming Company upgraded Jianlan 1
by installing a turnplate with a diameter of 18.0 m. The turnplate has a loading capacity of 2000 tons
and could release the cable by 0 - 18.0 m/min under the infinitely variable speed mode, which increases
the safety and efficiency of cable-laying operations. In addition, the monitoring system has also been
upgraded, and the electricity power configuration is more reasonable.

“Zhoudian 7” CLV was independently designed and built in 2011, which is suitable for offshore
operations, as shown in Figure 3. The CLV contains the dynamic positioning function, which can be
employed for cable laying, salvaging, and burying. Zhoudian 7 was developed by the Zhoushan
electricity bureau and the Navy communication and application institute jointly, with a length of 75 m,
a draft of 3.5 m, the full load displacement of 3000 tons, and the anti-wind capacity of level 8. The CLV can bury the cable into the ground with a depth of 3.5 m. Furthermore, Zhoudian 7 equipped the DP, side thrust, back twist, and burying systems. The longest laying distance is 30.0 km.

“Qifan 9” can be considered as the most advanced CLV in China, as shown in Figure 4, which was built in August 2018. It is the first 5000 ton CLV serving the 500 kV Zhoushan electricity connection project. Qifan 9 has a length of 110 m, the molded breadth of 32 m, a molded depth of 6.5 m, a maximum draft of 4.8 m, and a maximum displacement of 14,300 tons. This CLV equipped the eight-spot anchoring and mooring system, the single-point traction system, the DP system, and the shipboard purification room. The cable loading capacity is 5000 tons, which is the most of domestic. It also means that the longest laying distance of 30 km for the submarine cables at the voltage class of 220 kV could be doubled to 60 km. Furthermore, Qifan 9 can operate at different serve sea conditions, including complicated tidal stream conditions and higher levels of anti-wind.

Although the domestic CLVs were developed rapidly, the number of CLVs is still small, and the tonnages are also relatively small. The cable loading and laying capabilities and the operation efficiency have a big gap with the abroad advanced CLVs. Moreover, the number of domestic submarine cable laying projects is also relatively small, and these projects were also conducted in the nearshore shallow waters. Therefore, the independent development capacity on the large-tonnage CLV should be improved to satisfy the demands for high voltage-class cable laying projects under more complicated conditions.
3.2. International status
The abroad submarine cable projects started early, and the CLV with advanced technologies were designed to satisfy most marine environmental conditions. The cable loading and laying capabilities of abroad CLVs ran ahead of the domestic ones with more field operation experience accumulations, especially at the long-distance constructions of the submarine cables. In addition, their operation covers the shallow and deep waters, which means there is no limit for the abroad CLVs in the water depth. The cable loading capacity is the core capacity for a CLV, and some typical CLVs will be introduced in detail as the following.

Nexans Skaggerak was built in 1976, as shown in Figure 5, which belonged to Nexans engineering company. This CLV has a cable loading capacity of 7,000 tons. The vessel length is 118.25 m, and the molded breadth is 32.15 m [10]. Nexans Skaggerak utilized the jet flow to pave the grooves, which provided some new ideas for the submarine cable construction. Meanwhile, Nexans Skaggerak equipped the most advanced global positioning system at that time and several cranes. It has participated in many submarine cable projects between Norway and Netherland with a total length of 576 km. The Global Marine Systems engineering company built Bold Endurance in 1979, as shown in Figure 6. Its cable loading capacity is 5450 tons with a length of 139 m, a width of 20 m, and a draft of 5.8 m. The cruising speed is 6.3 knots [12].

![Figure 5. Nexans Skaggerak.](image)

![Figure 6. Bold Endurance.](image)

Deep Constructor was built in 1980, as shown in Figure 7, belonging to the Technip engineering company. It has a length of 126 m and a molded breadth of 25.0 m with a loading capacity of 2000 tons, which could be employed for deep-water tube construction and cable-laying [18]. After it was built, Deep constructor has experienced several modifications to adapt to the changes in the construction demands. Guilio Verne was built in 1983, as shown in Figure 8, belonging to the Pirelli and Prysmian engineering company. It has a length of 133.2 m, a molded breadth of 30.5 m, and the draft of 7.7 m.
with a loading capacity of 7000 tons [9]. This CLV equipped a DP-2 system, capable of conducting the most challenging underwater operations. The maximum operating water depth of Giulio Verne is 1600 m. It had advanced air injection and other types of trenching machines and could lay and bury the submarine cable simultaneously with a maximum burying depth of 3.0 m.

Discoverer Barge belongs to the Subocean Group engineering company, which was built in 1985, as shown in Figure 9. It has a length of 91.0 m, a molded breadth of 30.0 m, and a draft of 6.1 m with a loading capacity of 5500 tons [11]. Team Oman was built in 1999, as shown in Figure 10, belonging to the TEAM-Nico engineering company. It has a length of 86.1 m, a molded breadth of 24.0 m, and a draft of 4.8 m with a loading capacity of 4800 tons [13]. Deep Blue is a construction ship for cable and tube laying on the seabed, as shown in Figure 11, which was built in MIPO shipyard located at Ulsan, South Korea in 2001. It belongs to the Technip engineering company, having a length of 207 m and a molded breadth of 32 m with a loading capacity of 2800 tons. Seven Oceans was built in 2007, as shown in Figure 12, belonging to the Subsea engineering company. It has a length of 157.3 m and a molded breadth of 28.4 m with a loading capacity of 3500 tons [16]. The ship complement is 120 personnel. Seven Oceans equipped six diesel engines with a rated power of 3360 kW.

![Figure 9. Discoverer Barge.](image)

![Figure 10. Team Oman.](image)

![Figure 11. Deep Blue.](image)

![Figure 12. Seven Oceans.](image)

Atalanti was built in 2008, as shown in Figure 13, belonging to the Assodivers engineering company. It has a length of 97 m and a molded breadth of 31 m [15]. Atalanti has a loading capacity of 4500 tons as the maximum draft of 4.26 m is obtained. This CLV has equipped the DP system, which was designed especially for the cable laying in the shallow waters. Since 2008, it has participated in many projects, such as Sy1Win1, HelWin2, Cyclades, Western HVDC Link, Veja Mate, et al. For instance, Atalanti laid and buried a submarine cable with a length of 30 km and a burying depth of 1.55 m.
In 2009, the Oceanteam Power and Umbilical engineering company built the CLV “North Ocean 102”, as shown in Figure 14. It has a length of 137 m, a molded breadth of 27 m, and a draft of 6.8 m with a loading capacity of 7000 tons and a cruising speed of 12.3 knots [8]. North Ocean 102 has the DP system and vertical cable-laying system. The operation water depth covers the range from 10 m to 3000 m. In the same year, the Technip engineering company built a new CLV “Apache 2”, as shown in Figure 15. Actually, Apache 2 is a tube laying ship, which is also capable of laying the cables. It has a length of 138 m and a molded breadth of 27 m with a loading capacity of 2000 tons [19].

In 2010, a CLV called “Stemat Spirit” was built by the VSMC Company, as shown in Figure 16. It has a length of 90 m and a molded breadth of 28 m with a loading capacity of 2000 tons and a cruising speed of 9 knots [14]. The CLV equipped the DP system with a six-point mooring system. The advantage of Stemat Spirit is that it can lay the cable onshore. The new trenching technology, “Hi-plough”, can
assist the CLV to bury the cable deeper. Stemat Spirit has participated in several offshore wind farm projects, such as the cable-laying task of the Walney project.

The largest CLV in the world, “Lewek Connector,” as shown in Figure 17, can operate in the ocean under the depth of 4000 m. This CLV was built in 2011 and had two turnplates and a loading of 9000 tons. Lewek Connector equipped two cranes with the lift capabilities of 400 tons and 100 tons and two work-class remotely operated vehicles (WROV). The CLV has participated in the offshore wind farm project Hornsea Project One for 130 days.

![Figure 17. Lewek Connector.](image)

In 2011, the Acergy Company built the CLV “Polar Queen,” as shown in Figure 18. It has a length of 111 m and a molded breadth of 20 m with a loading capacity of 1600 tons [20]. Polar Queen is a multifunctional ship, which can operate in severe sea conditions. Ndurance was built in 2013, as shown in Figure 19, belonging to the Boskalis Company. It has a length of 99 m and a molded breadth of 30 m with a loading capacity of 5000 tons and a cruising speed of 11.5 knots. This CLV equipped the diesel and electric engines and had a newly designed turnplate. The ship installed a DP system and used the six-point mooring system.

![Figure 18. Polar Queen.](image) ![Figure 19. Ndurance.](image)

In 2013, the Technip Company built the CLV “Deep Energy,” as shown in Figure 20. It has a length of 195 m and a molded breadth of 31 m with a loading capacity of 1600 tons and a cruising speed of 19.5 knots [17]. Deep Energy is one of the most advanced CLV in the world, which is suitable for all kinds of water depths with a larger speed and strong mobility. In 2015, the Jan DeNul Company built the CLV “Isaac Newton,” as shown in Figure 21, which has the largest cable loading capacity. It has a length of 138 m and a molded breadth of 32 m with the loading capacity of 7400 tons and the rated
power of 12 MW supplied by the MAN diesel engines [7]. Isaac Newton was designed especially for the offshore wind farm, which has participated in the UK’s Race Bank project with a cable length of 148 km. It also took charge in the submarine cable laying between Crete Island and Peloponissos, Greek, with a water depth of 980 m.

Except for the aforementioned CLVs, there are several large CLVs under construction. For instance, the largest CLV in the world, “Leonardo da Vinci,” as shown in Figure 22, will be finished in 2021. Its maximum cable loading capacity will be 10,000 tons, and it could lay the cable in the water depth of 3000 m and will participate in the cable laying project between the UK and Denmark. Except for the direction of the large-scale development, environment-protection and energy-saving are also important directions. The Dutch maritime company Van Oord is constructing a new environment-protection CLV, as shown in Figure 23, which will be finished in 2023. It has a length of 130 m and a molded breadth of 28 m with a loading capacity of 8000 tons. This CLV is a hybrid power ship using the biomass fuel and will equip the intelligent cable-laying control system and the DP-2 system [21].

From the aforementioned introductions, it can be seen that the abroad CLVs have a larger loading capacity, and most of the CLVs could afford the cables exceeding 3000 tons. These CLVs are suitable for ocean waters with different depths. The laying equipment and control systems are advanced to enhance the laying efficiency. The plane back-twist on the turnplate is the most popular mode, which is suitable for a smoothing cable easing out and realize the full back-twist.

4. Development trends of the CLVs
With the utilization of the high voltage-class and big cross-section submarine cables and the emergence of the submarine electricity and communication composite cable, the demands for long-distance operation with a large cable loading capacity have been proposed to the CLVs. Meanwhile, with massive
utilization of modern information technologies, automatic control technologies, and big data technologies, for the new developed CLVs, a large cable loading capacity, the modular technology, the capacity to operate on complicated bathymetries, multifunction, and environment protection will be the trends in the future [6, 22, 23].

With the development of grid connections across sea areas, the lengths of the submarine cables keep increasing. To improve the laying efficiency, the demands for a larger cable loading capacity will be greater. For instance, the CLV “Leonardo da Vinci” developed by the Prysmian Group will come into service using two turnplates with the load capacity of 10,000 tons and 7000 tons.

Modularization is an important design direction for present engineering ships. By using the modular technologies, the operation period will be reduced through the rapid change of the modules. In addition, according to different subjects, the functions of the CLVs could be modified using various modules, which will expand the operation range of the ships.

For the former cable-laying projects in the shallow waters, the soil in the shallow surface layers was soft. The cables were not buried or were buried shallowly, which were easy to be damaged by the anchors or the marine organism. As the demands of reliability and safety were increased, the deep-burying technology in the hard seabed will be a problem to be solved in the future.

Currently, the CLVs, which only have a single function, cannot satisfy the present demands of the cable-laying. False inspection and repairing of old submarine cables, the sweeping survey of the seabed, underwater operations, and salvaging have become some of the functions of the advanced CLVs. For instance, Lewek Connector has a large deck area and crane covering area, which can be used to construct the inspection and repairing platform. The equipped WROV can assist the accurate cable laying operations.

Considering the depletion of fossil fuel and the protection of the ocean environment, the future CLVs should be more environmentally friendly and reduce any possible pollutions in the ocean. For instance, the CLV developed by the Van Oord Company will utilize biomass fuel for hybrid power to reduce carbon dioxide emissions.

5. Conclusions
With the rapid development of the ocean, the demands for submarine cables are growing day by day. The CLVs acting as the main tool to lay submarine cables is playing a key role in the relative human activities. In this study, a brief history of the CLV was summarized, and the current status of the domestic and international CLVs was reviewed. Based on the development trends, the design directions of the CLV in the future were also proposed.

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