

## ANALYSIS OF THE INFLUENCE OF DIFFERENT INSTALLATION CONDITIONS ON AMPACITY OF HVDC SUBMARINE POWER CABLES BY USING CYMCAP SOFTWARE

### PHÂN TÍCH ẢNH HƯỞNG ĐỐI VỚI KHẢ NĂNG MANG TẢI CỦA CÁP NGẦM BIỂN HVDC THEO ĐIỀU KIỆN LẮP ĐẶT KHÁC NHAU SỬ DỤNG PHẦN MỀM CYMCAP

Kim Long Huynh, Van Phu Duong<sup>1</sup>,  
Quang Thuc Vo<sup>2</sup>, Thanh Long Duong<sup>3</sup>, Dang Toan Nguyen<sup>4</sup>

<sup>1</sup>Power Engineering Consulting Joint Stock Company 4, <sup>2</sup>Industrial University of Ho Chi Minh Chi city,

<sup>3</sup>Power System Technological Solutions Limited Company – CYME Software Distributor,

<sup>4</sup>Electric Power University

Ngày nhận bài: 16/2/2023, Ngày chấp nhận đăng: 26/5/2023, Phản biện: TS. Tống Văn Luyện

#### Abstract:

The high voltage direct current (HVDC) using submarine power cables is the optimal solution that carries out the offshore wind source into onshore power systems because of its advantages such as greater stability and less power loss than the high voltage alternating current (HVAC). Currently, there are no guide standards for calculating the ampacity of HVDC submarine power cables according to installation conditions subsea regard to topography, geology, temperature difference ...etc in the world, the factors that affect to continued rating current of HVDC submarine power cables. The paper analyses the influence of installation conditions on the ampacity of HVDC submarine cables by using CYMCAP software. The simulation results indicate the influence of installation conditions on the ampacity of HVDC submarine cables in different scenarios and applications for HVDC submarine projects in the future.

#### Keywords:

HVDC submarine power cables, Ampacity, CYMCAP, Temperature rise.

#### Tóm tắt:

Cáp ngầm dưới biển một chiều cao áp (HVDC) là một lựa chọn để kết nối và truyền tải các nguồn điện gió ngoài khơi vào hệ thống điện chính trong đất liền vì ưu điểm như có tính ổn định cao cũng như mức tổn thất thấp so với hệ thống truyền tải xoay chiều (HVAC). Nhưng hiện nay thế giới vẫn chưa có tiêu chuẩn hướng dẫn tính toán khả năng mang tải của cáp ngầm HVDC vượt biển theo các điều kiện lắp đặt khác nhau về mặt địa hình, địa chất đáy biển, chênh lệch nhiệt độ... Những yếu tố này có ảnh hưởng trực tiếp, làm thay đổi khả năng mang tải của cáp ngầm HVDC. Bài báo này đã sử dụng phần mềm CYMCAP để mô phỏng ảnh hưởng của các điều kiện lắp đặt cáp theo nhiệt độ, độ sâu và khoảng cách giữa các sợi cáp có ảnh hưởng đến khả năng mang tải của cáp ngầm biển HVDC. Các kết quả mô phỏng trong các kịch bản đã cho thấy ảnh hưởng đáng kể của điều kiện lắp đặt đến khả năng mang tải của cáp ngầm biển HVDC và có thể ứng dụng cho thực tế chọn cáp HVDC vượt biển cho các dự án quan trọng trong tương lai.

**Từ khóa:**

Cáp HVDC (HVDC cable), cáp ngầm biển (Submarine power cable), khả năng mang tải (Ampacity), CYMCAP.

## 1. INTRODUCTION

HVDC is one of the most efficient solutions that carry out the offshore wind energy source into onshore power systems. However, it's a challenge that determines the ampacity of submarine power cables in relatively different complex installation conditions of HVDC projects. Currently, the technical standard organizations still have no issued guide standards for calculating the ampacity of submarine power cables. Heiner Brakelmann and his partner proposed a method to calculate the ampacity of HVDC power cables [2] by rejecting the part's independence frequency from calculating the ampacity of HVAC power cables. Boda Zhou and his partner [4] proposed a method to simulate and optimize the ampacity of submarine power cables by a finite method using COMSOL MULTIPHYSICS software and Redy Mardiana's researchers analyzed factors that affect the ampacity of HVDC submarine power cables in different simulation scenarios.

In this paper, the researchers used CYMCAP software that simulates the ampacity of HVDC submarine power cables installed under the seabed in different installation conditions.

CYMCAP software is dedicated to performing ampacity and temperature rise

calculations for power cable installations, especially underground power cables, and submarine power cables. The software was developed by CYME T&D International and widely applied in consulting projects related to power cable installations in the world. CYMCAP Software is fully compliant with the standards such as IEC, Neher-Mcgrath, Cigre...etc. It allows for building and configuring the detailed construction of power cables according to specifications from manufacturers such as diameter, thickness, and thermal resistivity of different materials layers for each distinct voltage level. It enables engineers and designers to model and quickly simulate installation conditions of power cables based on actual conditions such as depth, ambient temperature, soil thermal resistivity, and load factor according to various cable installation conditions such as directly buried, duct banks, underground ducts, in air, Immersed in water or on the seabed.

The paper is divided into 5 parts: Part 1 introduces the topic, part 2 indicates a method of calculating the ampacity of submarine power cables by rejecting the part's independent frequency from calculating the ampacity of AC cables [1], [2]; It performed to simulate the continued rating current of HVDC submarine power cables HVDC

$\pm 320\text{kV}/2000\text{mm}^2$  in the installation conditions extracted in [1]; the influence of installation conditions on the ampacity of HVDC submarine power cables which is analyzed in part 4. The final part is the conclusions.

## 2. THE METHOD FOR CALCULATING THE AMPACITY OF VDC SUBMARINE POWER CABLES

In [3], the ampacity of HVAC power cables is presented in formula (1):

$$I = \sqrt{\frac{\Delta\theta - W_d[0.5T_1 + n(T_2 + T_3 + T_4)]}{R_{AC}T_1 + nR_{AC}(1 + \lambda_1)T_2 + nR_{AC}(1 + \lambda_1 + \lambda_2)(T_3 + T_4)}} \quad (1)$$

where:

$\Delta\theta$ : Temperature between Conductor ambient temperature ( $^{\circ}\text{C}$ );

$W_d$ : Dielectric losses;

$R$ : AC resistance of conductor;

$T_1$ : Thermal resistance between conductor and shield of insulator (W/m.k);

$T_2$ : Thermal resistance between lead shield and armor of cable (W/m.k);

$T_3$ : Thermal resistance of outer covering (W/m.k);

$T_4$ : External thermal resistance (W/m.k);

$\lambda_1$ : Loss factor for sheath;

$\lambda_2$ : Loss factor for armor;

$n$ : Number of the conductor in the cable.

In [2] indicated a method for calculating the ampacity of HVDC submarine cables by rejecting the part's independence frequency which is shown in Figure 1.

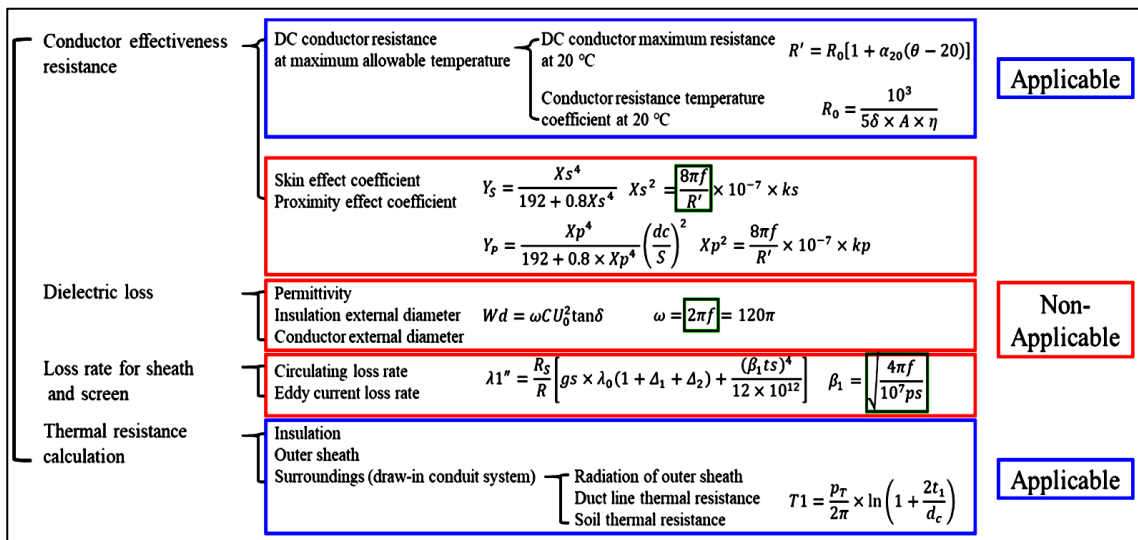


Fig 1. AC allowable calculation factor

In Figure 1, the part's independence frequency such as  $\lambda_1$ ,  $\lambda_2$ , and  $W_d$  in formula (1) by setting up  $f = 0$  leads to the factors that are rejected equal 0. The formula which calculates the ampacity of HVDC submarine power cables is

presented in formula (2).

$$I = \sqrt{\frac{\Delta\theta}{R_{DC}T_1 + nR_{DC}T_2 + nR_{DC}(T_3 + T_4)}} \quad (2)$$

Today, there are no guide standards for calculating the ampacity of HVDC

submarine power cables in different installation conditions, formula (2) has been considered the basic formula for this work.

The factors that affect the ampacity of HVDC submarine power cables which has been determined as below:

### 2.1. Determination of Temperature gradient between conductor and ambient temperature $\Delta\theta$

One of the most important factors that directly affect to the ampacity of HVDC submarine power cables is the maximum allowable temperature of the conductor and ambient temperature.  $\Delta\theta$  is determined in formula (3).

$$\Delta\theta = \theta - \theta_{amb} \text{ [}^\circ\text{C]} \quad (3)$$

where:

$\Delta\theta$ : Temperature gradient between conductor and ambient temperature ( $^\circ\text{C}$ );

$\theta$ : Maximum allowable temperature of the conductor ( $^\circ\text{C}$ );

$\theta_{amb}$ : Ambient temperature ( $^\circ\text{C}$ ).

### 2.2. Determination Of DC Resistance $R_{DC}$

DC Resistance depends on temperature and material, so DC Resistance is determined in formula (4).

$$R_{DC} = R_0[1 + \alpha_{20}(\theta - 20)] \text{ [}\Omega\text{/m]} \quad (4)$$

where:

$R_0$ : DC Resistance of conductor at  $20^\circ\text{C}$  ( $\Omega\text{/m}$ );

$\alpha_{20}$ : Conductor temperature coefficient at  $20^\circ\text{C}$  at Kelvin [ $1\text{/K}$ ].

### 2.3. Determination of Thermal Resistance $T_1$

Thermal resistance  $T_1$  of the cable insulator is determined by the material of the insulator and the inner and outer semiconductor layers. Although the electrical characteristics inside the cable are different, in terms of allowable current, it is determined by the unit thermal resistance.

In the IEC 60287-2-1 standard, 3.5 K.m/W for XLPE (Cross Link Polyethylene) and 6 K.m/W for MI\_PPLP (polypropylene laminated paper) insulation materials are applied as thermal resistance values for each insulation material. In general, Polyethylene based materials are used for inner and outer semiconductor layers. If the material of the insulator cable is XLPE, the thermal resistances of the inner and outer semiconductor layers and the insulator are the same. In [1,3,7], it presents formula (5) that determines  $T_1$  of HVDC submarine power cables.

$$T_1 = T_{1\_wb\_con} + T_{1\_csc} + T_{1\_i} + T_{1\_isc} + T_{1\_wb\_ins} \text{ (K.m/W)} \quad (5)$$

where:

$T_{1\_wb\_con}$ : Thermal resistance of semi-conductive water blocking tape over conductor (K.m/W);

$T_{1\_csc}$ : Thermal resistance of semi-

conductive conductor screen (K.m/W);

$T_{1_i}$ : Thermal resistance of insulation (K.m/W);

$T_{1_{isc}}$ : Thermal resistance of semi-conductive insulation screen (K.m/W);

$T_{1_{wb\_ins}}$ : Thermal resistance of semi-conductive water blocking tape under the wire screen (K.m/W).

#### 2.4. Determination of Thermal Resistance $T_2$

There are semi-conductive waterproof tape and an air gap between the insulator and the metal sheath. The IEC 60287 standard does not consider these waterproof tape and air gap, because they have a smaller thickness than other structures and have lesser effects on the ampacity of HVDC submarine power cables. However, this increase in thermal resistance will affect the calculation of the ampacity of HVDC submarine power cables. it is determined in formula (6) [1,3,7].

$$T_2 = T_{2_{scPE}} + T_{2_{scBED}} + T_{2_{ntape}} \text{ [W/m.k]} \quad (6)$$

where:

$T_{2_{sc}}$ : Thermal resistance of sc metal sheath (K.m/W);

$T_{2_{scBED}}$ : Thermal resistance of sc bedding (K.m/W);

$T_{2_{ntape}}$ : Thermal resistance of plastic nylon tape (K.m/W);

#### 2.5. Determination of Thermal Resistance $T_3$

$T_3$  is the thermal resistance of the outer serving of HVDC submarine power cables that calculate in formula (7) [1,3,7].

$$T_3 = \frac{\rho_{pp}}{2\pi} \ln\left(\frac{D_e}{D_{Arm_2}}\right) \text{ [K.m/W]} \quad (7)$$

Where:

$D_{Arm_2}$ : external diameter of second armor layer (mm);

$D_e$ : outer diameter of the cable (mm);

$\rho_{pp}$ : Thermal resistivity of PP-yarn (K.m/W).

#### 2.6. Determination of Thermal Resistance $T_4$

$T_4$  dependence on the surrounding environment of cables such as the thermal resistivity of the soil, the distance between cables, the distance from the surface of the ground to the cable axis, and the external diameter of one cable. It is calculated by formulas (8) and (9) [1,3,7].

$$u = \frac{2L}{D_e} \quad (8)$$

$$T_4 = \frac{1}{2\pi} \rho_T \left[ \ln(u + \sqrt{u^2 - 1}) + \frac{1}{2} \ln \left[ 1 + \left( \frac{2L}{s_1} \right)^2 \right] \right] \text{ [K.m/W]} \quad (9)$$

where:

$D_e$ : External diameter of one cable (mm);

$L$ : Distance from the surface of the ground to the cable axis (mm);

$\rho_T$ : Thermal resistivity of the soil (K.m/W);

$s_1$ : Distance between cables (mm).

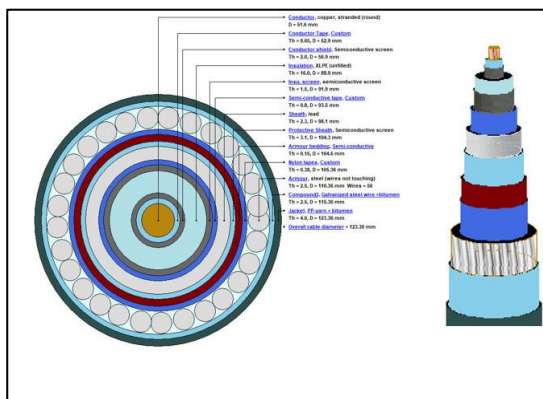
## 2. SIMULATION OF AMPACITY OF HVDC SUBMARINE POWER CABLES IN DIFFERENT INSTALLATION CONDITIONS

To perform the calculation of the

ampacity of HVDC submarine power cables based on formula (2), they can consider the construction of cables. [1] shown data sheet of HVDC cables  $\pm 320$  kV/2000 mm<sup>2</sup> and presented in Table 1. The researchers built this cable model and presented it in Figure 2.

**Table 1. Cable data sheet 320kV HVDC 2000mm<sup>2</sup> CU/XLPE/PB/SCPE/SWA/PP, outer diameter is 123.4mm**

Element	Construction	Thickness (mm)	Outer diameter (mm)
Conductor	Profile/copper, longitudinal water sealed	-	51.6
Conductor tape	Semi-conductive	-	52.9
Conductor screen	Semi-conductive PE	2.0	-
Insulation	XLPE	16.0	-
Insulation screen	Semi-conductive	1.5	-
Semi conductive tap	Semi- conductive PE		93.5
Lead sheath	Lead alloy	2.3	-
Protection sheath	Semi- conductive PE	3.1	-
Armor bedding	Semi-conductive bedding		104.6
Steel wires	Galvanized steel + bitumen	2.5	-
Plastic nylon tape	-	-	110.4
Steel wires	Galvanized steel + bitumen	2.5	-
Outer serving	PP yarn + bitumen	4.0	-



**Fig 2. HVDC submarine power cable  $\pm 320$  kV/2000 mm<sup>2</sup>**

This document [1] listed the surrounding environment of cables below.

Cables are directly buried under the seabed;

Thermal resistivity of the soil: 0.8K.m/W;  
Temperature of soil: 15°C;

Burial depth: 1m;

Distance between two cables: 2000 mm;

Maximum allowable temperature of conductor: 70°C.

Based on the HVDC submarine power cables model presented in figure 1 and the method introduced in [2]. The simulation result of the ampacity of HVDC submarine power cables is shown in Figure 3 and Table 2.

The ampacity of HVDC submarine power cable  $\pm 320\text{kV}/2000\text{mm}^2$  is 2311A that is same the result of document [1]

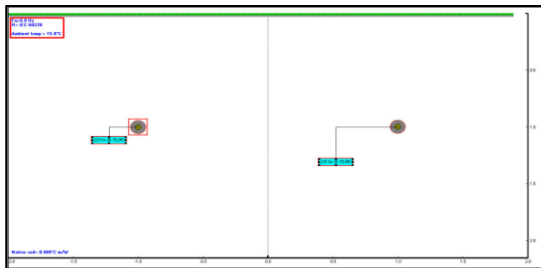


Fig 3. The simulation result of the ampacity of HVDC submarine power cable  $\pm 320\text{kV}/2000\text{mm}^2$

Table 2. prepare between the simulation result and the result of the document [1]

The simulation result [A]	The result of document [1] [A]	Error [%]
2311	2311,0958805122	0

Based on Table 2, the result between the simulation result and the result of the document [1] is similar. However, the actual error is less than 5% (Maximum permissible limit) so this method is highly reliable.

## 2. ANALYSE THE INFLUENCE OF DIFFERENT INSTALLATION CONDITIONS ON THE AMPACITY OF HVDC SUBMARINE POWER CABLES

In this part, researchers simulated the ampacity of the HVDC submarine power cable  $\pm 500\text{kV}$  presented in the document [4] and analyzed the factors such as

environment temperature, Burial depth, the distance between two cables, and thermal resistivity of the soil in supposed scenarios that is listed in the document [5].

The document [5] indicate detailed construction of the HVDC submarine power cable  $\pm 500\text{ kV}$  that is presented in Figure 4 and Table 3.

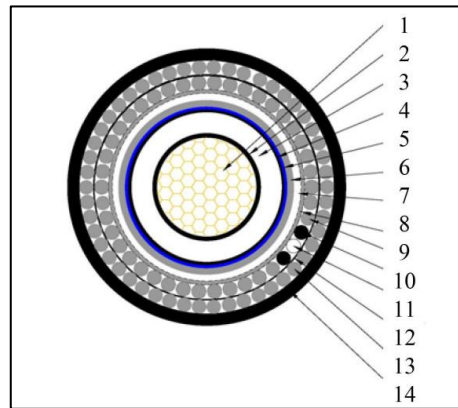


Fig 4. HVDC submarine power cable  $\pm 500\text{kV}/2500\text{mm}^2$

Table 3. Cable data sheet HVDC  $\pm 500\text{kV}$   $2500\text{mm}^2/193.8\text{mm}$

Construction	thickness (mm)	Outer diameter (mm)
Conductor	-	65.1
Conductor shield	2.5	70.1
Insulation XLPE	31	132.1
Insulation shield	1.5	135.1
Water blocking buffer	2x1.0	138.1
Metal sheath	4.6	147.3
MDPE sheath	4.5	156.3
Inner lining layer	2.0	160.3
Optical fiber cables	6.0	172.3
Cable filling layer	6.0	-

Construction	thickness (mm)	Outer diameter (mm)
Alloy wire	6.0	-
Package belt	2x0.3	173.8
Armoured layer	6.0	185.8
Outer ply	4.0	193.8

This HVDC cable  $\pm 500\text{kV}$  model is simulated based on data in Table 3 by CYMCAP software which is shown in Figure 5.

The cables are installed in Figure 6 [5], and the installation conditions are listed in the document [5]:

Ambient temperature:  $30^\circ\text{C}$ ;

Thermal resistivity of the soil:  $1.2 \text{ K.m/W}$

Maximum allowable temperature of conductor:  $70^\circ\text{C}$ .

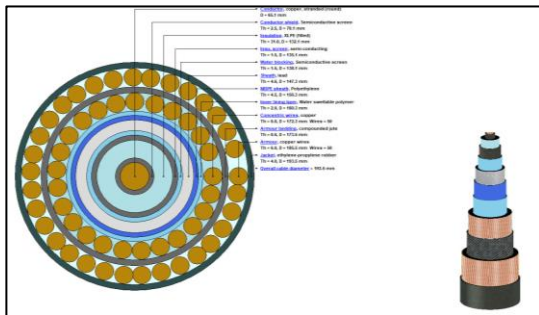


Fig 5. HVDC  $\pm 500\text{kV}$   $2500\text{mm}^2$  model

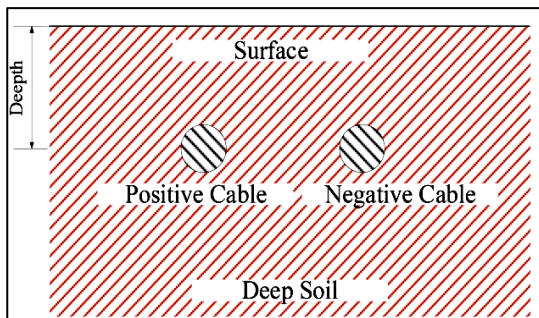


Fig 6. Installation of two poles HVDC $\pm 500\text{kV}$   $2500\text{mm}^2$  under the seafloor

Because the structure under the seabed is complex the installation of cables affects the ampacity of HVDC submarine power cables. The supposed scenarios include 04 different scenarios.

#### 4.1. SCENARIO 1

HVDC submarine power cables are buried at a depth of 1m from the seabed; the distance between the two cables is 2m and the ambient temperature changes from  $6\text{--}30^\circ\text{C}$ .

The influence of ambient temperature on the ampacity of HVDC submarine power cables which show in Figure 7.

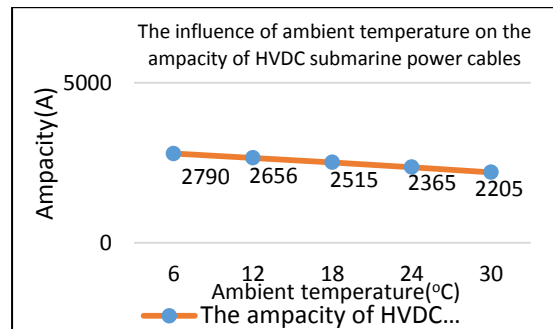
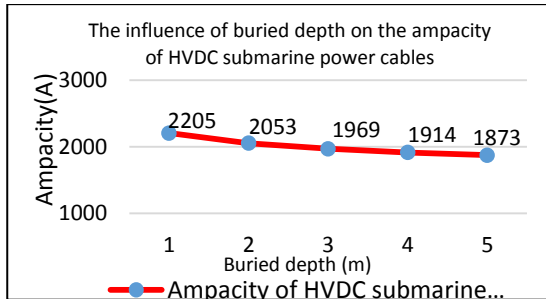


Fig 7. The influence of ambient temperature on the ampacity of HVDC submarine power cables  $\pm 500\text{kV}$   $2500\text{mm}^2$

The ambient temperature directly affects the ampacity of HVDC submarine power cables. Figure 7 indicates when the ambient temperature changes from  $6\text{--}30^\circ\text{C}$  (the weather under the seabed), the ampacity of these cables will decrease from  $2790\text{A}$  to  $2205\text{A}$  (20.96%). So, the ambient temperature under the seabed must be considered in calculating the ampacity of HVDC submarine power cables.

#### 4.2. SCENARIO 2

The ambient temperature and the distance between the two cables are like scenario 1. The buried depth changed from 1m to 5m. The result is presented in Figure 8.

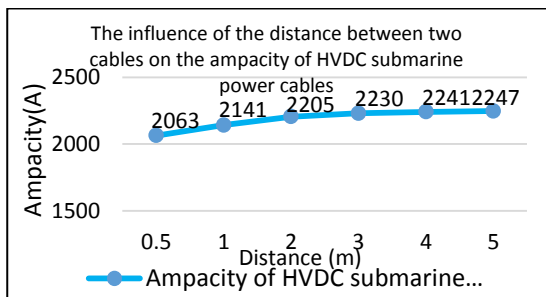


**Figure 8. The Influence of buried depth on the ampacity of HVDC submarine power cables  $\pm 500\text{kV}$   $2500\text{mm}^2$**

When the buried depth changed from 1 to 5m, the ampacity of HVDC submarine power cables could be about 15% less than the case of these cables being buried at 1m.

#### 4.3. SCENARIO 3

The ambient temperature and the buried depth are maintained and the performing distance is changed between the two cables from 1m to 5m, the result is presented in Figure 9.



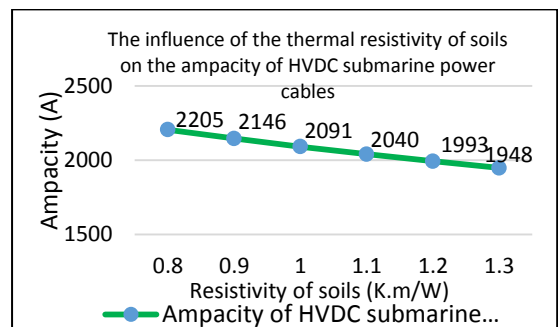
**Fig 9. The fluence of the distance between two cables on the ampacity of HVDC submarine power cable  $\pm 500\text{kV}$   $2500\text{mm}^2$**

When their distance is increased from 0.5 to 1m, the ampacity of these cables changed from 2063A to 2141A (increase 78A), and this distance is 5m, the ampacity of these cables is 2247A (increase 184A).

#### 4.4. SCENARIO 4

These cables are buried at a depth of 1m from the seabed; this distance is 2m, and the ambient temperature is  $30^\circ\text{C}$  and performing the change in the thermal resistivity of soil from 0.8 to 1.2 K.m/W.

Marine geology consists of many different types of material layers, the activities of volcanic craters, or some natural phenomena affecting the geology of the seabed. Therefore, the determination of the thermal resistivity of the seabed environment is complicated and the cost of the survey is high. The thermal resistivity value of the seabed directly affects the heat dissipation capacity and changes the ampacity of HVDC submarine power cables, which is shown in Figure 10.



**Figure 10. The fluence of the thermal resistivity of soils on the ampacity of HVDC submarine power cable  $\pm 500\text{kV}$   $2500\text{mm}^2$**

**Table 4. Thermal resistivity of the soils**

Soil	Thermal resistivity (Dry) (K.cm/W)	Thermal resistivity (Wet) (K.cm/W)
Well graded gravel	40	120
Poorly graded gravel	45	190
Silty gravel	50	140
Caly gravel	55	150
Well graded sand	40	130
Uniform sand	45	300
Silty sand	55	170
Clay sand	60	180
Slit	65	240
Silty clay	70	210
Organic slit	90	350
Micaceous slit	75	300
Clay	85	270
Soft organic clay	110	400
Silty peat	150	>600

Figure 10 indicated the ampacity of these cables decreased from 2205A to 1948A when the thermal resistivity increased from 0.8 to 1.3 K.m/W. Table 4 shows the thermal resistivity value of many soil types [6].

## 5. CONCLUSION

The paper used the method that rejects

frequency-dependent components [1] and it is performed to simulate the ampacity of HVDC submarine power cables by CYMCAP software. The simulation results are similar as shown in reference [1]. Researchers also analyzed the fluence of installation conditions on the ampacity of HVDC submarine power cables in 4 proposed scenarios. When the temperature changes from 6°C to 30°C, the load-carrying capacity of the cable tends to decrease from 2790A to 2250A; In response to the change of the cable burial from 1m to 5m, the load-carrying capacity of the cable decreases from 2205A to 1873A; The distance between 2 HVDC submarine cables from 1 to 5m reduces the temperature mutuality between the two cables and leads to the load carrying capacity of the submarine cable increases from 2063A to 2247A and the difference between the resistivity of the material layer around the cable from 0.8K.m/W to 1.3K.m/W makes the load carrying capacity of the cable decreases from 2205A to 1948A. The results provide the basis for application in the selection of an HVDC submarine cable cross-section suitable for future HVDC transmission works across the sea in Vietnam while offshore wind projects are coming.

## REFERENCES

- [1] Cigre – Reference 880 – Power cable rating examples for calculation tool verification;
- [2] Heiner Brakelmann, George J. Anders, F. IEEE – Rating Consideration in design HVDC cable Installations;

- [3] IEC 60287:2022 SER Electric cables;
- [4] Boda Zhou, Yanjie Le, Yalin Fang, Tao Dai, Lu Sun, Jiapeng Liu, Lekai Zhou – Temperature field simulation and ampacity optimization of 500kV HVDC cable – The 14th IET International Conference on AC and DC power Transmission (ACDC 2018);
- [5] Redy Mardiana, The Petroleum Insititute PO Box 2533, Sas AI NakhI, Umm Al Naar Abu Dhabi, United Arab Emirates – Parameter Affecting the Ampacity of HVDC Submarine power cables;
- [6] Electric Power Distribution Equipment and Systems.Storage Systems on Stochastic Unit Commitments in Microgrids”. Energies, 2021, 14, 470. <https://doi.org/10.3390/en14020470>.
- [7] Thomas Worzyk - Submarine power cable: Design, Installation, Repair, Environmental Aspects-2009th Edition.
- [8] <https://neo.gsfc.nasa.gov/view.php?datasetId=MYD28M>.

### Biography:



Kim Long HUYNH graduated with a degree in electronic engineering from the Industrial university of Ho Chi Minh City, Viet Nam, in 2020. Currently, He has worked at Power Engineering Consulting Joint stock Company 4. His research interests include power system studies, renewables energy, HVDC, FACT and Cables



Van Phu DUONG was born in 1973, He graduated Master Engineering at HCMC University, Viet Nam, the year 2005. Currently, He is director of R&D and QM Centre at Power Engineering Consulting Joint Stock Company 4. His research interests include power system studies, renewables energy, Microgrid, HVDC, FACT, and operation management.



Quang Thuc VO graduated with a degree in electrical and electronic engineering from Da Nang university of technology, in 2012. Currently, He is working at Power System Technology Solutions Co.,Ltd, CYME Software Distributor in Vietnam. His research interests include power system studies, renewable energy, and power engineering software.



Thanh Long DUONG received Ph.D. degree in Electrical Engineering from Hunan University, China, in 2014. Currently, He is vice dean of the Faculty of Electrical Engineering Technology at the Industrial University of Ho Chi Minh City. His research interests include power system operation, power system optimization, FACTS, renewable energy, optimization algorithms and power markets.



Dang Toan Nguyen received Ph.D. degree in Electrical Engineering from Grenoble-INP in France in 2008. He is currently dean of Energy Faculty at Electric Power University. His research interests include power system stability, HVDC/FACTS, and renewable energy.