Lightning-Induced Voltage Surges in Submarine Fiber Optic Cables for Offshore Data Centers

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***Abstract*— In an offshore data center, the armor of a submarine fiber optic cable is electrically grounded to the structure of the platform. When lightning strikes the structure, a voltage surge is impinged on the armor inducing a voltage surge in the copper tube of the cable due to the distributed capacitance between the armor and the tube. The induced voltage surge in the cooper tube could exceed the rating of the surge protective devices and could damage cable joints, power feed equipment, and repeaters. The voltage surge in the armor can also affect the dielectric integrity of the sheath in a submarine cable with an impervious outer sheath. The grounding of the armor in submarine fiber optic cables is studied in this paper to determine its influence on the copper tube induced voltage and dielectric stress of the insulation when lightning strikes the offshore data center.**

***Index Terms*—Lightning strike, offshore data center, surge impedance, underwater fiber optic cable, voltage surge.**

I. INTRODUCTION

Seawater cooling and offshore collocation have been the main drivers of offshore data centers planning in recent years [1], [2], [3]. These offshore structures are prone to lightning strikes [4]. A lighting strike induces a current surge that reaches the electrical equipment mounted on the structure platform. Of particular interest in this paper is the current surge impinged in the armor of the submarine fiber optic cables (SFOC) entering the water body, which can be a river, a lake or the ocean [5]. The SFOC armor is connected to the local earth (platform) following the guidelines given in [6]. A depiction of the voltage surge entering the submarine cable armor is shown in Fig. 1.

The amplitude of the current surge in the armor is a function of the surge impedance of the cable and the surge impedance of the offshore structure, as described in [7]. In floating or elevated offshore platforms, the current surge in the armor results in a voltage surge that travels along the submarine cable and away from the local earthing connection on the platform. This voltage surge in the armor imposes a voltage across the insulation between the copper tube and the armor.

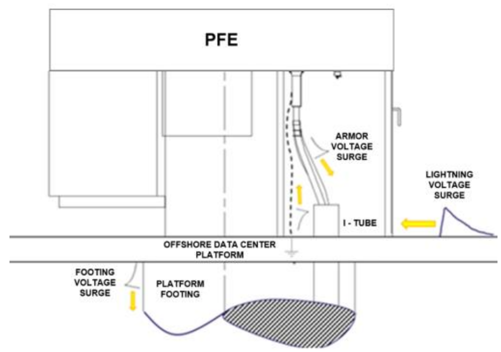

Figure 1. Illustration of an approaching current surge (from the right) caused by a lightning strike in the offshore platform of a data center. The current surge splits between the earthing connection of the armor and the footing of the platform.

For systems with a single power feed source, one end of the copper tube in the SFOC is connected to ground. Therefore, the voltage across the insulation between the armor and tube could exceed the insulation level and could result in an electrical discharge, as illustrated in Fig. 2.

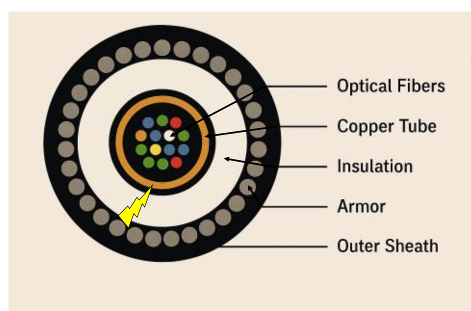

Figure 2. Illustration of an electrical discharge between the armor and the copper tube at a location of the SFOC where the potential between the copper tube and the armor peak voltage surge exceeds the dielectric capability of the insulation (image partially generated using Microsoft 365 Copilot).

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II. Cable Model

This paper presents a frequency-dependent model of a SFOC with an impervious outer sheath. The cable model was developed for an above water offshore data center but can also be used for the analysis of lightning strikes in oil and gas rigs, offshore wind power and wave and tidal power facilities which require SFOCs. The analysis of SFOCs for undersea facilities is outside of the scope of this paper.

A. Model of the Submarine Fiber Optic Cable Layers

Fig. 3 shows the PSCAD model of a SFOC. The cable has the fiber optic strands at the center (not shown in the PSCAD model), surrounded by a copper tube (depicted in the figure only by its outside diameter), a main insulation (Insulation 1), the armor layer (sheath), and the outer over sheath (Insulator 2). The insulators have the typical dielectric properties for a standard SFOC.

For the analysis of the voltage surge across the insulations the outer layer of the cable was considered impervious in this paper, and the seawater surrounding the individual cables was considered equivalent to the electrical ground at that location.

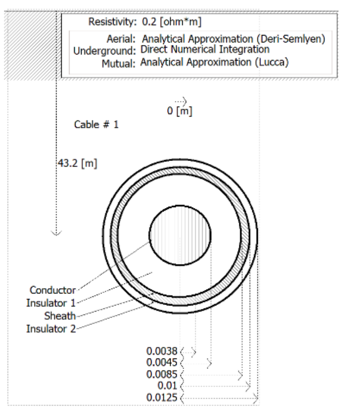

Figure 3. PSCAD model of a submarine fiber optic cable with its layers (dimensions in m).

B. Model of the Submarine Cable Interconnections

Measuring the voltage in the submarine cable armor and copper tube is possible by adding connections to the model of the cable, as shown in Fig. 4, with the internal interconnections shown in Fig. 5.

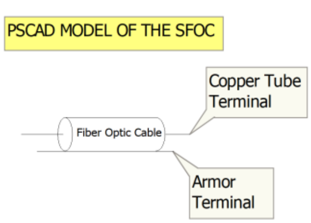

Figure 4. PSCAD model of a SFOC with its terminals.

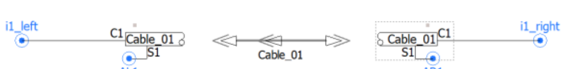

Figure 5. PSCAD model of a SFOC with internal interconnections.

III. Interconnection Model of an Offshore Data Center

Fig. 6 shows the model of two interconnected offshore data centers mounted in platforms with the characteristics listed in Table II of the Appendix; a 100 km-long ($l_1 = 0.1$ km, $l_2 = 49.9$ km, and $l_3 = 50$ km) SFOC interconnecting the platforms, an intermediate repeater represented by a 1,000 Ohm resistance, and voltage-to-ground measuring points for the armor ($E_{a\_g\_1/2/3/4}$) and for the copper tube ($E_{tb\_g\_1/2/3/4}$) along the submarine fiber optic cable. The model of the lightning strike is a 200 kA, 10/350 μs surge generator based on a lightning protection level of I (LPL I) according to [8].

Although the platforms in Fig. 6 do not represent complete offshore data center facilities, the author assumes that the results obtained using this reduced PSCAD model are similar to those obtained using a more complete model. The rationale behind this assumption is that the rest of the facilities and equipment do not affect significantly the transient response of the armor in the SFOC affected by lightning strikes.

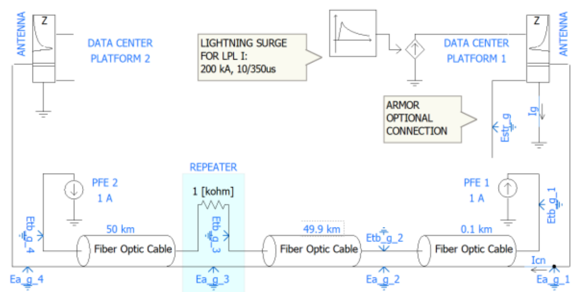

Figure 6. PSCAD model of two offshore facilities interconnected by a SFOC with a repeater at the midspan of the cable.

IV. Voltage Surge in the SFOC

Using the models described in Sections II and III and applying the current surge representing a lightning strike to the antenna in the platform, we measure in the PSCAD model the armor voltage surge at 0 km, 0.1 km and 50 km from the footing of the platform.

The lighting protection level assigned to the electrical equipment in offshore structures is either LPL I, II, III or IV [8]. For an offshore data center, the highest level of protection, LPL I, is recommended. The maximum values of the lightning current parameters relevant to LPL I will not be exceeded with a probability of 99 %. The maximum lightning current for the equipment with an LPL I is I_O = 200 kA with a 10/350 µs waveform shape.

Fig. 7 shows the measurement of a large voltage surge applied to the SFOC armor at the beginning of the cable near the platform ($E_{a\_g\_1}$ peak > 200 kV). This figure also shows how the peak voltage is dampened as the surge wave travels along the cable, with a peak voltage decreasing to approximately $E_{a\_g\_2}$ peak ≈ 150 kV at 100 meters from the cable terminal. Fig. 8 shows that the voltage surge peak is substantially dampened (approximately to $E_{a\_g\_2}$ peak ≈ 850 V) at 50 km from the platform. The voltage peak dampening is a function of the SFOC design (dimensions).

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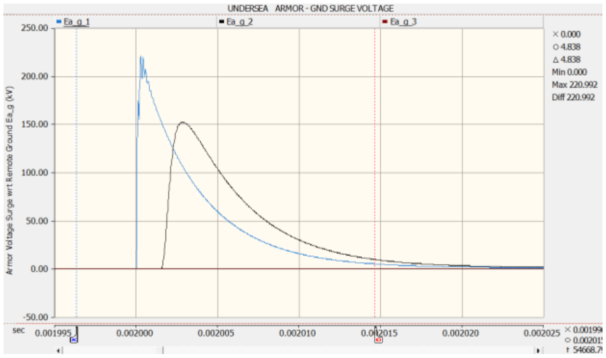

Figure 7. Voltage surge in the armor of a SFOC at a distance of 0 km and 0.1 km from the offshore structure footing, when a 10/350 µs, 200 kA current surge is impinged to the armor (with platform dimensions of h_1=10 m and h_2=5 m from Table II).

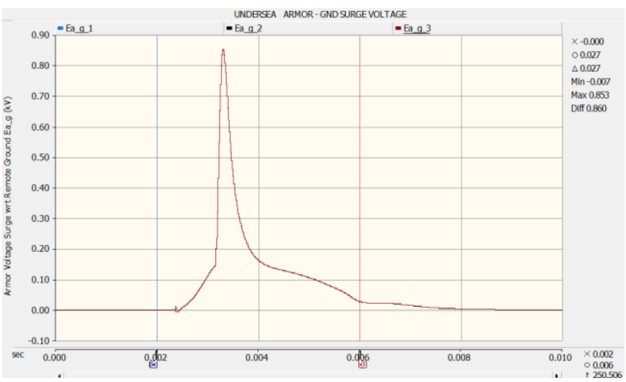

Figure 8. Voltage surge in the armor of a SFOC at a distance of 50 km from the offshore structure footing, when a 10/350 µs, 200 kA current surge is impinged to the armor (with platform dimensions of h_1=10 m and h_2=5 m from Table II).

The power feed equipment (PFE) connected to the copper tube at the ends of the cable are current sources, which electrically have high resistance to ground. Also, there is a distributed capacitance across the insulation between the armor and the copper tube. These two factors combined result in a voltage surge induced in the copper tube by the voltage surge in the armor. Figs. 9 and 10 show the voltage surge induced in the copper tube at different cable locations.

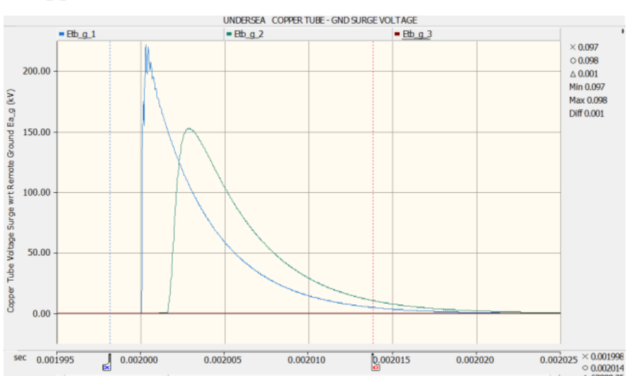

Figure 9. Induced voltage surge in the copper tube of a SFOC at a distance of 0 km and 0.1 km from the offshore structure footing, when a 10/350 µs, 200 kA current surge is impinged to the armor (with platform dimensions of h_1=10 m and h_2=5 m from Table II).

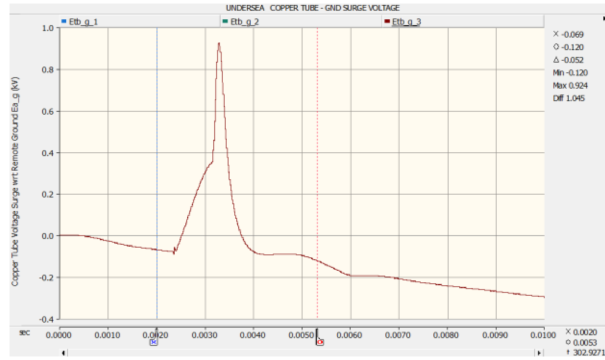

Figure 10. Induced voltage surge in the copper tube of a SFOC at a distance of 50 km from the offshore structure footing, when a 10/350 µs, 200 kA current surge is impinged to the armor (with platform dimensions of h_1=10 m and h_2=5 m from Table II).

The transient analysis of the voltage surge responses shown in Figs. 7 to 10 shed the following observations:

A. Dielectric Integrity of the Outer Sheath Insulation

The peak magnitude of the voltage surge in the armor due to a lightning strike in the platform exceeds the insulation level of the typical submarine cable outer sheath, which, according to [9], is in the order of 30 kV. This could be detrimental to the life span of the submarine cable, especially for the impervious outer sheath type, because the voltage surge will result in the puncture of the insulation and promote the corrosion of the cable armor.

B. Transient Overvolatge Applied to the Components Electrically Connected to the Copper Tube

The induced voltage surge in the copper tube travels in the same direct ion of the armor voltage surge. The peak magnitude of this induced voltage surge is several times the peak magnitude considered during the design of the submarine cable system because the expectation is that the induced voltage surge will originate in a lightning striking near the submarine cable system and not directly impinged into the cable armor. Hence, the equipment connected to the copper tube is exposed to an overvoltage that cannot be clamped down by the surge protection devices (SPDs). According to Fig. 8, the exposure to this overvoltage is substantially decreased for the equipment connected to the copper tube far from the point of ingress to the armor of the voltage surge.

C. SFOC with Single-End Power Feed Equipment

When the SFOC system is designed to operate with a single PFE, there is an end of the SFOC that is solidly grounded. This operational model is also true when a two PFE system is temporarily operating with a single PFE due to maintenance or breakdown. In both cases, the copper tube potential at the grounded end will be near zero in the vicinity of the offshore platform. Therefore, the voltage surge in the armor will not induce a voltage surge in the copper tube but instead, the dielectric capability of the insulation between the armor and the copper tube insulation will be damaged, creating a permanent shunt fault.

V. Reduction of the Voltage Surge in the SFOC Armor

Reduction to voltage surge in the armor of a SFOC requires the proper arrangement of the connection between the armor and the structure (local earth), the proper design of the offshore platform, or the inclusion of an intermediate earthing point below seawater level and near the platform. The following subsections describe these options.

A. Proximity to the Seawater of the SFOC Armor Earthing

When the armor is connected to local earth in a platform that is near the seawater surface, the current surge from the lighting strike favors the path to the seawater and seabed rather than the path of the SFOC armor. This is shown in Fig. 11, which presents a much lower voltage surge than Fig. 7. The reduced voltage surge shown in Fig. 11 was achieved by modifying the dimensions of the platform in Fig. 13 in the Appendix, with h_1 = 15 m and h_2=0 m. This last dimension represents the distance between the seawater surface and the structure platform where the armor is connected to the equipment frame.

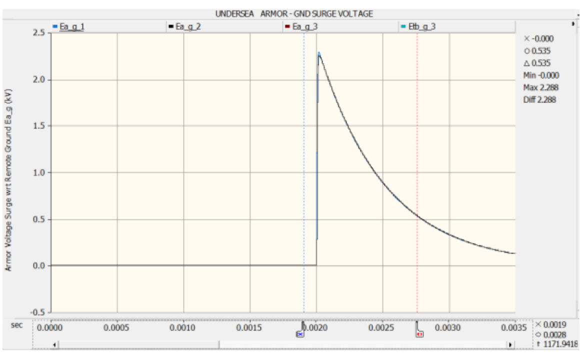

Figure 11. Voltage surge in the SFOC armor measured at a distance of 0.1 km from the structure footing, when a 10/350 µs, 200 kA current surge is impinged at the antenna of a data center and for a platform that has been lowered to the level of the seawater (h_1=15 m and h_2=0 m in Fig. 13).

Table I shows the voltage surge amplitude variations measured in the SFOC armor as a function of the platform heights from the seawater surface in the data center offshore structure.

TABLE I. Voltage Surge in the Armor as a Function of the Platform Heigth from Seawater Surface

Platform Dimension *h1* (m)	**Platform Dimension *h2* (m)**	**Armor Voltage Surge Amplitude (kV)**
15	0	2.3
13	2	122
10	5	221

B. Diameter of the Offshore Structure

Offshore structures with lower surge impedance benefit from a lower SFOC armor voltage surge amplitude. According to [10], the surge impedance of a structure with a cylindrical shape is approximately equal to (1), where r is the radius of the cylinder encompassing the platform and L is the structure height. Hence, a cylindrical structure with a larger diameter will have a smaller surge impedance.

$$Z \approx 60\ \left(\ln\left(\frac{2\sqrt[2]{2}L}{r}\right) - 1\right) \qquad (1)$$

Fig. 12 shows the voltage surge in the SFOC armor for the data center structure described in the Appendix, but with an increased diameter (double the average diameter D listed in Table II), which resulted in a reduction in both the surge impedance and the voltage surge amplitude compared to Fig. 7.

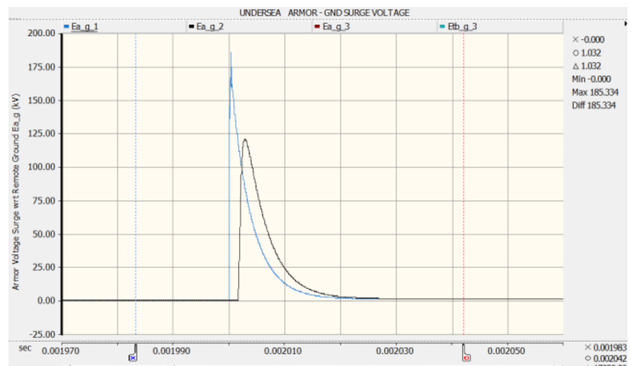

Figure 12. Voltage surge between the SFOC armor and the remote earth due to a lightning strike at the antenna of the platform of an offshore data center. The surge impedance of the structure has been lowered by increasing its diameter to double the diameter listed in Table II, with all other dimensions unchanged.

When considering re-designing an offshore structure to affect its surge impedance, the focus shall be on the external shape of the platform rather than its interior, similar to the design of an antenna.

C. SFOC Armor Electrically Connected to Seawater

The exposure of the SFO armor to the seawater at the beginning of the cable run will resemble the solution proposed in subsection A for this Section. The rationale behind this approach is that the armor electrically connected to the seawater eliminates the surge impedance of the footing of the offshore structure for the armor. The exposure of the armor to the seawater does not need to extend too deep into the sea. Only the beginning of the run underwater needs to be exposed. Alternatively, a direct connection of the SFOC armor to the seabed in the form of an underwater earthing or to the footing of the platform below the seawater level will suffice. The voltage surge transient response in this case will be similar to the one shown in Fig. 11.

VI. Conclusions

We have shown in this paper that there are techniques that help to reduce the voltage surge amplitude in SFOC armors in the event of lighting striking an offshore data center structure. The voltage surge amplitude in the armor is strongly related to the distance between the armor earthing connection to the structure and the seawater surface. The smaller the distance to the seawater surface, the lower the voltage surge amplitude, as shown in Section V. A.

Selecting structures with lower surge impedance also reduces the voltage surge amplitude in the armor. Therefore, SFOC armors connected to structures that have a slim profile are at higher risk of experiencing the stress of over voltages in the outer sheath insulation and in the insulation between the armor and the copper tube during lightning strikes. Additionally, slim structures have a higher risk of equipment damaged due to the induced voltage surge in the copper tube when lightning strikes the data center offshore structure.

Selecting the armor earthing connection point below the water level and at a short distance from the ends of the SFOC is a practical way to reduce the voltage surge amplitude in the armor, as shown in section V. C.

Selecting an SFOC with a higher insulating level of its outer sheath may be the last of the options available for submarine cables in offshore environments where a high voltage surge amplitude in the armor is expected.

VII. Appendix

A. *Offshore Structure Model*

The simple cylindrically shaped data center offshore structure example used in this paper and shown in Fig. 13 has the characteristics listed in Table II, with the surge impedances reflected by the PSCAD model on the right side of the figure. Dimensions h_1, h_2 and D are modified in Section V to demonstrate the sensitivity of the voltage surge amplitude impinged in the armature when these parameters are changed.

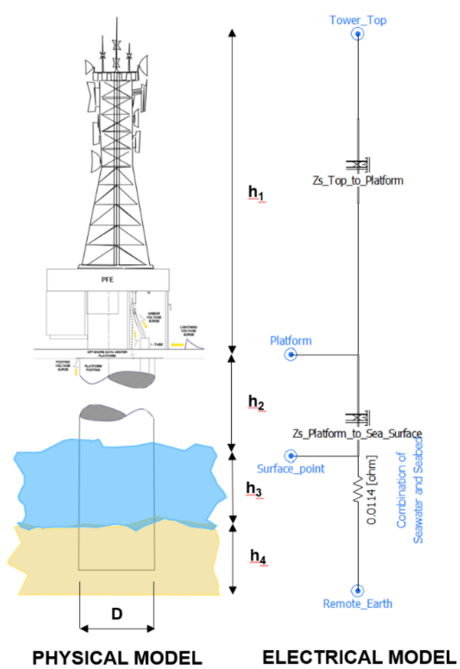

Figure 13. Dimensions and PSCAD model of the data center offshore platform.

TABLE II. Characteristics of an Offshore Platform, the Surrounding Seawater and the Seabed

Structure and Surroundings	**Structure Characteristics**	
	Data	**Impedance**
h1	10 m	201.5 Ohms[ce]
h2	5 m	201.5 Ohms[ce]
h3	43.2 m	0.0114 Ohms[d]
h4	25 m	
D (average)	9.86 m	---
ρ seawater[a]	0.2 Ohm-m	---
ρ seabed[b]	20 Ohm-m	---

a. [11]; b. [12]; c. [10] and (1); d. [13]; e. +seq. travel time for 1 m: 3.92e-9 [s/m], +seq. resistance: 3.576e-5 [ohm/m], typical for steel structures.

References

[1] “5 Largest Underwater Data Centers in the World,” Brightlio Technology Illuminated. https://brightlio.com/underwater-data-centers/

[2] H. Morgan, “Resurrecting oil rigs for a sustainable future,” Facility Management. https://www.fmmedia.com.au/sectors/resurrecting-oil-rigs-for-a-sustainable-future/

[3] L. Dignan, “Google wins floating data center patent,” ZD NET/Business. https://www.zdnet.com/article/google-wins-floating-data-center-patent/

[4] L. M. Miller, R. Krishnamurthy, “Offshore lightning more active and intense in U.S. East Coast wind areas than in North Sea,” *Letter, Environmental Research Communications,* 7 (2025) 061003.

[5] “Submarine Cables,” Hexatronic Fiber Solutions, Online catalogue. https://www.hexatronic.com/en/fiber-solutions/products?category=submarine-cables

[6] *National Electrical Code (NEC)*, NFPA 70 2026, Articles 770.93 and 770.100.

[7] E. H. Enrique, “Submarine cable jackets affected by lightning strikes in offshore environments,” in 2025 I&CPS Annual Meeting and Conference, Montreal, QB, Canada.

[8] *Protection against lightning - Part 1: General Principles*, IEC 62305-1:2010

[9] *Electric cables - Tests on extruded oversheaths with a special protective function*, IEC 60229:2007.

[10] J. A. Martinez-Velasco, *Power System Transients – Parameter Determination*, CRC Press, Taylor & Francis Group, Dec. 2017.”

[11] “Spreadsheets Engineering Calculations & Spreadsheets Resistivity of Seawater,” Civil Web https://civilweb-spreadsheets.com/marine-design-spreadsheets/cathodic-protection-design-spreadsheet/resistivity-of-seawater/

[12] M. Rømoen, A. A. Pfaffhuber, K. Karlsrud, T.E. Helle, “Resistivity on marine sediments retrieved from RCPTU-soundings: a Norwegian case study,” in Proc. *2nd International Symposium on Cone Penetration Testing, Huntington Beach, CA, USA, May 2010.*

[13] L. Zhang, S. Fang, G. Wang, T. Zhao, L. Zou, “Studies on an Electromagnetic Transient Model of Offshore data center Turbines and Lightning Transient Overvoltage Considering Lightning Channel Wave Impedance.” MDPI Dec. 2017.

979-8-3315-8138-1