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Improvement of Risk Assessment Using Numerical Analysis for an Offshore Plant Dipole Antenna

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Abstract: This paper proposes a numerical analysis method for improving risk assessment of radio frequency (RF) hazards. To compare the results of conventional code analysis, the values required for dipole antenna risk assessment, which is widely used in offshore plants based on the British standards (BS) guide, are calculated using the proposed numerical analysis. Based on the BS (published document CENELEC technical report (PD CLC/TR) 50427:2004 and international electrotechnical commission (IEC) 60079 for an offshore plant dipole antenna, an initial assessment, a full assessment, and on-site test procedures are performed to determine if there is a potential risk of high-frequency ignition. Alternatively, numerical analysis is performed using the Ansys high frequency structure simulator (HFSS) tool to compare results based on the BS guide. The proposed method computes the effective field strength and power for the antenna without any special consideration of the structure to simplify the calculation. Experimental results show that the proposed numerical analysis outperforms the risk assessment based on the BS guide in accuracy of the evaluation.

Keywords: risk assessment; numerical analysis; ignition hazard; effective field strength; offshore plant

1. Introduction

At offshore plants, high-frequency waves, such as ultra high frequency (UHF) and very high frequency (VHF), are used for wireless communication, and automatic identification system (AIS), global positioning system (GPS), and radar scanners are installed. In such wireless communication devices, electromagnetic waves with high waves are generated. Additionally, structures such as metal objects, pipelines, crane ropes, etc. existing in the offshore plant can act as receivers. High-frequency electromagnetic waves from various devices induce voltage and current in metallic conductor structures at the offshore plant. The amplitude of such induced current depends on the wavelength of the transmitted signal, the surrounding electromagnetic field, and the shape and size of the structure. In addition, if the induced voltage or current is large enough, sparks can occur and cause large fires and explosions.

Offshore plants are subject to a variety of marine environmental conditions during operation, with more than 70% of accidents involving explosions or fires. This can lead to large-scale explosions in the event of an accident, leading to human casualties, and can cause serious marine pollution, which can lead to great economic and industrial losses. The possibility of fires and explosions caused by high-frequency radiation is analyzed considering the electromagnetic wave intensity generated from the communication facility of the offshore plant, the characteristics of the metallic structure acting as a receiving antenna, the size of the induced received power, and the characteristics of combustible material at the plant. The risk should be evaluated and reflected in design and construction.

The current state of related papers is as follows. Sang-Won Choi and Hyuk-Myun Kwon [1] performed an experiment to reduce electric shock and ignition by current and voltage induced by electromagnetic waves from a large crane. The necessity of various studies on the energy required to cause fires and explosions by a spark has been suggested. Eckhoff and Thomassen [2] studied various sources of ignition in offshore plants. Among them, the influence of high-frequency propagation was considered. According to their paper, electromagnetic waves are emitted by all systems that generate high-frequency electrical energy (10^4 Hz to 10^{11} Hz), and ignition sources can be generated if the field is strong enough and the receiver antenna is large enough. In this regard, a method of securing safety levels based on guidance was studied. Bradby [3] studied various practical applications of fire risk assessment based on BS 6656:2002 code. BS 6656:2002 [4] is a code detailing a systematic approach, such as initial assessment and full assessment, to assess radio frequency-induced ignition risk. The initial assessment is performed in three steps: (1) determine the size of the maximum vulnerable zone, (2) identify significant transmission sources within the vulnerable zone, and (3) screen each type of transmission source using BS 6656. Full assessment performs the full assessment methodology for the remaining sources. The study by Rajkumar and Bhattacharjee [5] carried out a step-by-step risk assessment from transmission based on BS 6656:2002. The evaluation step calculated the effective field strength according to frequency. The risk of fires and explosions in the explosion environment was evaluated by calculating the energy generated by sparks in the conductive structure caused by electromagnetic waves, and safety measures for the risk of radio frequency (RF) ignition were suggested. Wang [6] recommended RF mechanisms that directly or indirectly cause fires and explosions and summarized RF risk studies in flammable and explosive environments. In addition, some issues of RF risk studies were discussed, and RF risk studies were conducted.

Examining the status of related papers, most studies on high-frequency and RF risk assessment were based on the BS guide, and studies conducted in parallel with numerical analysis were rare. In addition, overall studies on land and sea have been conducted on the risk of high-frequency ignition. In this paper, a risk assessment for a dipole antenna commonly used in an offshore plant is performed. The assessment is based on BS PD CLC/TR 50427:2004 [7] and IEC 60079 [8–10] for risk assessment for high-frequency radiation. BS PD CLC/TR 50427:2004 is a guideline for assessing the risk of ignition of a facility where flammable gases due to RF emissions from communications, radar or other transmit antennas may be present. It specifies procedures and formulas necessary for risk assessment. IEC 60079 standard refers to IEC 60079-0, IEC 60079-10-1, and IEC 60079-10-2. IEC 60079-0 specifies the general requirements for the manufacture, testing and marking of electrical equipment and explosive (EX) components for use in explosive atmospheres. IEC 60079-10-1 is an international standard for identification and classification of explosive gas atmospheres and regions where combustible gases, vapors of mist can exist. IEC 60079-10-2 is an international standard for the identification and classification of explosive dust atmospheres and regions where combustible dust layers may be present. The IEC international standard was used to determine the gas threshold. At the same time, Ansys HFSS numerical analysis is performed to contribute to the accuracy of the existing risk assessment based on the BS guide.

2. Detailed Specification of the Analysis Object

In this paper, code and numerical analysis are performed by choosing antennas that are widely used in offshore plants. Code and numerical analysis are performed for both single and multiple transmission. In the code analysis, the risk of high-frequency ignition is evaluated according to the BS and IEC, and numerical analysis is compared with code analysis by modeling and analysis of the selected antenna.

A case study evaluates whether installed transmissions are at risk of high-frequency ignition in the vulnerable area. The case study is performed for a single transmission and multiple transmissions.

Additionally, the dipole transmission used selects MP4 among various AEP VHF antennas; the shape and detailed specifications for MP4 are shown in Table 1. Many marine companies use the MP4 [11] model because of the wide frequency bandwidth, the wide applicability, and the included mounting nut.

Table 1. Detailed specifications of MP4 [11].

Bottom Diameter (mm)	Length (m)	Weight (kg)	Frequency (MHz)	Max Input (W)	Gain (dB)	Impedance (Ω)
28	1.20	1.00	163	100	3	50

3. Risk Assessment Based on the BS Guide

Analysis of the risk assessment is performed in accordance with the BS guide, and methods for assessing potential RF ignition risk include initial assessment, full assessment, and on-site tests. There are two initial assessments: assessment of the risk to a particular plant and assessment of the risk from a particular transmitter. First, referring to the table of the BS guide for the risk to a particular plant, the different radii of vulnerable zones are calculated for all loop structures whose inside perimeter is 40 m or less, for horizontal loops whose height is 5 m or less, and for all other loop structures. The second is a risk assessment for a particular transmitter. For the cases where the inside circumference of the roof structure is less than 85 m at the frequency of 30 MHz or more and the maximum circumference of the largest structure in the plant is 40 m at the frequency of 30 MHz or less and the height is less than 5 m for the horizontal loop structure, the radius of the zone of vulnerable is calculated by referring to the table of BS guide. If the initial assessment indicates a risk inside the vulnerable zone, a full assessment is performed. In this paper, a risk assessment based on the BS guide was performed for a frequency of 30 MHz or more and an inner circumference of the loop structure of 85 m or less.

In the full assessment, the power or energy that can be extracted is calculated and compared with the threshold value according to the gas group. Finally, if a potential hazard is indicated in the full assessment, the power that can be extracted from the on-site test is measured and compared with the threshold value according to the gas group. If an on-site test indicates a hazard, measures such as plant design changes, plant movement, and transmission power reduction are considered. The full assessment of the entire procedure for performing a risk assessment from an antenna is shown in Figure 1, which is taken from the BS guide. As shown in Figure 1, all information about the plant or transmission is first collected (① of Figure 1), and then the effective field strength is calculated (② of Figure 1) according to the equation provided by the BS guide. Then, the equation is classified into three types according to frequency and polarization. Once the effective field strength is calculated, the extractable power is calculated (③ of Figure 1). The extractable power is calculated according to the formula provided by the BS guide, and classified into two types according to frequency. At this time, if the frequency is less than 30 MHz, the internal circumference of the structure is taken into account. If the frequency exceeds 30 MHz, the inside circumference of the structure is not considered. If the transmission used in the evaluation is a single transmission (④ of Figure 1), risk is evaluated by comparing it with the extracted power and the code-based threshold power. On the other hand, when the transmission is a multiple transmission (⑤ of Figure 1), the maximum extractable power is recalculated and compared with the threshold power to assess the risk. Finally, the threshold power is compared with the extractable power (⑥ of Figure 1). If the extractable power is smaller than the threshold power, it is checked whether there is no potential ignition risk (⑦ of Figure 1). On the other hand, if the extractable power is greater than or equal to the threshold power, it is checked whether there is a potential ignition risk (⑧ of Figure 1) and the on-site test should proceed.

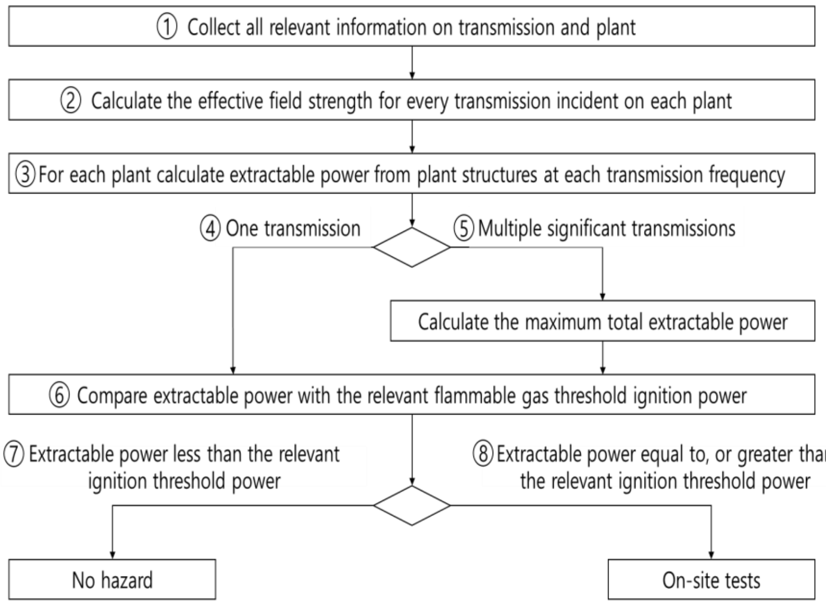

Figure 1. Full assessment procedure [7].

To evaluate the potential risks to the analysis object, risk assessment is performed based on the BS guide from Sections 3.1–3.3. For the dipole antenna to be analyzed in this paper, initial assessment is carried out for general and offshore plant-specific criteria in Section 3.1. As a result, of the analysis, it is judged if there is a potential risk, and the full assessment is performed in a single transmission environment in Section 3.2. Similarly, the full assessment in a multiple transmission environment is performed at Section 3.3. As a result, the analysis object determines whether there is a potential ignition risk under the condition.

3.1. Initial Assessment

Initial assessments are carried out on land and offshore plants in accordance with the BS guide. Offshore plants are a special concern in the assessment of ignition hazards by RF emissions. Therefore, the BS guide represents the standard for all transmissions, and the transmission criterion for offshore plants is a separate set of transmissions for special offshore plants.

A transmission in accordance with the BS guide is selected to determine the zone of vulnerability; then, it is determined if any gases or vapors that may be dangerous are inside or outside the zone of vulnerability. If gases or vapors are found to be outside the vulnerable area, the transmission is considered not to cause an RF ignition hazard, and the evaluation is stopped. Conversely, if gases or vapors are found to be located inside a vulnerable zone, the transmission is considered to cause an RF ignition hazard, and a full assessment procedure is followed.

First, initial assessment is conducted using general criteria, including land and sea. Here, the frequency is 30 MHz or more, and the loop structure is initialized to a specific transmission by setting the inner circumference to 85 m or less. Since the frequency of the antenna is 163 MHz, the transmission given in Table 2 is selected and performed. Table 2 is a reference to the radii of vulnerable zones of the BS guide and includes all land and sea transmissions. If the details of the transmissions are different from those shown in Table 2, the IIC group representing the largest vulnerable area of the closest equivalent transmission in Table 2 is selected. The initial assessment results are most similar to serial number 54 VHF and UHF land, fixed, and mobile and maritime mobile transmission, which is the largest IIC group, and the size of the vulnerable zone was determined to be 6 m.

Table 2. Radii of vulnerable zones (subsection) [7].

Serial No.	Type of Transmission	Frequency	Power	Modulation	Antenna Gain (dBi)	Radii of Vulnerable Zones (m)		
						Group I/IIA	Group IIB	Group IIC
54	VHF and UHF land, fixed and mobile and maritime mobile	68 MHz to 470 MHz	25 W	AM/RM	2	3.5	4.5	6

Second, offshore plants are a special issue in the assessment of risk of ignition by RF radiation. Thus, from general RF transmissions and antennas used in offshore plants, the vulnerable zone radius is based on the most common size of structures or cranes that can exist in an offshore plant according to BS PD CLC/TR 50427:2004. Antenna specifications and structural conditions apply equally to the general standards. Initial assessment should be performed by selecting the transmission given in Table 3. If the details of the transmission are not identical to those shown in Table 3, the vulnerable area of the nearest equivalent transmission is selected. The initial assessment results are compared to the transmission details given in Table 3. The most similar is marine VHF fixed, and the size of the vulnerable zone is determined to be 1.1 m.

Table 3. Radio frequency transmitters offshore (subsection) [7].

Transmitter	Frequency	Maximum Output Power (kW)	Typical Antenna Gain (dBi)	Radius of the Vulnerable Zone in the Main Beam (m)
Marine VHF fixed	156 MHz to 174 MHz	0.025	3	1.1

Both initial assessment on the general criteria and initial assessment specific to the offshore plant were performed on the transmission. The results on land were more conservative, with the vulnerable area of 6 m, compared to the 1.1 m of the offshore plant.

3.2. Full Assessment

Full assessment should be carried out in the initial assessment when a potential hazard appears and proceeds as follows:

- Collect all relevant information on transmissions and the plant
- Calculate the effective field strength taking into account effects of modulation
- Calculate the extractable power or energy from the adventitious antenna
- Compare the extractable power or energy from the adventitious antenna with the threshold values

Because most transmissions are modulated, the modulation must be made with clearance, and the calculated field strengths use the modulation factor to obtain the effective field strength.

The transmission is subjected to full assessment up to 6 m in the vulnerable area where the initial assessment result is more conservative. Effective field strengths are classified into three categories based on 10.4.3 [7] of the BS guide. The first one is horizontal polarization with a frequency of less than 30 MHz. The second one is vertical polarization with frequency below 30 MHz. The third one is when the frequency exceeds 30 MHz. The effective field strength is calculated by selecting one of three equations for each transmitter condition [12]. Since the frequency of the transmission is more than 30 MHz at 163 MHz, the effective field strength is calculated as follows:

$$E = \frac{0.173mF\sqrt{(PG)}}{d} \tag{1}$$

In this case, the modulation factor (m) of the VHF is 1.0 as a frequency of phase modulation (FM), and the horizontal radiation pattern (F) is 1. The antenna gain (G) is measured by the directional power (dB). If the gain is expressed in decibels, it is calculated by the following equation of BS guide [7]:

$$G = 10^{0.1g} \tag{2}$$

The calculated effective field strengths are quantified in Table 4.

Table 4. Effective field strength for single transmissions.

No.	m	F	P (kW)	g (dBi)	G	d (km)	E (V/m)
1	1	1	0.1	3	1.995	0.001	77.3
2	1	1	0.1	3	1.995	0.002	38.6
3	1	1	0.1	3	1.995	0.003	25.8
4	1	1	0.1	3	1.995	0.0035	22.1
5	1	1	0.1	3	1.995	0.004	19.3
6	1	1	0.1	3	1.995	0.005	15.5
7	1	1	0.1	3	1.995	0.006	12.9

The extractable power is calculated considering the inner circumference of the loop-type structure when the frequency is 30 MHz or less. In contrast, for frequencies above 30 MHz, without considering the perimeter of the structure, the equation given below is calculated, taking into account only the effective field strength and frequency.

$$P_{max} = \frac{124E^2}{f^2 + 3030} \tag{3}$$

The calculated extractable power is shown in Table 5.

Table 5. Extractable power for single transmissions.

No.	f (MHz)	d (km)	E (V/m)	P_{max} (W)
1	163	0.001	77.3	25.02
2	163	0.002	38.6	6.25
3	163	0.003	25.8	2.78
4	163	0.0035	22.1	2.04
5	163	0.004	19.3	1.56
6	163	0.005	15.5	1.00
7	163	0.006	12.9	0.69

The calculated power is compared to the threshold value specified in the BS guide. Table 6 shows the threshold power and thermal initiation time criterion from the BS guide. In this paper, the risk of ignition was evaluated using threshold power. If the P_{max} calculated for each gas group is less than Pth on the BS, the evaluation is no longer carried out because there is no risk of RF ignition. If P_{max} is greater than or equal to Pth, there is a potential risk of high-frequency ignition.

Table 6. Radio frequency power thresholds [7].

Gas Group	Threshold Power, *P*th (W)	Thermal Initiation Time (µs)	Representative Gas
I	6 for long narrow structures, e.g., cranes; 8 for all other structures	200	Methane
IIA	6	100	Propane
IIB	3.5	80	Ethylene
IIC	2	20	Hydrogen

The gas type is assumed to be the IIC group, considering the hydrogen as a high-risk gas located in the offshore plant, and the results are compared. As a result, of evaluating risk of ignition depending on distance, there is a risk of high-frequency ignition because P_{max} is equal to or larger than *P*th from the transmission to 3.5 m. In contrast, from 4 m to 6 m, P_{max} is smaller than *P*th, so there is no danger of high-frequency ignition.

The full assessment result and the initial assessment result at 30 MHz or more were compared with each other. In the initial evaluation using the general criteria, it was judged that there was a risk of ignition within 6 m of the vulnerable zone, and there was a danger from the full assessment to 3.5 m after the initial assessment. However, in the initial assessment, which applied specific criteria for offshore plants, it was judged that there was a risk of ignition within 1.1 m of the vulnerable zone. This analysis shows that the BS guide on general criteria including land and sea produces more conservative results, and that marine plant-specific criteria are limited.

3.3. Multiple Transmission Assessment

In the case of multiple transmissions, the effective field strength and P_{max} for each transmission are calculated according to frequency. If the sum of all the values of P_{max} is less than *P*th, there is no risk of RF ignition, and the assessment can be stopped. However, if the sum of these values of P_{max} is larger than *P*th, then the off-resonance effects should be considered by calculation of the modulus match power, P_{mm}. P_{mm} can be obtained using the following equation, where f_r is the resonant frequency of structure, $\mathrm{f_t}$ is the transmission frequency, and Q_k is the circuit factor:

$$\frac{P_{mm}}{P_{max}} = \frac{2}{1+n} \tag{4}$$

$$n = \frac{Q_k\left[1+\left\{Q_k-\left(Q_k+\frac{1}{Q_k}\right)\left(\frac{f_r}{f_t}\right)^2\right\}^2\right]^{1/2}}{\left(1+{Q_k}^2\right)^{1/2}\left(\frac{f_r}{f_t}\right)^2} \tag{5}$$

Q_k (quality factor or circuit factor) [13–15] at resonance is the quality of the frequency selection characteristic and is calculated using the equation below. The resonance frequency divided by the 3 dB bandwidth on both sides is Q_k, which means that the band is wide when the value is low and narrow when it is high.

$$Q_k = \frac{\text{resonance frequency}}{\text{3dB Bandwidth}} \tag{6}$$

f_t is the frequency of the transmission used in the assessment, 163 MHz, and f_r and Q_k are obtained through calculation. f_r is the resonance frequency of the structure and is determined to be the most conservative value at which the ratio of f_t:f_r is 1.0 with reference to Figure 2. f_r is determined to be 163 MHz since f_t is 163 MHz. Figure 2 is taken from the BS guide, and the Q_k value is 5 as an example.

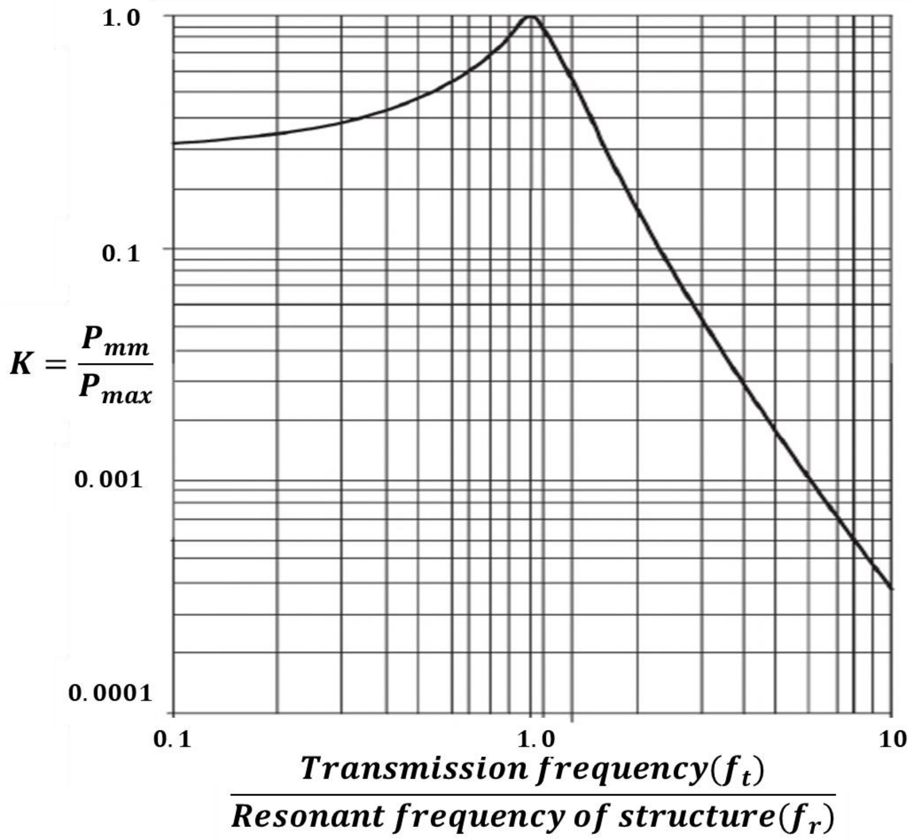

Figure 2. Modulus match powers.

As a result, if f_t and f_r are the most conservative values, n is 1 regardless of Q_k, according to the above Equation (4). Therefore, the value of P_{mm} is equal to the value of P_{max}. That is, the power of the multiplex transmission is the sum of P_{mm} of the transmitters as shown in Table 7. Comparing the threshold power and the sum of P_{mm} in Table 6, it is determined that there is a danger of high-frequency ignition because the sum of P_{mm} is equal to or greater than the threshold power up to a distance of 5 m. However, when the distance is more than 5 m, it is assumed that there is no danger of high-frequency ignition because P_{mm} is less than the critical power.

Table 7. Extractable power for multiple transmissions.

No.	f (MHz)	d (km)	P_{mm} (W)	Sum of P_{mm} (W)
1	163	0.001	25.02	50.03
2	163	0.002	6.25	12.51
3	163	0.003	2.78	5.56
4	163	0.0035	2.04	4.08
5	163	0.004	1.56	3.13
6	163	0.005	1.00	2.00
7	163	0.006	0.69	1.39

Therefore, the on-site test should be performed at the point, where it is judged if there is a risk of high-frequency ignition because the power value that can be extracted from the threshold power is greater than or equal to the threshold value. The on-site test is used to measure the actual extractable power and compare it with the threshold power of the gas group. if the results of on-site tests indicate a risk, we can investigate measures such as plant design changes, plant movement, transmission movement, and transmission power reduction. Methods include bonding, insulation, reducing the effectiveness of the structure as a receiving antenna, and de-tuning.

4. Numerical Analysis

To compare with the results based on the BS guide, the effective field strength and power are calculated by Ansys HFSS. Numerical analysis derives the effective field strength and power at a specific distance from the transmission without considering the structure to simplify the calculation. Numerical analysis was performed to measure the effective field strength up to 5 m because of the risk assessment of code analysis. Numerical analysis was performed for a single transmission and multiple transmissions. The actual shape of the dipole antenna, which is the basic transmission, and the modeled shape are shown in Figure 3. The detailed specifications are shown in Table 1.

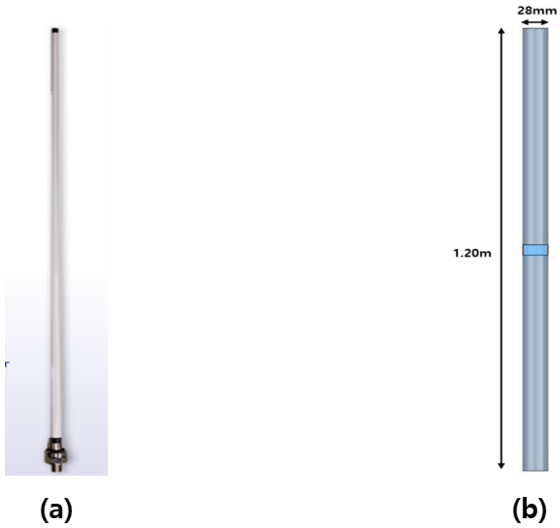

Figure 3. (**a**) Actual dipole antenna; (**b**) model for the dipole antenna.

In the numerical analysis, the effective field strength (E) of 1 m to 5 m from the transmission to the X-axis is measured from 0 to 360 degrees in 5-degree intervals according to phase and power (P). The effective field strength was calculated by assuming root mean square (RMS), which is an average value index widely used in antenna analysis. The RMS equation is defined as follows:

$$E_{rms} = \sqrt{\frac{{E_1}^2 + {E_2}^2 + \cdots + {E_n}^2}{n}} \tag{7}$$

The power passing through the surface of a specific location was calculated using the Ansys HFSS Fields Calculator. The defined power equation is as follows. Here, S is the surface used to calculate the force, and $\vec{n}$ is the normal vector for S.

$$W = \int_S Re(\vec{P}) \cdot \vec{n}\, dS \tag{8}$$

The Fields Calculator [16] referenced HFSS's Fields Calculator Cookbook's Fields Calculator Recipes.

4.1. Analysis for a Single Transmission

For a single transmission, the effective field strength (E) and power (P) were calculated from 1 m to 5 m from the transmission on the X-axis. The modeling of the transmission is shown in Figure 4, and the main specifications are as follows. Since the boundary conditions cannot be infinite in the analysis space, the boundaries are selected to be ±5.2 m on the X-, Y-, and Z-axes, and radiation conditions are given to the outermost surfaces. The port is a lumped condition, and the impedance is fed to the default value of 50 Ω. The frequency of the transmission is 163 MHz, the power is 100 W, the antenna length is 1200 mm, and the antenna thickness is 28 mm. The E field had an omni-directional shape, as shown in Figure 5. Table 8 shows the effective field strength and power measured by Ansys HFSS.

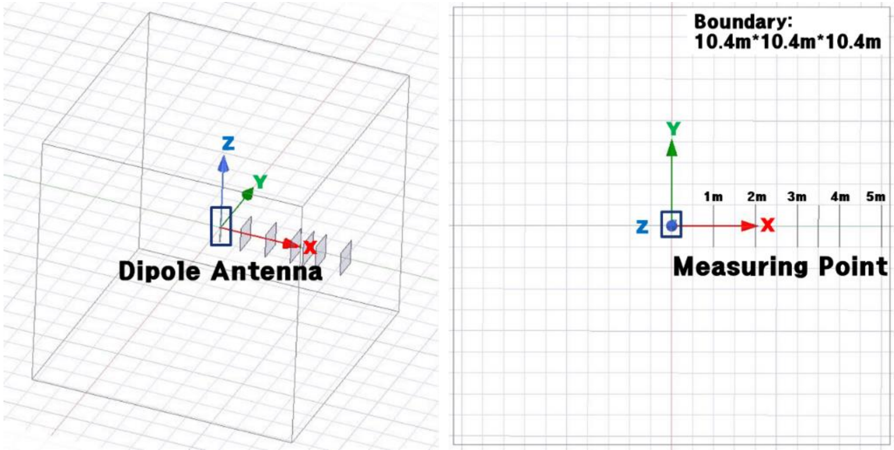

Figure 4. Modeling and measurement point for a single transmission.

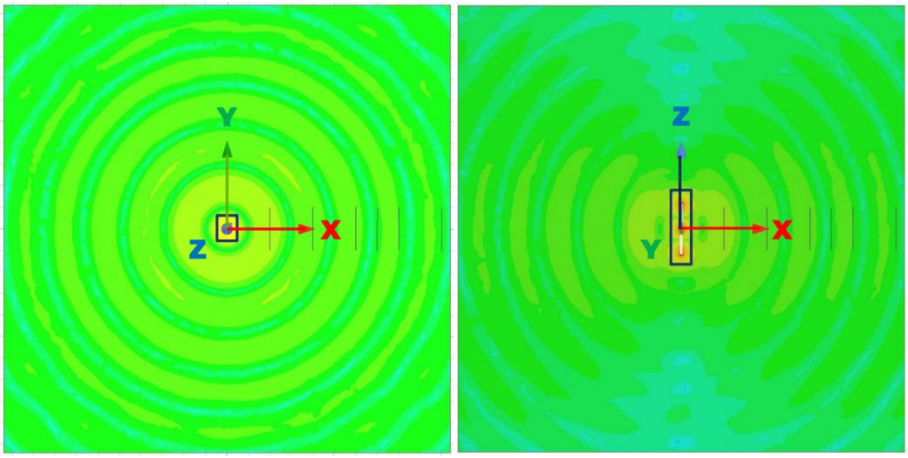

Figure 5. E field for a single transmission.

Table 8. Results for a single transmission.

No.	F (MHz)	P (kW)	d (km)	E (V/m)	P_{max} (W)
1	163	0.1	0.001	39.3	3.98
2	163	0.1	0.002	32.0	1.36
3	163	0.1	0.003	26.3	0.64
4	163	0.1	0.0035	23.8	0.48
5	163	0.1	0.004	22.3	0.37
6	163	0.1	0.005	17.6	0.25

4.2. Analysis of Multiple Transmissions

In the case of multiple transmissions, modeling is done as shown in Figure 6, and the condition is the same as a single transmission. The E field is shown in Figure 7. Unlike a single transmission, two antennas transmit to each other, producing interference. Both transmissions emit the same radiation and are located 4.5 m from each other. The effective field strength (E) and power (P) were calculated from the axis between the two transmissions, from 1 m to 5 m, on the same X-axis as the single antenna. The results of Ansys HFSS are shown in Table 9.

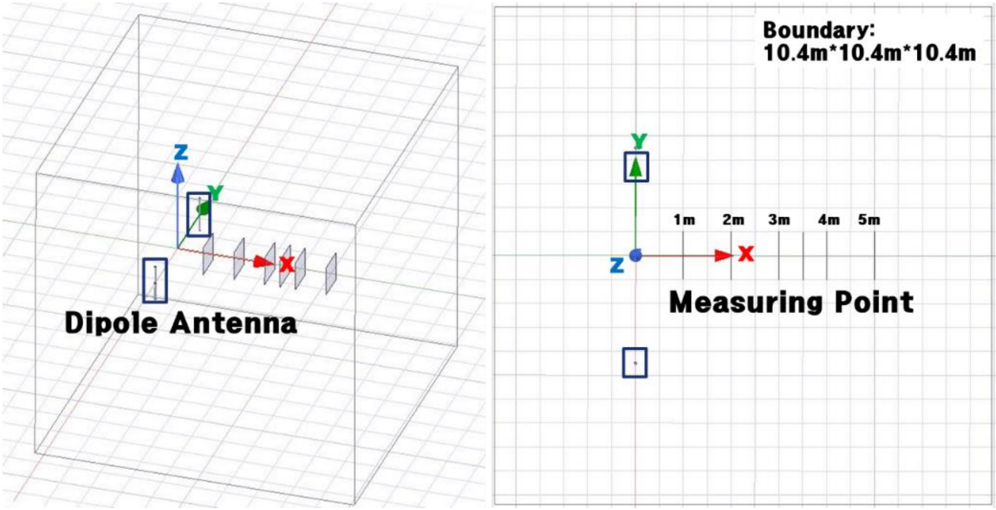

Figure 6. Modeling and measurement point for multiple transmissions.

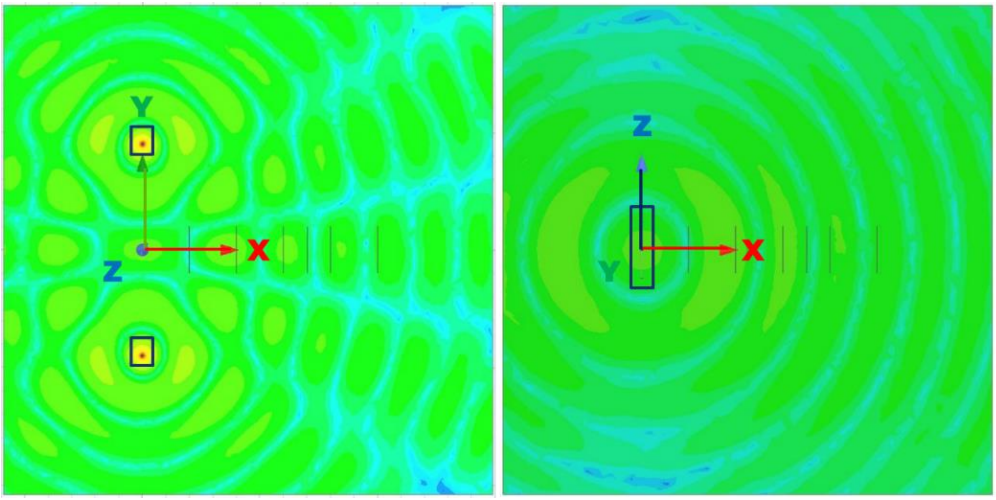

Figure 7. *E* field for multiple transmissions.

Table 9. Results for multiple transmissions.

No.	*F* (MHz)	*P* (kW)	*d* (km)	*E* (V/m)	P_{max} (W)
1	163	0.1	0.001	41.5	0.91
2	163	0.1	0.002	23.4	1.14
3	163	0.1	0.003	15.4	1.04
4	163	0.1	0.0035	13.9	0.97
5	163	0.1	0.004	11.7	0.86
6	163	0.1	0.005	10.0	0.66

5. Comparison and Analysis

In this paper, risk assessment was performed based on the BS guide and numerical analysis using Ansys HFSS to improve the accuracy of the results.

Table 10 compares the effective field strength and power for a single transmission. The code analysis calculates the effective field strength and power according to the entire procedure of the BS guide. Numerical analysis is performed by measuring the Ansys HFSS results. As a result, the effective field strength and power for a single transmission are calculated to be more conservative in the results based on the BS guide. Figure 8 shows comparison between P of BS guide and P of HFSS for a single transmission.

Table 10. Comparison between BS guide and HFSS for a single transmission.

No.	d (km)	E of the BS Guide (V/m)	E of HFSS (V/m)	P of the BS Guide (W)	P of HFSS (W)
1	0.001	77.3	39.3	25.02	3.98
2	0.002	38.6	32.0	6.25	1.36
3	0.003	25.8	26.3	2.78	0.64
4	0.0035	22.1	23.8	2.04	0.48
5	0.004	19.3	22.3	1.56	0.37
6	0.005	15.5	17.6	1.00	0.25

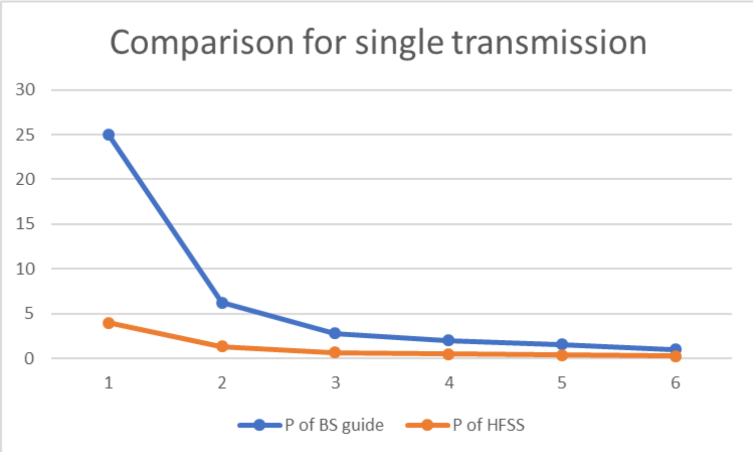

Figure 8. Comparison between P of BS guide and P of HFSS for a single transmission.

Table 11 compares the power for multiple transmissions. In the multiple transmission environment, it is possible to calculate the effective field strength and power in the numerical analysis. However, since the BS guide cannot calculate the effective field strength, only power can be calculated. Therefore, only power values are compared in the multiple transmission environment. The results are calculated at the same point as for the single transmission. The power for multiple transmissions is calculated to be more conservative for the results based on the BS guide. Figure 9 shows comparison between the power of BS guide and that of HFSS for multiple transmission. The BS guide calculates the effective field strength by using the distance difference, the antenna gain, and the antenna power, and simply calculates the power considering the antenna frequency. On the other hand, the Ansys HFSS calculates the intensity of the electric power by calculating the 3D electromagnetic field formula. Therefore, it is expected that the accuracy of risk assessment based on the BS guide can be improved by using the proposed numerical analysis.

Table 11. Comparison between BS guide and HFSS for multiple transmissions.

No.	d (km)	P of the BS Guide (W)	P of HFSS (W)
1	0.001	50.03	0.91
2	0.002	12.51	1.14
3	0.003	5.56	1.04
4	0.0035	4.08	0.97
5	0.004	3.13	0.86
6	0.005	2.00	0.66

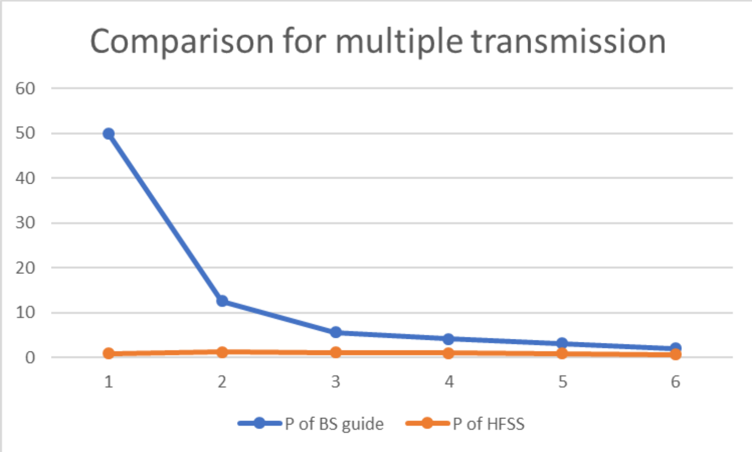

Figure 9. Comparison between the power of BS guide and that of HFSS for multiple transmission.

6. Conclusions

This paper proposed a numerical analysis method to improve the accuracy of risk assessment based on the BS guide. In this paper, risk assessment was performed based on BS PD CLC/TR 50427:2004 and IEC 6007 for a dipole antenna with an inner circumference of less than 85 m and a frequency of 30 MHz or more, which are commonly used in offshore plants. In addition, the proposed numerical analysis was performed using Ansys HFSS. Initial assessment and full assessment were performed according to the assessment procedure of the BS guide for the dipole antenna. Then, to simplify the calculation, the proposed numerical analysis was performed under conditions that did not consider the structure, and the effective field strength and power were derived. Comparing the effective field strength and power of a conventional code analysis and the proposed numerical analysis, the results of code analysis were more conservatively calculated. Experimental results showed that the proposed method using numerical analysis outperforms the code analysis in accuracy of the evaluation. n our observation, code analysis based on risk assessment was ineffective for practical site because it performed with the most general conditions without any consideration of actual environment such as structure. Therefore, it is possible to improve the accuracy of the result by using the proposed numerical analysis method.

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