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Effects of Conducted Noise on Long Power Cable Considering Submarine Environment

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Abstract

In this paper, we analyze the conducted noise level of a long cable considering a subsea environment. Because conducted noise causes distortion for a signal and power line, it must be removed. As it have a negative effect on system reliability. Thus, we analyzed the effects of the conducted noise, which is caused by the temperature at the depth of the sea. To design conducted noise, we transformed the effect of the temperature changes influencing the cable into an equivalent circuit, and co-simulated it with FEM (finite element model) tools. This method allowed us to propose a proper design method for a long cable and determine the relationship between the noise and temperature.

1. Introduction

Because of the increased demand on global resources, existing reserves of crude oil in the world are being depleted rapidly. Recently, significant attention has been paid to studies on offshore plant construction around the world in order to obtain various marine resources.

An offshore plant normally consists of a three-phase power source and VSD (variable speed drive), which are operated in the sea, and long-distance umbilical cables over 2 km and induction motors, which are run in the deep subsea [1]. An induction motor is an apparatus that converts electrical energy into mechanical energy efficiently, which has been employed in various industrial areas as a main power source. To facilitate the speed control of such induction motors, a PWM (pulse-width modulation) control method using an IGBT (insulated-gate bipolar transistor) that can perform high-speed switching has been used [2]. However, the aforementioned control method has a problem with transient voltages due to high-speed switching in contrast to a low-frequency control method. The transient voltage that occurs because of high-speed switching control has been known to influence the dielectric strength, life time, and reliability of the induction motors significantly [3].

Previous studies have mainly concentrated on transient voltage analysis through changes in voltage rising time, operation frequency, and cable length [2]. In addition, the transient voltage phenomenon has been analyzed using a transformation of the changes in the subsea cable length into an equivalent circuit. Furthermore, it was verified that as the voltage rising time was reduced, the transient voltage increased [3].

In the deep subsea, temperature changes according to the change in depth, so cable analysis and design should take this phenomenon into account. However, no studies have been performed on the analysis of transient voltage by taking temperature change occurring in the subsea into consideration until now.

Therefore, the present study aims to analyze the transient voltages that occur on the input terminal of an induction motor as well as cable modeling due to temperature change through the FEM analysis of subsea cables and the equivalent circuit configuration. Through the

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results of the study, the characteristics of the conducted noise that are changed by temperature can be analyzed, and guidelines for cable design can be proposed.

2. Analysis of Factors Acting on Cables

2.1 Occurrence of Transient Voltage

Figure 1 shows an AC motor drive system, which is analyzed in this study. The type of noise generation can be divided into conducted emissions and radiated emissions. The conducted emissions category is then divided into a common mode (CM) and differential mode (DM).Among them, noise generated because of the CM has a significant effect on the transient voltage applied to the induction motor. The CM voltage occurring because of cables can be represented by Equation (1) [1].

$$V_{CM} = \frac{2(V_{AO}+V_{BO}+V_{CO})}{3} + V_{OG} \,. \qquad (1)$$

$$= 2V'_{CM} + V_{OG} \,.$$

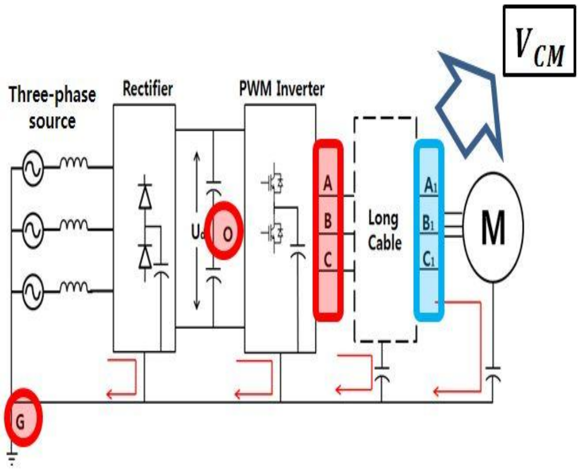


Figure 1. AC motor drive system

As shown in Figure 1, the conducted noise occurring in long cables generates impedance mismatching because of the difference between the cable characteristic impedance and load impedance.In addition, impedance mismatching can cause power transmission loss. The reflected voltage $E_r$and transmission voltage E_t at the input terminal of the motor can be represented by Equations (2) and (3) [2].

$$E_r = \frac{Z_M - Z_C}{Z_M + Z_C} \times E_i \,. \qquad (2)$$

$$E_t = \frac{2Z_M}{Z_M + Z_C} \times E_i \,. \qquad (3)$$

$Z_M$is the motor impedance, $Z_C$is the cable impedance, and $E_i$is the input voltage. Because Z_M and Z_C designed in this paper are 1 kΩ and 50 Ω, the motor input transient voltage at room temperature (25°C) is approximately doubled.

2.2 Capacitance Change with Respect to Temperature

As shown in Equation (4), the electrical characteristics of cables are expressed as impedance (Z), and the resistance increases with the cable length. However, the size of the inductance (X_L) can be negligible because its change is small compared to the resistance. In addition, for capacitance (X_C), as the cable length increases, the mutual capacitance (C_m) between the three-phase cables is a large proportion of the total impedance (Z). As the temperature increases, the distance between conductors decreases, so the mutual capacitance (C_m) decreases.Thus, the capacitance (X_C) of the cable affects the generation of the conducted noise greatly. The capacitance with respect to the temperature is shown in Equation (5) [4].

$$Z = R + j(X_L + X_C)\ .$$

$$X_C = \frac{1}{2\pi f C}\ . \tag{4}$$

$$C = C_m + C_i + C_g\ .$$

$$C = \frac{1}{63\times(2.79+0.0158T)\times10^{-5}}\ . \tag{5}$$

T is the temperature [°C], and C is the capacitance [pF]. Because this paper takes into account the capacitance with respect to the temperature change in a vacuum condition, the capacitance value is the same when the pressure is zero.Thus, as capacitance increases because of the change in the cable, reactance and noise decrease.

3. Simulation of Temperature Change in Cables

3.1 Configuration of the Thermal System

A circuit analysis program (Simplorer) and FEM analysis program from Ansoft were used to analyze the transient voltage with respect to the temperature change. Through the FEM analysis program, temperatures were applied to cables modeled in this paper, and VSD modeling consisting of three-phase power, a DC link, and a PWM inverter was conducted with the circuit analysis program. Figure 2 shows the system used to induce a transient voltage generated in long cables. As shown in Figure 2, the simulation was performed by assuming that a heating chamber was used to apply heat to the cables. Figure 3 shows the application of the temperature into the cable in FEM tools.

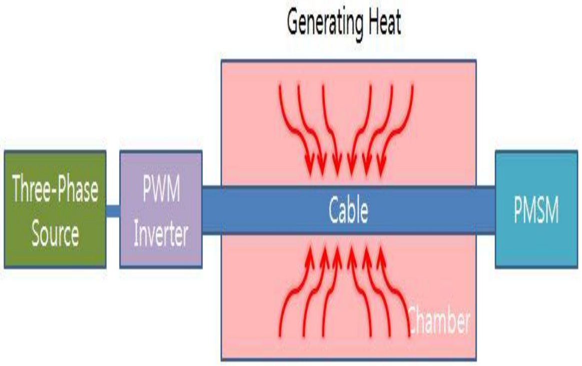
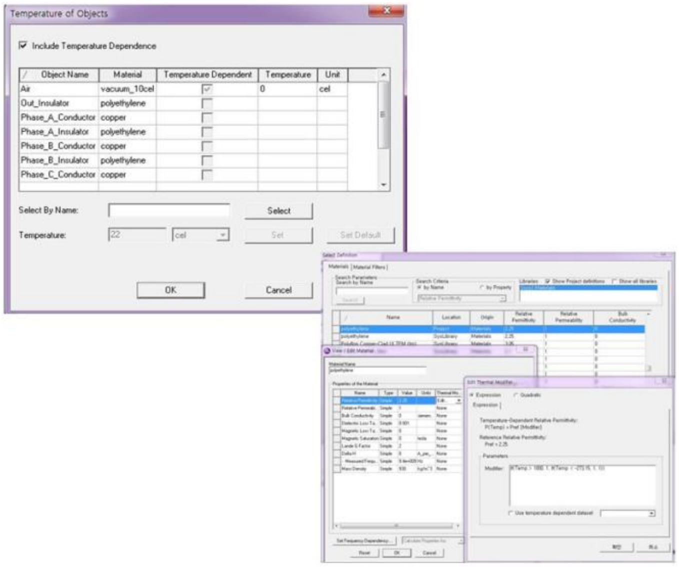


Figure 2. System configuration of the cable



Temperature of Objects

☑ Include Temperature Dependence

Object Name	Material	Temperature Dependent	Temperature	Unit
Air	vacuum_10cel	☑	0	cel
Out_Insulator	polyethylene	☐		
Phase_A_Conductor	copper	☐		
Phase_A_Insulator	polyethylene	☐		
Phase_B_Conductor	copper	☐		
Phase_B_Insulator	polyethylene	☐		
Phase_C_Conductor	copper	☐		

Select By Name:

Temperature: 22 cel

Figure 3. Appliaction of temperature into the cable

3.2 Cable Modeling

Figure 4 shows the equivalent circuit of the three-phase four-wire cables modeled in this paper. The three-phase four-wire cables were modeled with an FEM (finite element method), thereby deriving L, R, and C circuits according to changes in the shape of the cable. As a result, it was verified that a three-phase cable structure affected the reactance greatly. Figures 5 and 6 show the resistance and reactance of the cable with respect to the frequency. As shown in Figures 5 and 6, as the frequency increased, the resistance and reactance increased as well. In other words, when the reactance of the cables had a negative value, the effect of the capacitance increased.

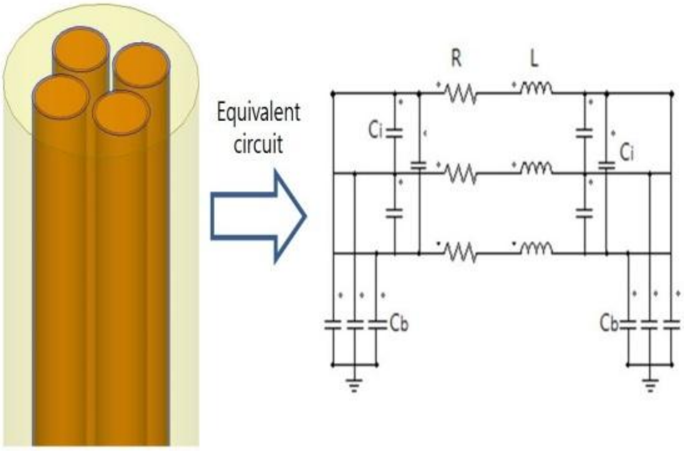


Figure 4. Equivalent circuit of cable model

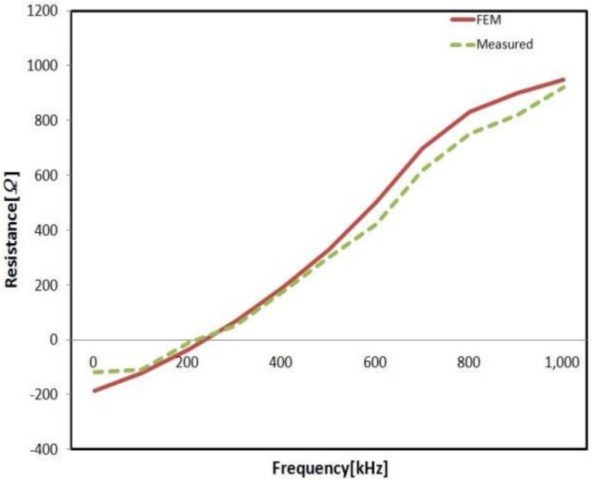


Figure 5. Resistance of cable

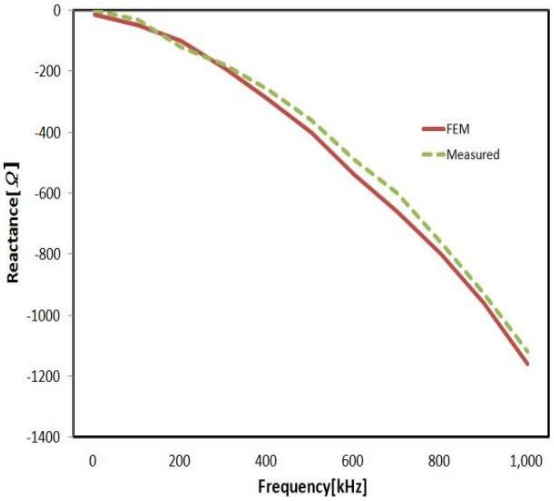


Figure 6. Reactance of cable

4. Simulation and Results

Three-phase power with a voltage of 300 V was applied as a simulation input voltage, and a commercial frequency (60 Hz) was set for the input frequency of the PWM inverter. In addition, an analysis was conducted by setting the temperature range (0–25°C) to be equivalent to a deep subsea environment. Figure 7 shows the transient status change in the PWM input voltage (0–300 V) at 0°C and 25°C. Voltages generated at the motor at 0°C were -68 to 369 V, whereas the motor voltages generated at 25°C were -18–418 V. As mentioned earlier, as the temperature decreased, the conducted noise decreased because of the increase in the capacitance. As shown in Figure 7, the transient voltage at 0°C decreased more than the transient voltage at 25°C. This is because the distance between conductors decreases as a result of the volume contraction of the internal insulation of the cable as the temperature decreases while increasing the mutual capacitance. The increase in the mutual capacitance also results in noise reduction.

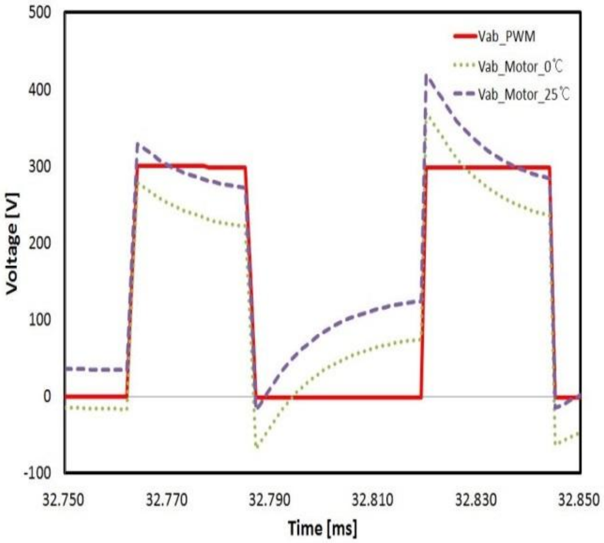


Figure 7. Input voltage of the motor at 0℃ and 25℃

Figure 8 shows the noise level generated at the motor. As shown in Figure 8, a conducted noise of approximately 36.4 [dB] at 0° was generated. At room temperature (25°C), a conducted noise of approximately 41.4 [dB] was generated, which indicated that the noise effect increased with temperature. A formula representing the plot in Figure 8 is shown in Equation (6).

$$\text{Noise level [dB]} = 2.7916\ln(T) - 36.35\,. \quad (6)$$

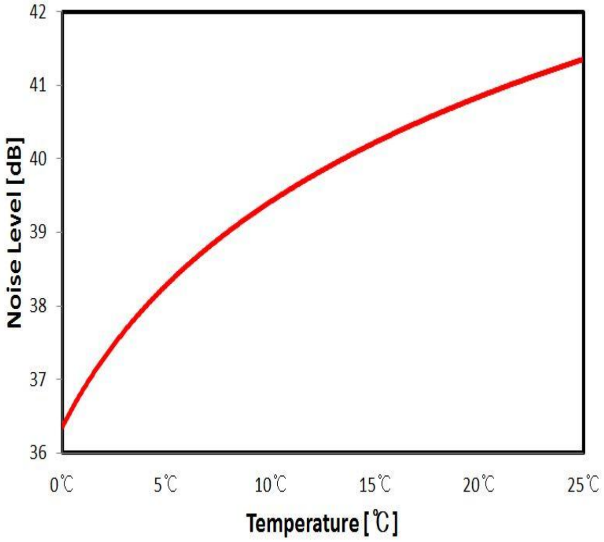


Figure 8. Noise level of the cable

5. Conclusion

In this study, the characteristics of conducted noise in long cables with respect to temperatures in a subsea environment were analyzed.The result of cable noise analysis showed that a transient voltage was generated up to a maximum of 40.1% and a minimum of 23.6% in a temperature range (0–25°C) defined as the subsea environment temperature. This is because changes in the distance between conductors occurred as a result of temperature change, thereby affecting capacitance.Through the study results, reliable systems can be constructed as transient voltages generated in the motor drive and can be determined in advance. Furthermore, design guidelines for subsea plant systems can be presented by analyzing transient voltages in the temperature range of a subsea environment.

For a future study, the conducted noise due to an increase in the cable length with varying temperature will be analyzed as well as the capacitance change due to the rising time of noise, and the noise reduction effect will be studied.

Acknowledgments

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