QUANTIFICATION OF INFLUENTIAL FACTOR TO ELF MAGNETIC FIELD DISTRIBUTION AROUND ELECTRIC POWER INSTALLATION

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Abstract: For the optimum design and construction of electric power installations, extremely low frequency (ELF) magnetic field distribution in and around them is to be quantified from electromagnetic environment viewpoints. From the background, it is important to know which power line strongly influences the magnetic field distribution. This paper describes how the magnetic field changes with the distance from various types of magnetic field sources in actual power substation. The results give us knowledge on how to mitigate the magnetic field strength and how to optimize the power substation layout and its operating condition.
Key words: ELF magnetic field, power substation, finite element method, power line current, influential factor.

1. Introduction

In recent years, the attention to the extremely low frequency (ELF) electromagnetic environment is being attracted from the viewpoints of reliability of the electric power supply and electromagnetic compatibility. Various forms of power transmission and substation installations are being introduced. Especially in populated regions, indoor or underground installations using XLPE (cross-linked polyethylene) cable, GIL (gas-insulated transmission line) and GIS (gas-insulated switchgear) are widely applied, taking the place of a conventional open-air installation. The change of the power installation form makes the electromagnetic environment complicated.

We are proceeding with research on the following items with an aim toward evaluation of the electromagnetic environment around power installations, (i) establishment of a precise technique for measuring the magnetic field (ii) quantitative evaluation of the magnetic field around power installations. We have carried out simultaneous measurement of power line current and the ELF magnetic field around various installations on-site, such as 275kV overhead power transmission lines (TL), 77kV open-air substation (SS), 500kV open-air SS, 500kV gas-insulated SS and 275kV underground SS [1-3]. We have also reasonably explained the measurement results using the numerical calculations like Biot-Savart's law and FEM (finite element method) [1-3].

For the optimum design and construction of electric power installations, it is important to know which power line strongly influences the magnetic field distribution as related to the power line configuration and current conditions. Firstly, we have to consider which power line is dominant to the magnetic field distribution in the region we focus on. Secondly, we have to consider the rate at which the magnetic field decays to the distance from the power line. This paper shows the quantitative investigation for them based on the measurement and calculation results. As typical power lines in substation, we choose an open-air bus bar, a gas insulated bus bar with enclosure and an XLPE cable with sheath conductor, and calculate respectively the changing characteristics of magnetic field with the distance from the power line. Using the characteristics, we explain the influential quantity of the power line on magnetic field. The influential quantity informs us which power line is important to mitigate or optimize the ELF magnetic field distribution in SS.

2. Features of the ELF magnetic field distribution around power installations

In actual power installations, the magnetic field distribution around them is influenced by various factors, as illustrated in Fig. 1. The main factors are

(1) conductor current,
(2) conductor configuration, and
(3) material property of structures.

In the evaluation of the magnetic field environment in the installations, we should carefully take these factors into account. As examples, Table 1 shows typical power line components in various forms of power SS. These components have different features each other on magnetic field as mentioned later.

We explain the example of the features of the ELF magnetic field distribution using Fig. 2. This figure indicates the measurement result of magnetic field distribution in an actual 500kV gas-insulated SS. From this figure the features of the magnetic field distribution are listed below,

(1) the magnetic field strength in the 275kV yard is higher than that in the 500kV yard.

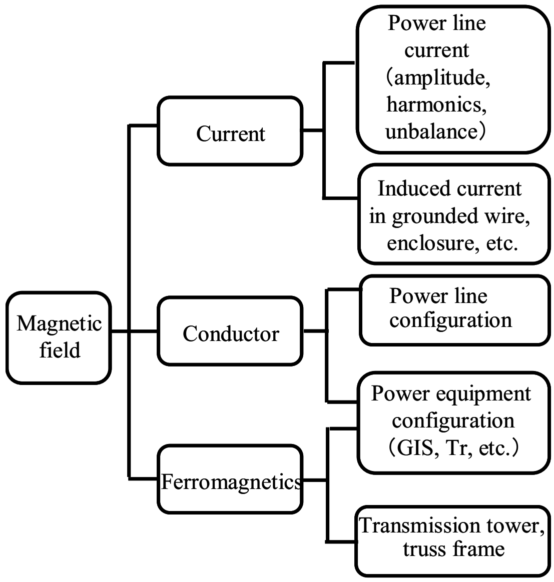


Fig. 1 Factors affecting ELF magnetic field around power installations.

(2) the peak value of magnetic field near GIS is similar strength with the one under the overhead TL

(3) the change of magnetic field with the distance from the power line differs between around GIS and around overhead TL, i.e. it is rapid from GIS while gradual from overhead TL.

3. Magnetic field characteristics from power line

3.1 Comparison of measurement and calculation

Figure 3 shows the magnetic field characteristics with distance from XLPE cable in the actual 275kV underground SS. We carried out the magnetic field measurement by 3-axial search coil type sensor. For calculation, we set a 2-dimensional model which consists of inner conductor, insulation layer and copper sheath, etc. The calculation result is derived by finite element method. The calculation data agree with the measurement one, which gives the validity of this finite element model. For other structure in substation, we conducted the calculation model in similar way to get enough validity [2-3].

Table 1 Components included in power substation

		SS form		
		Open-air	Gas-insulated	Under-ground
PL	AIB,AIS	***	**	*
	GIB,GIS	**	***	***
	XLPE	**	**	***
	Tr	***	***	***

AIB,AIS: air insulated busbar / switchgear
GIB, GIS: gas insulated busbar / switchgear
XLPE: cross-linked polyethylene cable
Tr: Transformer, PL: power line
***: mainly used, **: limitedly used, *: less used

3.2 Power line model

As the magnetic field sources in power SS, we choose three types of power line model as shown in Fig. 4. The three-phase power line in substation is simulated as different three types; open-air bus bar (OAB), gas-insulated busbar (GIB) and XLPE cable. The dimensions are determined based on the line configuration in the actual power SS. All models are 2-dimensional.

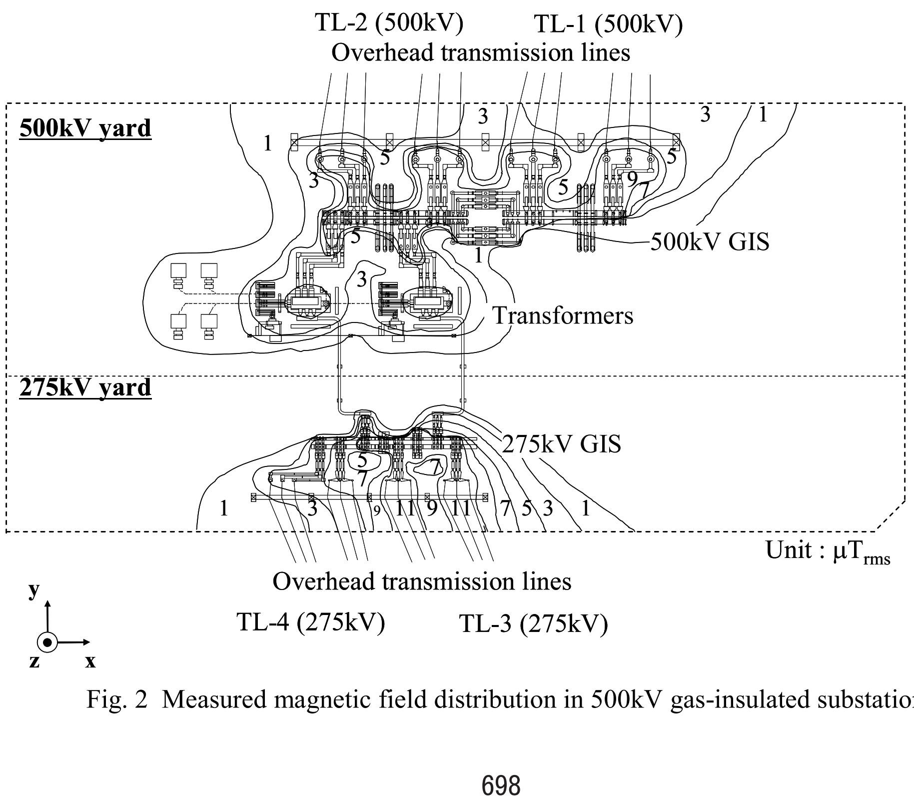
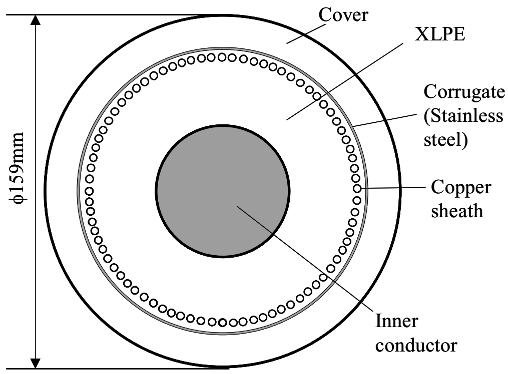
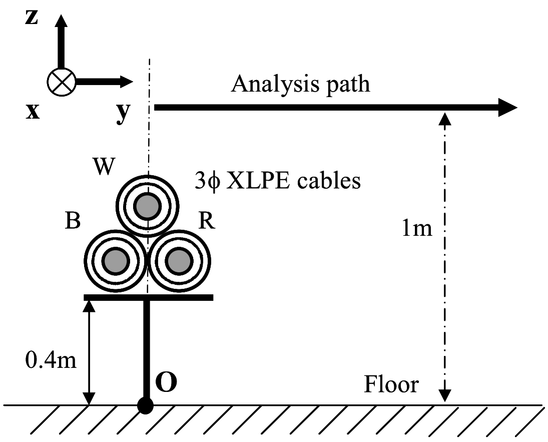


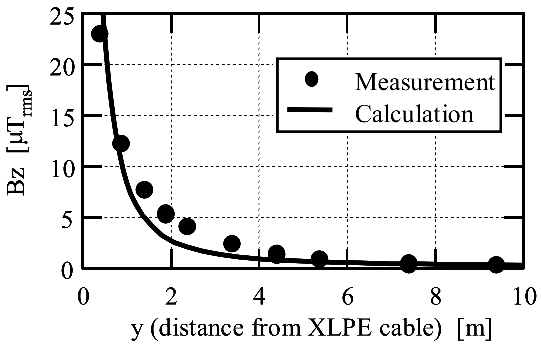
Fig. 2 Measured magnetic field distribution in 500kV gas-insulated substation.



(a) Cross section of XLPE cable.



(b) Configuration of 3-phase XLPE cables.



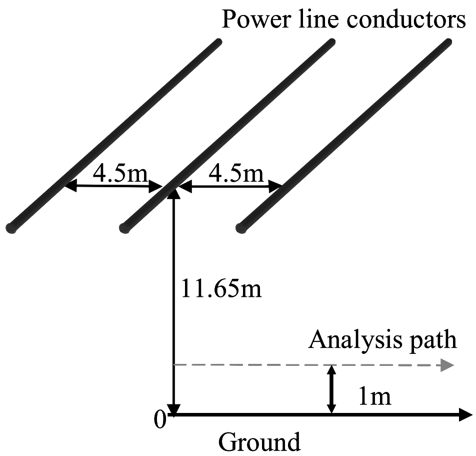
(c) Magnetic field along the analysis path.

Fig.. 3 Measurement and calculation results of magnetic field around XLPE cables.

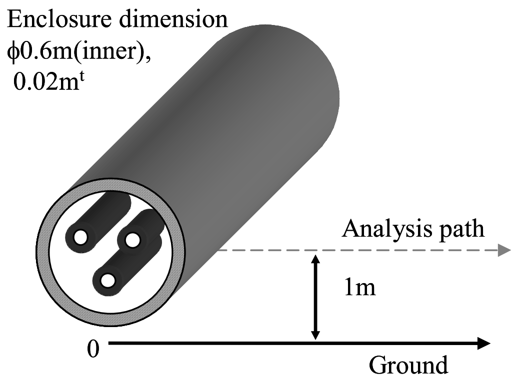
The three-phase power line current is given to be completely balanced and its amplitude is $1000A_{rms}$. As a way to analyze magnetic field distribution, Biot-Savart's law is used for OAB and finite element method is used for GIB and XLPE cable, respectively. The analysis path is set from the center of the source at a height of 1meter above the floor.

3.3 Magnetic field distribution with the distance

In order to evaluate the influential quantity how wide the power line gives the magnetic field, we define a measure K_d as that magnetic flux density is larger than $1\mu T_{rms}$ in $y< K_d$, where y the horizontal distance from the center of the power line. Figure 5 shows the result of K_d in the 3 models for magnetic flux density B_z. From the result, the K_d for OAB is much larger than GIB and XLPE cable. The ratio of K_d is about 2.8 between for GIB and for XLPE cable, while the K_d for OAB is 20 times larger than GIB.



(a) OAB (open-air bus bar) model.



(b) GIB (gas-insulated bus bar) model.

- XLPE cable model has the same configuration as that in Fig.3 (b).

Fig. 4 Configuration of analysis model.

3.4 Effect of the line type

The different characteristics of magnetic field among the 3 models are due to two factors. The first factor is the power line configuration (e.g. height and phase-phase distance). The second factor is the shielding effect of the grounded enclosure (sheath) for GIB and XLPE cable. The information which factor is dominant is important to understand the influence of the power line structure onto the magnetic field strength.

Let us compare the magnetic field between for OAB and for GIB. For investigation, a model GIBn is defined as that the enclosure part is removed from GIB model. In order to explain the shielding effect of the GIB enclosure, we use the following equation

$$\alpha_{GIB} = -20\log_{10}(B_{GIB}/B_{GIBn}) \quad (1)$$

When the another parameter

$$\beta_{GIB} = -20\log_{10}(B_{GIB}/B_{OAB}) \quad (2)$$

is defined, we can explain the effect of the power line configuration as the difference of β_{GIB} and α_{GIB}. By the similar way, we can define two parameters for XLPE cable as

$$\alpha_{XLPE} = -20\log_{10}(B_{XLPE}/B_{XLPEn}) \quad (3)$$

$$\beta_{XLPE} = -20\log_{10}(B_{XLPE}/B_{OAB}) \quad (4)$$

Figure 6 shows the dependence of parameters α_{GIB} and β_{GIB} on the distance from the line. From this figure we find that the α_{GIB} is independent on y, the distance from the power line. This figure also shows that the difference between α_{GIB} and β_{GIB} is small in the range from y=3.5m to 10m. This means that the difference of magnetic field characteristics between for OAB and GIB is dominated by the existence of the GIB enclosure. In y<3.5m, the α_{GIB} is greater than β_{GIB}. This means that the power line configuration effect of GIB works as field enhancement against OAB. At y=0.68m, it cancels the attenuation effect by enclosure of GIB.

We investigate for XLPE cable in the similar way. Figure 7 shows the result. The figure indicates that the α_{XLPE} is constant in whole distance region. In y<1.6m the α_{XLPE} is smaller than β_{XLPE} which means the power line configuration works as field enhancement factor as the same way in GIB case. In y>1.6m, the β_{XLPE} is greater than α_{XLPE}, which means the power line configuration works as attenuation factor for magnetic field, which appears different for the GIB model.

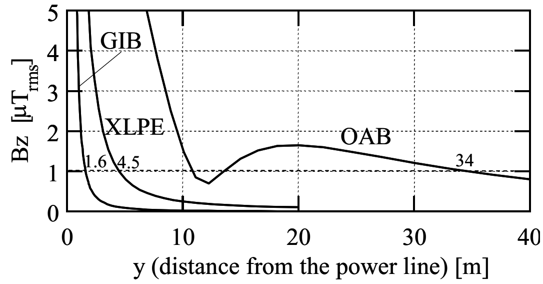


Fig. 5 Magnetic field distribution around 3 types of power line model.

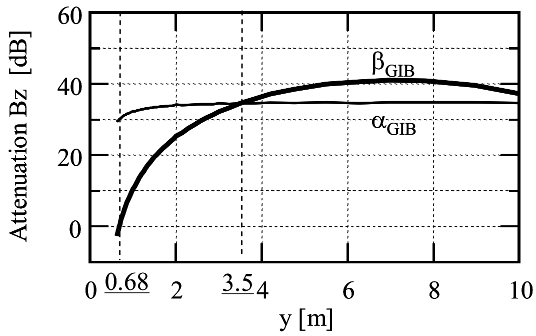


Fig. 6 Distance characteristics of α and β around GIB model.

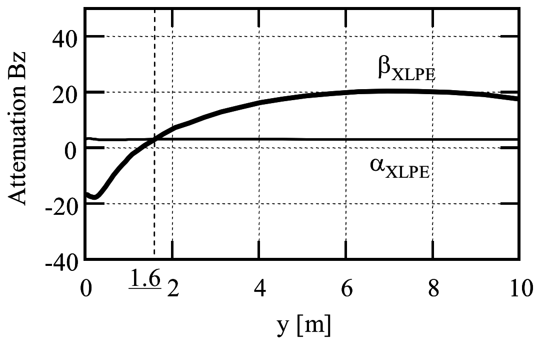


Fig. 7 Distance characteristics of α and β around XLPE cable model.

4. Conclusion

We compared the magnetic field distribution around different power lines in substations. We calculated the distance dependence from typical three power line models; open-air bus bar, gas-insulated bus bar and XLPE cable. From the results, we obtained the following conclusions.

(1) From the comparison result between measurement and calculation, the three power line models selected here are valid for the estimation of magnetic field distribution in the power substation.
(2) We quantitatively clarified the measure how far the power line gives the magnetic field. The open-air bus bar has the largest value among the 3 models; 20 times larger than gas-insulated bus bar model.
(3) The power line configuration and the enclosure shielding effect are influential factors to the magnetic field. We clarified their distance dependence from the power line. Enclosure shielding effect is independent on the distance from the line both for gas-insulated bus bar and for XLPE cable. The line configuration effect appears as different characteristics between gas-insulated bus bar and XLPE cable models.

These results contribute to the systematization and prediction of the magnetic field environment, and optimization technique in the power installation construction.

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