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Analysis of magnetic field generated by overhead cables

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ABSTRACT

Overhead cables are widely applied in power distribution and transmission networks due to their financial and geographical merits. But since the environment issue has become a general concern, negative impacts of overhead cables are no longer negligible. Although overhead transmission lines are gradually being replaced by underground cables for the purpose of improving the security and stability of power transmission system, a large number of overhead cables are still in use. If buildings are built below the high voltage cables, people who stay inside will be adversely affected by power frequency magnetic fields. In order to solve this issue, our paper studies the distribution of magnetic field produced by a 500 kV cable, and proposes a shielding method to reduce the indoor field intensity. In this research, field distribution is analyzed through simulation, and the maximum indoor field intensity is calculated and compared with safety limits in the guide rule of limitation. Shielding method proposed in this paper provides good protection performance and halves the indoor intensity of magnetic field produced by the 500 kV overhead cable.

1. Introduction

Cables used in power systems are generally categorized as overhead cable and underground cable. Although stability of overhead cables can be greatly affected by meteorological changes, which often causes electrical failures, they are commonly used in power transmission systems for the cost effective advantage. As overhead cable installation has no geographical limitation, it is often used for long distance power transmission. In recent years, with the development of power system, increased load on power grid and concerns for environment result in gradual replacement of overhead cables. Underground cables start to take place. But this process is highly costly and requires time for system re-planning, so there will be years until overhead cables are completely out of the power system. Since a great number of overhead cables are still in operation, the adverse impact needs to be dealt with.

Magnetic field is a public concerning pollution problem in modern society. If the magnetic field (MF) has high intensity or frequency, it could harm human health [1,2]. Changing power frequency magnetic fields produced by power cable is usually 50 Hz or 60 Hz. They are not high frequency fields, but when the power level of cable is high, magnetic field will have intense strength. To provide protection from magnetic field, many countries have proposed strict national standard of field intensity. Sweden presented a rule to limit the power level of transmission lines passing uptowns to ensure the magnetic field intensity does not exceed 20 μT. This limiting value is based on the research of relations between magnetic field level and the childhood leukemia [3]. This standard is also applied in the U.S. Several state and local governments have adopted electric and magnetic field limits for transmission lines, 10 kV/m within rights-of-way and 2 kV/m at the edge of rights-of-way for electric fields and around 20 μT for magnetic fields [4]. ICNIRP (International Commission on Non-ionizing Radiation Protection) formally published the “Guide rule of Limitation of varying of electric, magnetic and electromagnetic field (under 300 GHz)” in April, 1998 [5]. This Guide rule has introduced the limitation of direct and indirect effect of magnetic field. Limitations for power frequency electromagnetic fields are detailed in Table 1.

Currently, there are researches aiming at analyzing magnetic field produced by high voltage transmission lines. Machado evaluated the electromagnetic field of underground cables in 2010 [6]. He obtained the magnetic field distribution inside and outside the cables. With these data, Machado proposed a Magnetic Field Mitigation Shielding for power cables, and analyzed the magnetic shielding effects of 2 different materials for underground three-phase cable in a flat configuration. A comparison is made between the aluminum (conductive) and the steel (ferromagnetic) shielding cases [7]. It turned out that the aluminum is more efficient. Machado’s researches are focused on adding shielding

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Table 1
Guide rule of Limitation of varying of electric, magnetic and electromagnetic field.

Affected population	Basic limits (mA/m^2)	EMF intensity (kV/m)		Magnetic density (μT)		Current (mA)
		50 Hz	60 Hz	50 Hz	60 Hz	
Occupational population	10	10	8.3	500	417	1
General population	2	5	4.2	100	83	0.5

cases on cables, which is highly effective on minimizing magnetic flux density generated by cables. But for overhead cables that have already been set up, it is not applicable to install extra component, since it's not safe to let cables bearing extra weight. Based on Machado's research on shielding materials, aluminum is used as shielding for protection in this paper and shielding effect is further analyzed regarding its thickness.

There are many other researches on power cables magnetic field sensing, while very few aimed at the effects and shielding on residential buildings. In this paper, we focus on providing a feasible strategy for magnetic field protection. Before the method is proposed, magnetic intensity and distribution are analyzed. It has been proved by other researches that finite element method (FEM), finite difference method, charge simulation method can all be applied in complicated 3-D magnetic field analysis [8–12]. In this research we use Ansoft Maxwell to achieve the magnetic field simulation around high buildings. To improve the computational accuracy, we picked out encrypted and subdivided regions that need to be noted with adaptive grid encryption technology.

2. Method for magnetic field simulation and computing

2.1. Principle of finite element method

FEM is an approximate discrete interpolation method based on variation principle. This method is to divide target area into small regions, and solve each region with linear calculation. Final results for the whole area can be obtained by synthesizing solutions from all divisions. Small regions in this method are called "unit" or "finite element". After they are created, the model is simplified and computations are easier, only left with algebraic operations. Values of unknown area can be obtained by applying linear interpolation in finite elements, which means the regional integration is transformed into summations of data in units.

The finite element method for solving boundary value problems has three processes. The first is to use the variation principle to transform the boundary value problem into a variation problem, also known as functional extreme value problem. The second process is using the field dispersion and grid division as well as approximation of function interpolation on the unit to transfer the variation problem into a general extreme value problem of ordinary multiple functions. Finally, the problem can be listed as a set of algebraic equations. Numerical solution of these equations is the results of boundary value problems [13].

Applying FEM in a practical issue requires applicable boundary conditions to describe a physical quantity of boundary, which is also the initial step of computation. In practical problems, there are a variety of boundary conditions, commonly used are: (1) the natural boundary condition; (2) the Dirichlet boundary condition; (3) the subordinate boundary conditions; (4) the symmetric boundary conditions; (5) the impedance boundary condition; (6) Zero Tangential H Field; (7) Radiation Boundary. In the simulation in Section 3.2, radiation boundary condition is used.

2.2. Vortex field analysis

In 3D vortex field, both $\overrightarrow{B}$ (field density) and $\overrightarrow{J}$ (current density) have three components. Then there are six unknowns in the function. If using the magnetic vector potential to solve the equation, scalar potential cannot be subtracted out, so the mathematical model for 3D vortex field is important.

In the analysis of 3D vortex field, the research field is usually divided into two parts, the vortex area and non-vortex area. In vortex area, both electric and magnetic field need to be described. In non-vortex area, only magnetic field needs to be described. The combination of vector potential and scalar potential is required in eddy current region. In the non-eddy zone, only vector or scalar potential is required.

Select vector magnetic potential $\overrightarrow{A}$ and $A-\varphi$ as base, followed coulomb gauge $\nabla\cdot\overrightarrow{A}=0$, classify source current in non-eddy current region. Then uniqueness of $\overrightarrow{A}$ and φ is guaranteed, and stable numerical solution can be obtained for any harmonic field.

The vortex field function is,

$$\nabla\times\frac{1}{\mu}\nabla\times\overrightarrow{A}-\nabla\frac{1}{\mu}\nabla\cdot\overrightarrow{A}+\sigma(j\omega\overrightarrow{A})=0 \tag{1}$$

$$\nabla\cdot\sigma(-j\omega\overrightarrow{A}-\nabla\varphi)=0 \tag{2}$$

$$B=\nabla\times\overrightarrow{A},\quad E=-j\omega\overrightarrow{A}-\nabla\varphi \tag{3}$$

The non-vortex field function is,

$$\nabla\times\frac{1}{\mu}\nabla\times\overrightarrow{A}-\nabla\times\frac{1}{\mu}\nabla\cdot\overrightarrow{A}=\overrightarrow{J}_s \tag{4}$$

$$\overrightarrow{B}=\nabla\times\overrightarrow{A} \tag{5}$$

In the functions, $\overrightarrow{B}$ is field density; $\overrightarrow{J}$ is current density; $\overrightarrow{J}_s$ is source current density; σ is conductivity; μ is permeability. The advantage of this method is that, the interface condition is natural boundary condition, source current term is easy to deal with and the precision is high. When the geometric dimensioning, media electromagnetic parameters and source current distribution are given, spatial distribution and temporal variation of regional magnetic field (B or H) and eddy current density (Je) can be calculated.

3. Indoor magnetic field distribution analysis of high voltage cable

3.1. Model of high voltage cable and residential building

Assuming a 500 kV single circuit transmission cable is crossing above a building. The building is assumed as standard cuboid-shaped residential buildings, with dimensions of $30*10*35$ m. Middle conductor is right above the middle of the construction. Power delivers in form of parallel transmission. The distance between center line and side line $D=13.72$ m. Model is shown in Fig. 1.

In practical project, transmission lines are bundled conductors. 500 kV cable consists of 4 partial conductors. Each conductor has radius r of 0.0148 m, and bundling radius R' is 0.323 m [13]. For calculation convenience, we simplify the cable model, which is shown in Fig. 2. The computational formula of equivalent radius is,

$$R=R'\sqrt[n]{\frac{nr}{R'}} \tag{6}$$

In the formula above, n is the quantity of partial conductors. To cable with 4 partial conductors, $R'=d/\sqrt{2}$, in which d is the space between each sub conductor. In high voltage cable, the space is generally in the range of 400–450 mm. The equivalent radius of three phase cables A, B, C can be calculated with Eq. (6), and the