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Distribution Characteristic and Shielding of Power-frequency Electromagnetic Field

Van De Steenberg
Middle Tennessee State University, 1301 East Main Street, Murfreesboro, TN 37132-0001, USA
E-mail: vandesteenberg@mstu.edu

Abstract

In this paper, we studied the electromagnetic field intensity around the electrical equipments in 500 kV substations. The electromagnetic field intensity varied with the distribution of electrical equipment. We noted that 18% and 82% of electric fields intensity were higher than the national standard in 220 kV regions and 500 kV regions respectively in air insulated switchgear distribution substations. A lower percentage (74%) was observed in 500 kV regions of outdoor hybrid gas insulated switchgear distribution substations. Most electric field intensity was in 5kV/m~7kV/m which exceeded the Chinese national standard. However, no electric field intensity was higher than the national standard in indoor gas insulated switchgear distribution substations. The maximum magnetic fields exceed the professional exposure limit 5 times, which reach 2762 μT. Moreover, the experiments on application of nano-fabrics material for shielding power frequency electromagnetic field were carried. Results indicated that both shielding fabrics can almost completely shield the electric field, but have weak shielding effectiveness against magnetic field.

Keywords: power frequency electromagnetic field; distribution; shielding effectiveness.

1. Introduction

Substations are the points in the power network where transmission lines and distribution feeders are connected together through circuit breakers or switches via busbars, transformers, and other electrical equipment. Due to their expansive physical dimensions, transmission line and substation networks are the most critical components of a power system from an electromagnetic point of view. They act as huge transmitting antennas, inducing or radiating electromagnetic fields (EMFs) into the surrounding space. The 500 kV substations are a complicated system, in which the EMFs deserve more attention than ever. However, there have been a string of reports claiming the effects of EMFs on living systems although little is known about how these effects occur [1]. The health risk assessment and risk management of the evidence from exposures to occupational and residential have been studied [2-7]. The exposure limits to electromagnetic fields are quantified. Most of them were accompanied by measurements of electromagnetic field in substation or nearby transmission line. The electromagnetic field intensity around in substation depends on the distribution of electrical equipment. Thus, to ensure normal exposure levels of the substation operators present in this electromagnetic environment, the distribution regularities of electromagnetic fields must be accurately analyzed. In this paper 500 kV substations are evaluated in order to verify how electromagnetic fields are distributed inside its installation.

2. Materials and methods

2.1 Experimental measurements

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Electromagnetic fields are distributed in 500kV substation according to the equipments layouts, electrical distances, connections and grounding systems. We defined a limited number of typical substations in order to enable a comparison between the different equipments layout. Table1 lists these typical substations together with a short name. 3 representative 500kV substations belonging to the Guangdong Power Grid Corporation (CSG) were selected as the objects according the different features of electrical equipment. In each of the substations, measurements were performed using PMM 8053A electromagnetic radiation analyzer meter with the isotropic EPH-50B probe ((PMM, Italy) [8].

Table 1. Considered equipments layout for comparison.

Substations type	**Logical name**	**Description**
Type A	Open air insulated switchgear distribution	The electrical equipments were installed in outdoor. Circuit-breaker, switch mechanism, current transformer (CT), potential transformer (PT) and others were installed independently.
Type B	outdoor hybrid gas insulated switchgear distribution	The electrical equipments were installed in the outdoor, and which were installed in gas-insulated switchgear. It is known as the outdoor GIS layout.
Type C	indoor hybrid gas insulated switchgear distribution	The electrical equipments were installed in indoor, and which were installed in gas-insulated switchgear. It is known as the GIS indoor layout.

All measuring spots were set in patrol passages of 500kV substations, which mainly include relative high voltage regions (500 kV regions), relative low voltage regions (220 kV regions), and 35 kV regions, etc. The starting spots were set a distance near the enclosure wall 2 meters, and the next measuring spots were located in a 5 meters distance until to the other side enclosure wall. In 35 kV regions, the measuring spots were set from shunt reactors center to the position in which the EMFs were close to the background value. The next measuring spots were located in a 1 meter distance flowing in three directions.

Both the testing and evaluating directives have been transposed in the Chinese national standard. The testing method is the measurement of physical agents in workplace part 3: power frequency electric field (GBZ/T 189.3-2007). The values of electromagnetic field intensity were evaluated according to the occupational exposure limits for hazardous agents in the workplace part2: physical agents (GBZ 2.2-2007) and the labour environment monitoring technological specification of electric power industry part 7: monitoring of power frequency electromagnetic fields (DL/T 799.7-2010). Considering the 50 Hz power frequency, the professional exposure to the electric field is limited to 5 kV/m, and the professional exposure to the magnetic field is limited to 500μT, which is more rigorous than the guidelines for limiting exposure of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [9].

2.2 Electromagnetic shielding experiment

The nano silver fiber woven fabric and nano alloy coated fabric (Kangyi, Shenzhen) were selected as the shielding textile fabric. The electromagnetic shielding experiment was tested in high voltage laboratory. The characteristics of two kinds of textile fabric are depicted in Table 2.

Table 2. Comparison of the two shielding fabrics

Material	Structure	Character	Useage
Nano alloy coated fabric	Firm, hard film	The permeability and antioxidant capability are good	the lining or pockets in protective radiation suit
Nano silver fiber woven fabric	Firm, hard, antioxidant film	The product have functions of antibiotic and deodorize.	wearring close to the skin

The following formula can be used to compute the shielding effectiveness (SE).

$$SE_{E(H)} = 20\lg\frac{E_0(H_0)}{E_s(H_s)} \tag{1}$$

Where E0 (H0) and Es(Hs) are the inducing electric (magnetic) field intensity and the shielding electromagnetic field intensity in fabric.

3. Results and discussion

3.1 Electromagnetic field distribution in the type A substations

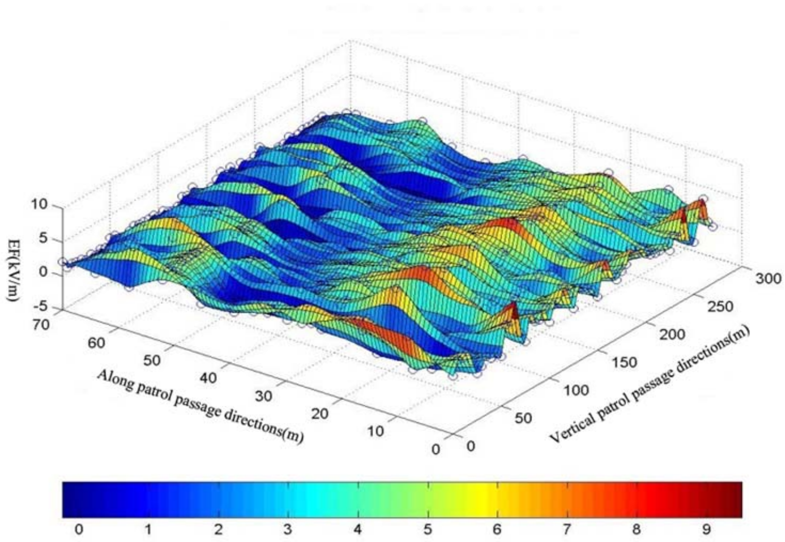

Figure 1. The electric field distribution of 220kV regions in Type A 500kV substations

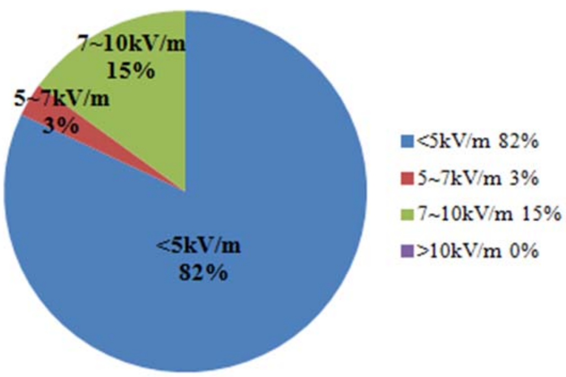

Figure 2. The pie chart of electric field intensity of 220kV regions in 500kV Type A substations

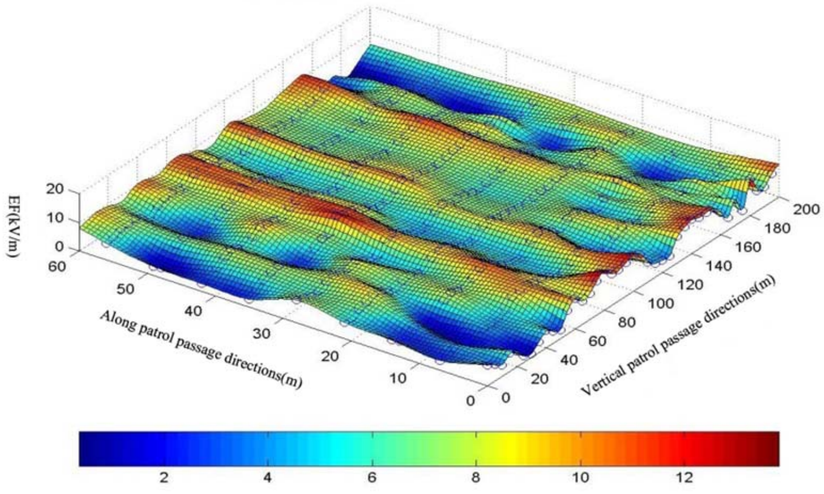

Figure 3. The electric field distribution of 500kV regions in Type A 500kV substations

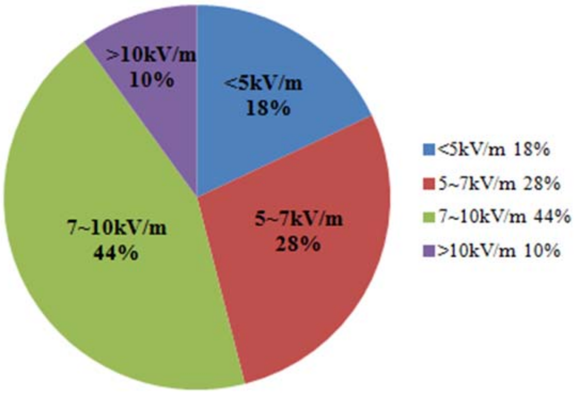

Figure 4. The pie chart of electric field intensity of 500kV regions in 500kV Type A substations

The electric field distribution was tested in type A substations. Experimental results of the electric field measurements are given by color maps and pie chart are built. As can be seen in figure 1 to figure 4, there are 82% measuring spots in which the electric field intensity is less than or equal to 5 kV/m. That is to say 18% measuring spots exceeds the professional exposure limit in 220 kV regions. Furthermore, there are 44% measuring spots in which the electric field intensity varies from 7 to 10 kV/m. In relative high voltage regions (500 kV regions), there are only 18% measuring spots satisfy the national standard (5 kV/m), which largely due to the higher voltage, similar to the other case [10].On the other hand, the magnetic fields intensity in both regions did not exceed the professional exposure limit. The maximum value is 60.11μT.

It has been very clearly asserted that the electric and magnetic fields may cause physiological effects due to the currents induced into the human tissues exceeding certain levels [11-12]. Thus, attention should be paid to those regions in which the electric fields intensity exceeds the professional exposure, especially time for staying and proper protection.

3.2 Electromagnetic field distribution in the type B substations

Because the busbar and switchgears is properly sealed and gas-insulated by steel or aluminium enclosures, the measuring spots exceeds the professional exposure was decreased in the type B substations.

There are no measuring spots in 220 kV regions which the electric field intensity is higher than 5 kV/m. However, in 500 kV regions, as depicted in figure 5 and figure 6, 74% of the measuring spots exceed the professional exposure limit. Moreover, 21% electric field strength of total number is greater than 10kV/m. This suggests that the increased percent may be due to some main subaerial connecting electric wiring outside in type B substation.

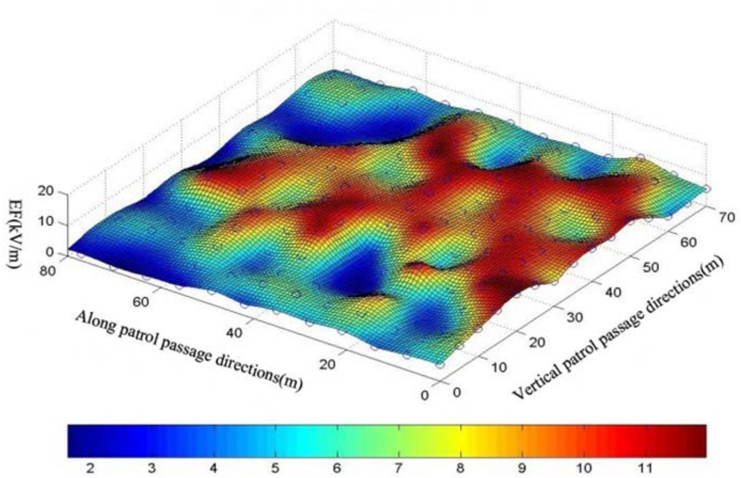

Figure 5. The electric field distribution of 500kV regions in Type B 500kV substations

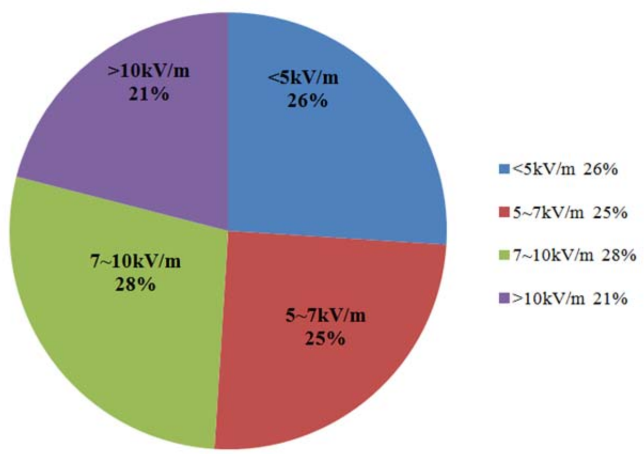

Figure 6. The pie chart of electric field intensity of 500kV regions in 500kV Type B substations

3.3 Electromagnetic field distribution in the type C substations

As the same with type B substations, there are no measuring spots exceed the professional limits in 220kV regions. Figure 7 shows the electric field distribution in 500kV regions. Obviously, no measuring spots in which the electric field strength are higher than 5kV/m can be found. In addition, the highest magnetic field does not exceed professional limits (500 μT). Thus the professional exposure to the magnetic field in 500kV Type C substations satisfied the limits legislation. It demonstrates that, GIS enclosure indoor can effectively reduce the electric field intensity even in high voltage equipment.

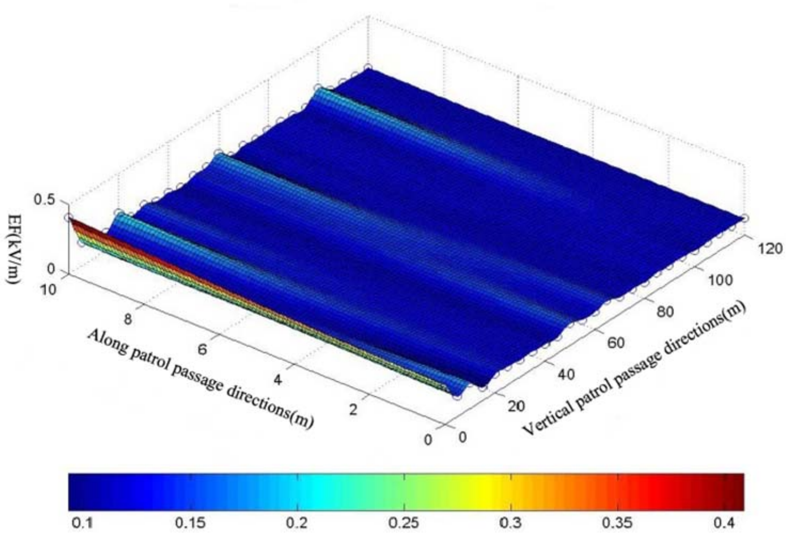

Figure 7. The electric field distribution of 500kV regions in Type C 500kV substations

3.4 Electromagnetic field distribution in 35kV regions

The 35 kV region contains a variety of devices (such as a capacitor, reactor). Due to the reactor can induce high magnetic flied intensity. it could be useful to take into account the reactor's electromagnetic characteristics under steadystate operation condition.

Table 3. Comparison of the electromagnetic filed intensity in 35 kV regions

Experimental value	Electric field	Magnetic filed	
	Maximum (kV/m)	Maximum (μT)	Distance to the professional exposure limits (m)
Xi An Zhong Yang	1.567	2762	9
Shun De	1.752	2651	9
Xi An Yangtze	0.852	2501	7

The distribution of electromagnetic field is different with brands of power reactor. As shown in table 3, the maximum electric field is only 1.752kV/m (Shun De). Nevertheless the maximum magnetic fields reach 2762 μT (Xi An Zhong Yang), which exceed the professional exposure limit of 5 times. The magnetic fields decay as the distance, and the magnetic field intensity below the 500 μT when far away 7~9 meters from the reactor center.

3.5 The effect of shielding material

Nowadays, many positively techniques have conducted in order to face the requirements of the governmental documents regarding the professional and residential exposure to the electromagnetic fields. Wearing protective clothing and expanding working distance were the main two ways to reduce the adverse effect of electromagnetic fields.

Two shielding textile fabric were selected to test in a power frequency electric field environment. Figure 8 shows the effect of two shielding fabrics on the electric field. In table 4, the comparison of the shielding effectiveness is shown.

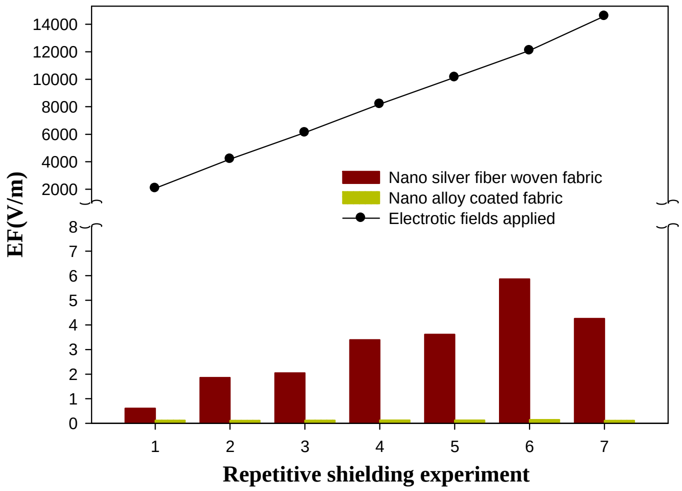

Figure 8. The effect of two shielding fabrics on the electric field

As the test voltage increasing, the electric field intensity were from 2.069kV/m to 14.59kV/m, the magnetic field intensity were from 44 μT to 115 μT. After coated nano alloy coated fabric, the electric field intensity were not higher than 6 V/m, and the shielding effectiveness was 66.28dB~70.69dB. Accordingly, the electric field intensity after coated the nano silver fiber woven fabric were not higher than 1 V/m, and the shielding effectiveness was 84.45dB~101.99dB, by which the shielding effect is better. The effects of both were higher than the previous literature [14]. That is to say the nano silver fiber woven fabric and nano alloy coated fabric can effectively shield the power frequency electric field. However, we found that both materials can hardly shield the power frequency magnetic field in the shielding experiments. The power frequency magnetic field intensity were nearly the same to magnetic field intensity applied.

Table 4. Comparison of the shielding effectiveness using the two shielding fabrics

experimental value		shielding effectiveness (dB)	
		nano silver fiber woven fabric	Nano alloy coated fabric
electric field intensity (V/m)	2069	70.58	84.45
	4191	67.07	90.94
	6117	69.5	94.08
	8186	67.64	96.25
	10130	68.94	97.97
	12090	66.28	98.18
	14590	70.69	101.99
magnetic field intensity (μT)	0.044	0.4	0.39
	0.07	0.92	1.63
	0.073	0.74	1.14

0.102	0.62	1.38
0.103	0.17	0.17
0.105	0.78	1.15
0.115	0.79	0.39

Nano alloy coated fabrics has good function of anti-static, anti-ultraviolet radiation and so on, but the other function of bad softness and easy breakage meant it was not suitable for the shielding cloth. On the contrary, with the characteristic of anti-bacterial, deodorant, anti-static, good absorption and permeability, the nano silver fiber woven fabric can be used for personal wearing and have good application prospects.

4. Conclusions

Some 500kV substations were chosen to measured, and two kinds of shielding material were studied for their shielding effectiveness. The results showed that the power frequency electric field intensity varied with the electric equipments layout. The electric field intensity in the GIS indoor layout is minimum in 3 type substations layout, in which all the measurement values were significantly lower than the professional exposure limit (5kV/m). On the contrary, there were about 82% and 74% in total measuring points of which the power frequency electric field intensity exceed the professional exposure limit in the type A and type B substations, respectively. It should be noted that the power frequency magnetic field were low in 220 kV and 500 kV regions, whereas high in 35 kV reactor regions. The maximum magnetic fields exceed the professional exposure limit 5 times. On the other hand, the results of shielding experiment showed that two kinds of material can effectively reduce the external power frequency electric field intensity. The shielding effectiveness were 66.28dB~70.69dB and 84.45dB~101.99dB respectively. However both materials had no serious effect on the shielding power frequency magnetic field.

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