Calculation of Electric Field Distribution in the Simulating Device for Animal Experiment

Tong Sun\textsuperscript{1}, Tao Chen\textsuperscript{2}, Ziyin Xie\textsuperscript{3} and Hakbong Kim\textsuperscript{3,4*}

\textsuperscript{1}State Grid Zhejiang Electric Power Co., Ltd. Research Institute, Hangzhou 310000, China
\textsuperscript{2}State Grid Zhejiang Electric Power Co., Ltd., Hangzhou 310007, China
\textsuperscript{3}Institute of Environmental Process, Zhejiang University, Hangzhou 310058, China
\textsuperscript{4}Institute of semiconductor, Kim Chaek University of Technology, Pyongyang, DPR Korea
Email: 11631054@zju.edu.cn

Abstract. A main way to investigate the biological effects of 50Hz electromagnetic field is to conduct animal experiments by using the simulating device of 50Hz electromagnetic field. In order to determine the exposure strength of experimental animals in rearing cages in simulating device more accurately, the distribution of electric field should be simulated. Based on ANSYS, a software of finite element analysis, we simulated two-dimensional (2D) electric field distribution of the proposed simulating device of high voltage 50Hz electric field for a case when there were no rearing cages, and we validated those simulation results by comparison with actual measurements. Additionally, we simulated three-dimensional (3D) electric field distribution in the rearing cages for the cases when there was one rearing cage and when there were 8 rearing cages in the simulating device respectively. The simulation results showed that distribution of 50Hz electric field in rearing cage was not uniform when there were rearing cages in the simulating device, and the maximum difference was about 9kV/m. Therefore, based on the movement tracking of animals and the distribution of 50Hz electric field in rearing cages, the cumulative exposure dose of experimental animals could be determined accurately through integral method in order to increase the accuracy of experiments.

Keywords: 50Hz electric field; simulating device; ANSYS; animal experiment; rearing cage

1. Introduction
With the increasing transmission lines and the growing public environmental awareness, the electromagnetic environment problem of UHV AC transmission lines and transformer substations has received increasing attention [1, 2]. In order to determine the environmental standard limits of 50Hz electromagnetic fields, it is necessary to evaluate the impact of UHV electromagnetic fields on human health and clarify the biological effects of 50Hz electromagnetic fields [3, 4]. The use of simulating device of high voltage 50Hz electric field for animal exposure experiments is one of the main methods for biological effects research [5, 6, 7]. The simulating device of high voltage 50Hz electric field can produce a uniform electromagnetic field theoretically. However, when there are the rearing cages, experimental animals and other medium in the electromagnetic field, the electric field will be affected by the additional electric field generated from the polarization of the medium, and therefore the actual electromagnetic field exposure strength of the experimental animals will be differ from the theoretical exposure strength. The previous research works only give the theoretical exposure strength of experi-
mental animals in the simulating device without considering the influence of the polarization of the medium. ANSYS software is a powerful simulation tool and has excellent functions such as modeling, pre-processing, solution and post-processing, so it has been widely used in general electromagnetic field simulations. In this paper, we simulated 2D distribution of electric field distribution inside the simulating device of high voltage 50Hz electric field by using ANSYS software, and compared it with the actual measurements to verify the feasibility of the simulating method. Furthermore, we simulated 3D distribution of electric field when there were mediums in the simulating device of 50Hz electric field, and verified the actual exposure strength of the electric field in rearing cage. Based on these considerations, the optimal arrangement of rearing cage inside the simulating device of high voltage 50Hz electric field is proposed.

2. Simulating Device of High Voltage 50Hz Electric Field

In general, 50Hz electric field exposure experiments can be carried out in the actual environment or in a laboratory simulation environment [8, 9]. The former can directly use 50Hz electric field environment generated by the actual UHV transmission line, but it cannot exclude the interference of other environmental factors such as meteorological conditions and air pollution, which would result in degradation of experimental accuracy. The latter can better control the variables, but it needs a set of devices to simulate 50Hz electric field environment under the UHV AC transmission line.

The configuration of simulating device of high voltage 50Hz electric field developed by our research group is shown in figure 1. The input voltage to this device is 220V (AC) and the output voltage is continuously adjustable up to 50kV (AC). The simulating device of high voltage 50Hz electric field is consisted of three parts: an AC voltage controller, an AC voltage set-up system and an electric field generating device. The AC voltage controller realizes the regulation of the output voltage of high voltage AC power supply and the real-time measurement and feedback through the power control and signal acquisition system with the programmable logic controller (PLC) as the core. The AC voltage controller has passed the inspection of Shanghai High Voltage Electrical Product Quality Supervision and Inspection Station. The AC voltage set-up system consists of an oil immersed test transformer and a protective resistor, which is boosted according to the signal of the AC voltage controller. The electric field generating devices consists of upper and lower two parallel electrode plates with a spacing of 1m, whose diameters are 3m and 3.4m respectively, supplemented by corresponding corona prevention and insulation support structures [5, 6]. The end faces of two electrode plates are rounded to prevent corona discharge caused by high voltage and the lower plate is grounded. 50Hz electric field generated between two electrode plates can be adjusted to a maximum of 50kV/m.

![Figure 1. Configuration of simulating device of 50Hz electric field.](image-url)
3. The Methods of 50Hz Electric Field Measurement and Calculation

3.1. Method of 50Hz Electric Field Measurement

When the AC voltage of two electrode plates is 40kV, 50Hz electric field generated by the simulating device of high voltage 50Hz electric field is measured by SEM-600 electromagnetic radiation analyzer (probe model LF-01). When there is no rearing cage inside the electric field generating device, a series of measuring points are arranged with unequal intervals in random radial directions of the lower electrode plate, and the distance between the measuring points (1, 7, 2, 6, 3, 5, 4) and the lower plate center are 1.1m, 0.8m, 0.6m, and 0m respectively. (see figure 2 ) Measurement was repeated 5 times at each measuring points.

![Figure 2. Diagram of measuring point distribution.](image)

3.2. Method of Simulation Calculation

When there is no rearing cage inside the electric field generating device, the APDL module of ANSYS software is used to create a two-dimensional model (the vertical plane of central axis of electric field generating device) because of geometric symmetry of the electric field generating device. We calculated (2D) electric field distribution when the AC voltage between the upper and lower electrode plates is 40kV. The model size is the same as the actual electric field generating device. The analysis is performed using the PLANE121 unit, and the analysis type is harmonic. Similarly, when there is several rearing cage inside the electric field generating device, the 3D model created in the ANSYS Workbench software is imported through the APDL module, and then the electric field distribution is calculated in 3D simulation. The 3D model of the electric field generating device (including 8 rearing cages) is shown in figure 4. The distance between the center axis of each rearing cage and the center of the lower electrode plate is about 60 cm. In order to calculate the electric field distribution under different conditions, we establish 3D models in which one rearing cage (figure 3a) and eight rearing cages (figure 3b) are placed in the electric field generating device, respectively. The SOLID123 unit is used to automatically divide the grid, and the AC solver is used to calculate 3D electric field distribution. In the simulation calculation, the dielectric constant of the metal electrode plate is 1.0×10^{12}, the dielectric constant of air is 1, the dielectric constant of rearing cage is 8, and the dielectric constant of the drinking bottle is 80. In order to calculate the electric field distribution at 5 cm above the lower electrode plate in rearing cage (about half the height of the exposed animal’s body), the section above basal plane of rearing cage is divided by 1 cm×1 cm grid. Taking the simulation results of 50Hz electric field strength on each grid point (excluding the most edge grid points), the maximum and minimum values are recorded as \( E_{\text{max}} \) and \( E_{\text{min}} \), respectively. The arithmetic mean values of each grid point are recorded as \( E_{\text{ave}} \).
4. Results and Analysis
When there is a rearing cage inside the electric field generating device, the 3D simulation results of 50Hz electric field distribution at 5 cm above the lower electrode plate is shown in figure 4.

When there are 8 rearing cages inside the electric field generating device, the distribution of 50Hz electric field distribution in each rearing cage is shown in figure 5. As shown in figure 5, there is obvious electric field distortion inside the rearing cage and its surroundings. As shown in figure 6, the electric field distribution in the rearing cage is generally uniform, except the bottom region of the rearing cages. The electric field strength increases gradually along the arrow direction at 5 cm above the lower electrode plate, and the electric field strength near the water bottle is the largest. The potential difference between the edge of drinking water bottle and the bottom of rearing cage is about 4kV. Because the rearing cage has good insulation performance, electric shock phenomena for experimental animals will be rarely happened when they drink water during the experiment.
Figure 5. Distribution of 50Hz electric field inside the rearing cage.

The electric field strength increases gradually along the arrow direction at 5 cm above the lower electrode plate, and the electric field strength near the water bottle is the largest. The potential difference between the edge of drinking water bottle and the bottom of rearing cage is about 4kV. Because the rearing cage has good insulation performance, electric shock phenomena for experimental animals will be rarely happened when they drink water during the experiment. For the cases when there is a rearing cage or when there are 8 rearing cages inside the electric field generating device, the distribution of 50Hz electric field strength in rearing cage at 5cm above the lower electrode plate is shown in table 1 and figure 6. As shown in table 1 and figure 6, the maximum difference of 50Hz electric field strength at each grid point in rearing cage is about 9 kV/m.

Table 1. The strength of 50Hz electric field at 5 cm above the bottom electrode inside rearing cage.

| Condition          | $E_{\text{max}}$ (kV/m) | $E_{\text{mix}}$ (kV/m) | $E_{\text{ave}}$ (kV/m) | Standard deviation (kV/m) | Relative error (%) |
|--------------------|--------------------------|--------------------------|--------------------------|---------------------------|-------------------|
| One rearing cage   | 48.56                    | 39.09                    | 41.96                    | 1.37                      | 3.27              |
| Eight rearing cages| 48.03                    | 38.21                    | 41.14                    | 1.42                      | 3.45              |

Figure 6. The distribution diagram of 50Hz electric field at 5 cm above the bottom electrode inside the rearing cage.

When there are five mice in a rearing cage, the distribution of 50Hz electric field inside the rearing cage is shown in figure 7. The calculation results given in figure 7 show that the distribution of 50Hz


electric field strength in a rearing cage isn’t uniform, increasing monotonically along the positive direction of the x-axis. Therefore, the exposure strength of 50Hz electric field should be changed continuously as the experimental animals move in rearing cage. In order to determine the cumulative exposure dose of the experimental animals, the trajectory of the animals should be recorded and incorporated with 50Hz electric field distribution in rearing cage. The integral value of electric field exposure strength $E(t)$ in total exposure time $T$ might give the accurate exposure dose.

**Figure 7.** The distribution diagram of power-frequency electric field at 5cm above the bottom electrode when 5 mice were placed inside a rearing cage.

### 5. Conclusions

Finite element analysis software ANSYS was used to simulate 50Hz electric field distribution in the electric field generating device and the rearing cage. The following conclusions can be drawn:

1) The electric field distribution in the electric field generating device without rearing cage is simulated in two dimensions, and compared with the measured results, which verifies the reliability of the ANSYS simulation method and its results.

2) The electric field distribution inside the electric field generating device is not uniform. The actual electric field strength is the closest to the theoretical electric field strength at the center of the lower electrode plate. The closer to the edge of the lower electrode plate, the greater the actual electric field strength, and then the greater the deviation from the theoretical electric field strength.

3) The electric field distribution in the electric field generating device with rearing cages is also uneven, and the maximum difference of 50Hz electric field strength in rearing cage is about 9kV/m.

4) Integral method should be used to determine the cumulative exposure dose of the experimental animals.

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