Research on the Influence of Haze Weather on Audible Noise of HVDC Transmission Line

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Abstract. In order to study the influence of haze weather on audible noise of HVDC transmission line, a calculation model of ion flow field of HVDC transmission line considering the influence of haze is established, and then the relationship between different haze levels, different haze particle concentrations and audible noise is analyzed by taking the maximum potential gradient on the conductor surface as the intermediary. Then a ± 800kV DC transmission line is simulated and the results show that the audible noise will be more prominent with the increase of haze concentration, and the increment is more obvious at higher haze concentration; The charging of haze particles is the principal origin for the increase of audible noise, and the effect of PM2.5 is the most significant.

1. Introduction

With the development of HVDC transmission technology, the problem of concomitant audible noise caused by DC transmission line has been gradually attracting more and more attention [1]. The audible noise phenomenon caused by corona effect is closely related to the space charge density near the discharge point. The movement of space charges around the conductor leads to corona current pulse. Meanwhile, the space charges collide with air molecules to generate sound pressure pulse and propagate around, which results in the audible noise [2-3].

As one of the main electromagnetic environment issues generated during the operation of HVDC conductor, audible noise may cause serious adverse effects around the line [4], which should be given comprehensive estimation during the project design stage. Due to the gradual deterioration of air quality and frequent smog in recent years, the impact of this extreme weather on the audible noise of HVDC transmission lines can not be ignored. In haze weather, there are a large number of suspended fog droplets and haze particles in the air. These particles will be charged, adsorb charged ions in the space near the DC transmission line and form new charged particles. The analysis of audible noise characteristics in haze weather is complicated by a large number of charged particles [5-6]. The environmental problems caused by haze will directly affect the structural design, site construction, operation and construction cost of transmission lines. Therefore, it is of great significance to study the audible noise characteristics of HVDC transmission lines in haze weather.

Thus, the impact of haze weather on ion flow field around the HVDC transmission line is considered in this paper. Reference [7] proposed a calculation method of ion flow field which simplified the two dimensions problem into one dimension with noteworthy errors; A grid like ion flow field calculation method is proposed in reference [8], which reduces the error; Then there are upwind finite element method [9], meshless method [10] and various improved methods [11-12], which have significantly...
improved the accuracy. The above method can effectively calculate the ion flow field under normal weather, but weak in the calculation under complex meteorological conditions.

Therefore, a calculation model of ion flow field that can take into account the influence of fog and haze weather is proposed in this paper, which analyses and calculates the project of a ± 800kV DC line with ANSYS Maxwell [5], and studies the audible noise characteristics under fog and haze weather through the maximum potential gradient on the conductor surface. The changes of audible noise under different haze levels and the degree of influence by different haze particles are analysed.

2. Calculation model of ion flow field in haze weather

2.1. Calculation model of ion flow field in haze weather

In haze weather, the main suspended particles in the air are PM2.5, PM10, and fog droplets. In this paper, these three components are used as the main indicators to determine the haze concentration level, which is divided into mild, moderate and severe for analysis [13]. The specific particle composition distribution of various concentrations of haze is shown in Table 1:

| Haze degree   | PM2.5/(ug/m³) | PM10/(ug/m³) | droplet /(ug/m³) |
|--------------|---------------|--------------|-----------------|
| Mild haze    | 50            | 80           | 20              |
| Moderate haze | 130           | 190          | 100             |
| Severe haze  | 310           | 430          | 200             |

The radius of PM2.5, PM10 and suspended droplets are selected as 1.3 μm, 5.6 μm, and 1.6 μm respectively. Combined with the concentration parameters of PM2.5, PM10 and suspended droplets in Table 1, the charge $q_s$ and charge density distribution of suspended particulate matter and suspended fog $\rho_p$ can be calculated through equation (1):

$$q_s = 12\pi\varepsilon_0 r_0^2 E_s \left( \frac{\varepsilon_r}{\varepsilon_r+2} \right)$$

$$\rho_p = q_s N$$

Where $q_s$ is the saturated charge of particles in C, $E_s$ is the electric field strength in V/m, $r_0$ is the particle radius in m, $\varepsilon_0$ is the dielectric constant of air in F/m, $\varepsilon_r$ is the relative dielectric constant of particles in F/m, $\varepsilon_r/(\varepsilon_r+2)$ is 0.8, and for suspended particulate matter, take $\varepsilon_r/(\varepsilon_r+2)$ is 0.9. N is the number of suspended particles per unit volume in PCs./m³.

2.2. Effect of haze on ion mobility

In the ion flow field, the movement speed of ions is much faster than that of droplets and suspended particles, and the haze particles are in the state of force balance after being charged and saturated. Therefore, the movement of haze particles is ignored in the calculation of the mobility of ion flow field, and it is considered that they do not participate in the migration of ions. However, a large number of haze particles in the air will still affect the ion mobility. Suppose the ion mobility is $K'$ in haze weather and $K$ in good weather, then:

$$\frac{K'}{K} = \frac{M}{M'}$$

Where $M$ is the relative mass of air molecules in good weather, $M'$ is the relative mass of air molecules in haze weather, and the value of $M$ is 29.

2.3. Effect of haze on corona onset field strength

In haze weather, suspended particles and suspended droplets are the main factors affecting the halo field
strength. Particles will adhere to the conductor surface and change the roughness of the conductor surface. Therefore, a modified formula for calculating the corona field strength $E_c$ of the conductor in haze weather is proposed:

$$E'_c = \frac{m'}{m} E_c$$  \hspace{1cm} (4)

Where, $E_c$ is the corrected corona onset field strength, $E_c$ is the corona onset field strength in normal weather, which can be calculated by Peek empirical formula, $M$ is the surface roughness coefficient of conductor in normal weather, which is set as 0.47; $M'$ is the surface roughness coefficient of conductor in haze weather, taken as 0.47.

2.4. Initial value of conductor surface charge density

In order to obtain the synthetic field strength around the conductor in normal weather, it is necessary to give the initial value of the conductor surface charge density to solve the space charge density distribution, and then use the modified formula to iterate repeatedly to achieve the ideal accuracy. The initial value formula in this paper is:

$$\rho_0 = \frac{4\varepsilon_0 U_0 E_g (U - U_0)}{R_0 HE (5 - \frac{4U_e}{U})}$$  \hspace{1cm} (5)

Where, $\varepsilon_0$ is the air dielectric constant, $U_0$ is corona starting voltage in kV, $E_g$ is the nominal field strength in kV/cm, $U$ is conductor voltage in kV, $R_0$ is the radius of split conductor, $E_c$ is corona onset field strength in kV/cm.

The correction formula of conductor surface charge density in each iteration is:

$$\rho_n = \rho_{n-1} (1 + \alpha \frac{E'_n - E_c}{E'_n + E_c})$$  \hspace{1cm} (6)

Where, $\alpha$ is the correction factor greater than 0, $E_M$ is the maximum electric field intensity on the conductor surface in kV/cm.

2.5. Calculation flow of ion flow field in haze weather

When smog occurs, it is mostly static and stable weather conditions, thus the impact of external weather conditions such as wind speed can be ignored. Therefore, the ion flow field of bipolar HVDC transmission in haze weather is similar to that in single gas condition, which can be expressed by the following basic equation:

$$\nabla \cdot \rho = (\rho^+ - \rho^-)$$  \hspace{1cm} (7)

$$E_s = -\nabla \varphi$$  \hspace{1cm} (8)

$$J^+ = \rho^+ K^+ E_s$$  \hspace{1cm} (9)

$$J^- = \rho^- K^- E_s$$  \hspace{1cm} (10)

$$\nabla \cdot J^+ = -R J^+ \rho^+$$  \hspace{1cm} (11)

$$\nabla \cdot J^- = R J^- \rho^-$$  \hspace{1cm} (12)

In which:

$$\rho^+ = \rho_+^p + \rho_+^p + \rho_+^p + \rho_+^p$$  \hspace{1cm} (13)

$$\rho^- = \rho_+^- + \rho_+^- + \rho_+^- + \rho_+^-$$  \hspace{1cm} (14)

In which, $\varphi$ is the potential in V, $E_s$ is the electric field strength in V/M, $\rho^+$ and $\rho^-$ are the positive
and negative space charge density in C/m³; \( \rho_+ \) and \( \rho_- \) are the space charge density of positive and negative ions in C/m³, \( \rho_{p+} \) and \( \rho_{p-} \) are the space charge density of positive and negative PM2.5 particles in C/m³, \( \rho_{p+} \) and \( \rho_{p-} \) are the space charge density of positive and negative PM10 particles in C/m³; \( \rho_{f+} \) and \( \rho_{f-} \) are the space charge density of positive and negative suspended droplets in C/m³, \( R \) is the positive and negative ion load coefficient in m³/s, \( e \) is the electron charge, \( e = 1.602 \times 10^{-19} \text{C} \).

According to the control equation of ion flow field in haze weather, the ion flow field is solved iteratively by finite element method. The calculation flow chart is shown in Figure 1.

![Flow chart of ion flow field calculation](image)

### 3. Correlation between audible noise and maximum potential gradient on conductor surface

The electric field intensity of the conductor is one of the main parameters of the classical empirical equation of audible noise. Electric Power Research Institute (EPRI) adopts the method of multiple images; while Eidgenössische Technische Hochschule Zürich (ETH) implements the charge simulation method (CSM), which sets 150 charge points and test points on each conductor, and sets the distance between the charge and test points as the gap between two adjacent charges to improve the accuracy. Then the distribution characteristics of the audible noise of the conductor can be deduced from the calculated conductor surface gradient. When the conductor is in different potential gradients, the accuracy of these two methods is within a reasonable range. It can be seen that it is more accurate to use the maximum potential gradient on the conductor surface to describe audible noise [14].

When the potential gradient on the conductor surface increases, a larger corona current pulse amplitude will be generated on the conductor, which will increase the audible noise. At the same time, changing the number of conductor splits, selecting different conductor models and applying conductors with different diameters will affect the audible noise. Considering the influence of these factors and combined with the data of the test line in the corona cage, an empirical formula for predicting audible noise with a wide range of applications is derived [15]:

\[
L_w = C_1 + C_2 \log_{10}(E_{am}) + C_3 \log_{10}(n) + C_4 \log_{10}(d) - C_5 \log_{10}(D) + C_6
\]

(15)

Where, \( L_w \) is the sound pressure level of audible noise in DB (A), \( E_{am} \) is the maximum potential gradient on the conductor surface in kV/cm, \( n \) is the number of conductor splits, \( D \) is the conductor diameter in mm, \( D \) is the distance between the conductor and the calculation point in m; \( C_1-C_5 \) are empirical fitting coefficients, \( C_6 \) is the environmental correction factor.
4. Changes of audible noise under different haze levels

The ion flow field of ±800kV UHV DC transmission line in China Yunnan-Guangdong ±800kV line is calculated by using the method proposed in this paper. The conductor model is 6 × Lgi-720 / 50, splitting spacing 0.45 m, pole spacing 22 m, ground height 21 m, sub conductor radius 1.68 cm, the calculation results are shown in Figure 2:

![Electric field intensity distribution near conductor surface](image)

Figure 2. Electric field intensity distribution near conductor surface.

According to the maximum potential gradient on the conductor surface, the audible noise at 20m from the projection of the conductor center under three different haze conditions is obtained, as shown in Table 2:

| Haze level | normal | light | moderate | severe |
|------------|--------|-------|----------|--------|
| Audible noise DB (A) | 45.9 | 47.4 | 49.7 | 54.4 |

In order to further study the influence of suspended particles on audible noise in case of haze, it is set that when there are only PM2.5 or PM10 suspended particles in the air, the change of audible noise with particle concentration is shown in Figure 3.

![Variation of audible noise with particle concentration](image)

Figure 3. Variation of audible noise with particle concentration.
It can be seen from table 2 and figure 3 that the audible noise will increase with the increase of haze concentration; When the haze concentration reaches severe haze, the change degree of audible noise with haze concentration will be more significant. In case of haze, PM2.5 in suspended particulate matter has the most obvious impact on audible noise, which can reach more than three times of PM10, which is one of the main factors leading to the increase of audible noise.

5. Conclusion
In order to analyse the influence of haze weather on the audible noise of HVDC transmission line, an ion flow field calculation model considering the influence of haze is established to calculate the maximum potential gradient on the conductor surface, and the relationship between haze and audible noise is established through empirical formula. Finally, the ±800kV DC line in China Yunnan-Guangdong ±800kV line is analyzed and calculated, and the following conclusions are obtained:

1) In haze weather, the potential gradient on the conductor surface will increase, resulting in the increase of corona current pulse amplitude, and finally affect the audible noise;
2) With the increase of haze concentration, the audible noise also increases; In severe haze, the change of audible noise with haze concentration will be more significant;
3) In case of haze, the charge of moderately suspended particles in the air is the main factor leading to the increase of audible noise, among which PM2.5 has the most significant impact on audible noise, which can reach more than three times of the same concentration of PM10.

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