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Study Committee B2

OVERHEAD LINES

10306_2022

Altitude Correction Method of Electromagnetic Environment for HVDC Transmission Line and Its Engineering Application

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Motivation

- To improve the cost-effectiveness of long-distance, high-capacity transmission, China has adopted HVDC transmission technology. At the same time, as the public awareness of environmental protection has enhanced, electromagnetic environment has become a major technical problem that must be considered in the design and construction of DC transmission projects.
- China has vast territory, where HVDC transmission lines are widely distributed. From west to east, the altitude span is large. Therefore, the problem of high altitude is inevitable for the development of DC transmission. Whether the electromagnetic environment altitude correction method of HVDC transmission line is accurate and reasonable or not has a direct bearing on environmental protection and project investment, which has become a key technical issue when constructing HVDC lines at high altitude areas.

Method/Approach

- To deeply study the characteristics of electromagnetic environments of HVDC transmission lines in high-altitude areas and its variation with altitude, State Grid Corporation of China(SGCC) built DC full-scale test lines with the same structure in Yangbajing (Tibet) at an altitude of 4,300 m and Changping (Beijing) at an altitude of 50 m, and four DC reduced-scale test lines with consistent parameters at altitudes of 50 m, 1,700 m, 3,400 m and 4,300 m. In the past six years, detailed experimental studies on the electromagnetic environment of HVDC transmission lines at different altitudes and voltages have been carried out by using the above-mentioned test means.

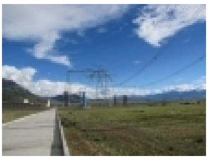
Objects of investigation

- The electromagnetic environment of DC transmission lines mainly includes DC total electric field(TEF) and AN(AN), which are directly related to corona discharge.
- With the increase of altitude, air density decreases, free path of electrons increases, accumulated kinetic energy of electrons in a free path increases, and the probability of ionization after collision of electrons with air molecules increases, resulting in easier corona discharge on the surface of the conductor. Under the same line voltage and line structure, electromagnetic environment problems caused by corona discharge in high-altitude areas are more serious than those in low-altitude areas.

Experimental setup & test results

- **Experimental setup**
- The DC reduced-scale test lines adopt double pole and single circuit erection, with a length of 100 m. The conductor type is 4×LGJ-95/15; pole spacing is 6 m; and ground height of the lowest point is 7m.
- The DC full-scale test lines are located in Tibet and Beijing respectively. The altitude of full-scale test lines in Tibet and Beijing is 4,300 m and 50 m respectively. The length of the full-scale test lines are 300 m, and the minimum ground height of the lines from the middle span are both 15 m.






- **Test results**
- (a) The maximum of ground-level TEF increases linearly with the increase of altitude. With the increase of conductor surface field strength, the increasing rate of ground-level TEF with the increase of altitude gradually decreases.
- (b) The AN increase of DC transmission lines has non-linear changes with the increase of altitude. In the altitude range of 50 m-4,300 m, with the increase of altitude, AN shows a characteristic of slow increase - rapid increase - slow increase.
- (c) The AN of HVDC transmission lines at different altitudes predicted by the altitude correction formula proposed is far less than results predicted by the AC formula.

Conclusion

- In view of the key problem of electromagnetic environment prediction and control at high altitudes faced in the development of HVDC transmission technology, a long-term test of DC ground-level TEF and AN is carried out by taking advantages of two full-scale test lines and four DC reduced-scale test lines at different altitudes from 50 m to 4,300 m. The TEF and AN level of high altitude HVDC lines as well as the TEF and AN altitude correction method in HVDC lines are obtained.

Study Committee B2

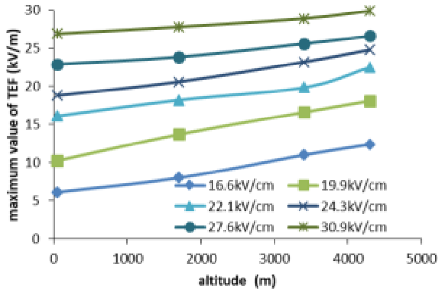
OVERHEAD LINES

10306_2022

Altitude Correction Method of Electromagnetic Environment for HVDC Transmission Line and Its Engineering Application

continued

Variation curve of ground-level TEF with altitude



- The maximum values of the ground-level TEF increase linearly with the altitude. Therefore, the univariate linear regression model is used to reflect the relationship between the ground-level TEF and altitude. The fitting formula is:

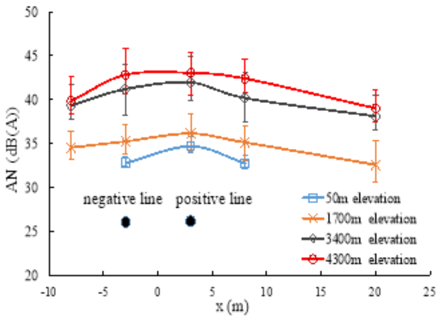
$$E_H = E_L(1 + kH)$$

Maximum ground-level TEF of DC full-scale test lines at different altitudes

Conductor type	Voltage (kV)	Conductor surface electric field strength (kV/cm)	Ground-level TEF (kV/m)	
			Altitude 50 m	Altitude 4,300 m
6×LGJ-300/40	±500	19.65	17.0	27.2
4×LGJ-500/45	±500	20.96	18.0	27.6
	±600	25.69	27.6	32.8
	±700	29.97	34.0	38.7

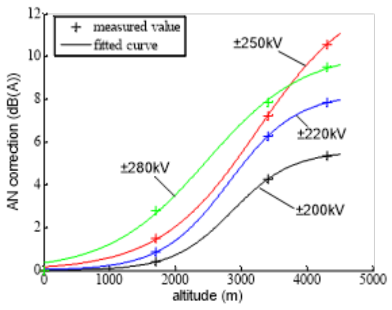
- The higher the altitude, the greater the ground-level TEF. There is little difference between the two conductors. The main reason is that the equivalent electrical radius of the two conductors are not much different, so their corona characteristics are also very close. For the same kind of conductor, with an increase of conductor surface field strength, elevation increases of ground-level TEF decreases gradually.

AN transverse distribution curves under DC reduced-scale test line



The AN right beneath the positive polarity conductor appears to be a maximum, which indicates that the main source of AN from DC reduced-scale test lines is positive polarity conductor. AN decreases with the increasing distance from observation point to positive polarity conductor, but it decreases more slowly at the negative side than at the positive side. This is because the AN of negative polarity conductor increases gradually as well with the altitude increasing to a certain value.

The law of AN changing with altitude



With the altitude increasing, the increment of AN of DC reduced-scale test lines at different altitudes is distinct. For example, in the range from 0m to 1700m, the increase of altitude correction amount of AN is quite less; in the range from 1700m to 3400m, the AN increases rapidly and reaches the maximum altitude correction amount; while the altitude is above 3400m, the noise of DC lines gradually reach saturation, and the increase rate of altitude correction amount of AN gradually slows down.

Study Committee B2

OVERHEAD LINES

10306_2022

Altitude Correction Method of Electromagnetic Environment for HVDC Transmission Line and Its Engineering Application

continued

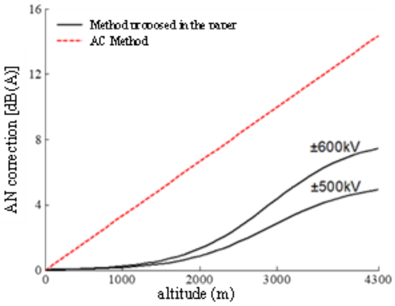
AN altitude correction method of HVDC

Voltage (kV)/ Conductor surface electric field strength (kV/cm)	Statistical average of AN [dB (A)]			k_{AN}
	Altitude 50 m	Altitude 4,300 m	AN correction (4,300 m - 50 m)	
500kV/21.41	34.49	39.41	4.92	5.31
600kV/25.69	39.94	47.39	7.45	8.05
650kV/27.83	41.41	49.43	8.02	8.67
700kV/29.97	43.74	51.02	7.28	7.87

According to the study on AN tests of DC lines at different altitudes, an important rule that the AN increase of DC transmission lines has non-linear changes with the increase of altitude is revealed.
Based on the full-scale test lines, the AN altitude correction formula of HVDC transmission lines at altitudes from 0 m to 4,300 m is proposed, solving technical bottlenecks encountered in AN prediction, conductor type selection and other aspects of HVDC transmission lines at high altitudes.

$$\Delta_{AN}=k_{AN}/\left[1+e^{-0.00\text{[illegible]}(x-3000)}\right]$$

Comparisons with AC correction method



- The AN of HVDC transmission lines at different altitudes, predicted by the altitude correction formula proposed is far less than results predicted by AC formula. Taking ±500kV as an example, from altitudes 0 m to 4,300 m, the AN increase predicted by the AN altitude correction formula of DC transmission lines obtained in this paper is 4.92 dB(A), which is 35% of the value predicted by the AC formula.

Engineering application

Conductor type		4×400 mm²	4×500 mm²	4×630 mm²	4×720 mm²	6×300 mm²	6×300 mm²
Conductor diameter (mm)		27.6	30	33.8	36.23	23.9	27.6
Conductor surface electric field strength (kV/cm)		23.26	21.71	19.7	18.63	19.96	17.74
AN calculation results at an altitude of 0 m [dB (A)]		38.11	35.30	31.70	29.11	31.49	26.70
AN calculation results at an altitude of 3,000 m [dB (A)]	AC Method	48.11	45.30	41.70	39.11	41.49	36.70
	Method proposed in this paper	**41.79**	**38.31**	**33.83**	**30.80**	**33.73**	**28.07**
AN calculation results at an altitude of 4,000 m [dB (A)]	AC Method	51.44	48.63	<u>45.03</u>	42.44	<u>44.82</u>	40.03
	Method proposed in this paper	**<u>44.04</u>**	**40.16**	**35.13**	**31.84**	**35.09**	**28.91**

According to relevant Chinese environmental protection standards, the AN generated by corona at 20 m from the projection of positive conductors is required to not exceed 45 dB (A). According to the calculation results for ±500kV DC transmission lines, if the AC altitude correction method recommended by EPRI is used, when the altitude is 4,000 m, it is necessary to use 4 × 630 mm² or 6 × 300 mm² conductors. However, according to the research results in this paper, in areas with an altitude of 4,000 m, 4 × 400 mm² conductors can reduce AN at 20 m from the projection of positive conductors to below 45 dB (A). The application of the AN altitude correction method proposed in this paper in DC transmission lines at high altitudes can avoid wrong conductor type selection due to inaccurate prediction formula, and greatly save line investment while meeting environmental protection requirements.