# Study on Lightning Dispersion and Breakdown Protection of Corrosion Protection Layer in Soil Adjacent to Buried Metal Pipeline

**Xiaole Su, Xianqin Qiao, Wei Liu, Zhipeng Jiang, Can Qiu, Jie Xiong, and Ju Sun**

**Abstract** Transmission lines in the vicinity of natural gas pipelines are vulnerable to lightning strikes during operation. High amplitude lightning currents expose buried natural gas pipelines to shock potentials of a certain amplitude. In this paper, the safety protection of the intersection of natural gas pipelines and power lines has attracted extensive attention. This paper uses ATP-EMTP software to calculate the characteristics of the current waveform and the influencing factors of the pylons near the natural gas pipeline, establishes a three-dimensional finite element model of the pressure resistance of the natural gas pipeline electrode and the anticorrosion layer, and illustrates the mechanism of the generation of the difference between the pipeline electrode potential and the anticorrosion layer potential. Secondly, the effects of lightning current amplitude, soil conditions and pipeline distance on the impact potential of natural gas pipelines are analysed through simulations, and a lightning impact protection method for natural gas pipelines based on the vertical dimensional scattered current of piles is proposed. Finally, the practical application effect and technical economy are verified through simulation examples and engineering application simulation tests. The conclusions of this paper can provide references for the design, construction and safe operation and maintenance of natural gas pipelines.

**Keywords** Natural gas pipelines · Adjacent crossings · Lightning strikes · Corrosion protection · Pipeline protection

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# 1 Introduction

As international demand for natural gas resources becomes more pressing, natural gas energy and electricity are becoming important factors in the international situation. Inevitably, electricity and natural gas transmission lines are faced with proximity and cross-over conditions in the form of "two lines, one place". Both the power and natural gas industries are paying more and more attention to the safe and stable operation of the two energy transmission lines in the case of "two lines and one place" crossings [1]. There are significant differences between the existing power transmission and distribution lines and natural gas energy transmission, with the former mainly using an overhead line structure in non-urban areas, while natural gas pipelines are usually buried in the underground soil. Both the power and natural gas industries are paying more attention to the safe and stable operation of the two types of energy transmission lines in the case of "two lines and a place" crossing each other [2, 3]. Some EMC protection measures have been applied on a pilot basis in the "two lines, one ground" cross-adjacent project. In addition to the impact of power lines on gas pipelines under normal operating conditions, some studies have found that incoming currents along towers after lightning strikes on power lines may create some risk of overvoltage to adjacent pipelines. Nagat et al. [4] used the ATP program to calculate the induced voltage of pipelines under normal and fault conditions and proposed a grounding system to suppress the induced voltage, and verified the effectiveness of this measure through tests. Amauri et al. [5] developed a transient circuit model based on frequency-dependent parameters for predicting the transient electromagnetic disturbance effects caused by lightning strikes. Ossama et al. [6] calculated the induced voltage of the pipe in a MATLAB program based on the "Distributed Source Analysis" method, and the calculated results were in good agreement with the actual measured induced voltage. The paper [7] used software to simulate the situation when a 500 km 1000 kV double transmission line with the same tower was struck by lightning, and verified the characteristics of the pipeline overvoltage distribution at a "tower-line" spacing of 50 m for a 100 kA lightning current striking the tower through simulation. The literature [8] suggests that the protective measures of installing drainage strips and changing the structure of the tower grounding device can reduce the lightning overvoltage of the pipeline corrosion layer. Huang Wanli et al. conducted theoretical calculations for the transient potential of the Haixi-Tala 750 kV transmission line in the Ulan section and the adjacent buried natural gas pipeline [9], where the pipeline potential reached 4.3 kV for a single-phase ground fault and 12.9 kV for a broken line ground fault. In, literature [10] analysed the potential risk of pipeline lightning strikes in the case of "two lines and one ground" crossed and adjacent to each other by using the simulation software CDEGS to analyse the soil resistivity frequency variation characteristics. but from a practical engineering application point of view the method requires a large amount of excavation and backfilling works. The above research shows that in order to avoid the problem of lightning overvoltage in the case of power lines and natural gas pipelines "two lines and one ground" crossed adjacent to each other, the natural gas industry and the power sector have high application value.

This paper analyses the mechanism and influencing factors of natural gas pipeline overvoltage through simulation modelling, which can provide theoretical reference for the maintenance of the actual natural gas pipeline corrosion layer.

## 2 Lightning Strike Dispersion Modelling and Calculation

High-voltage overhead lines in power systems are often set up with a single or double lightning line to prevent the natural connection of lightning clouds bypassing the lightning line to discharge the overhead conductors. Lightning flow shunt process as shown in Fig. 1, Ib1 and Ib2 for both sides of the lightning line shunt lightning flow component, Ia is hit by the tower tower and its grounding device installed to shunt the lightning flow component.

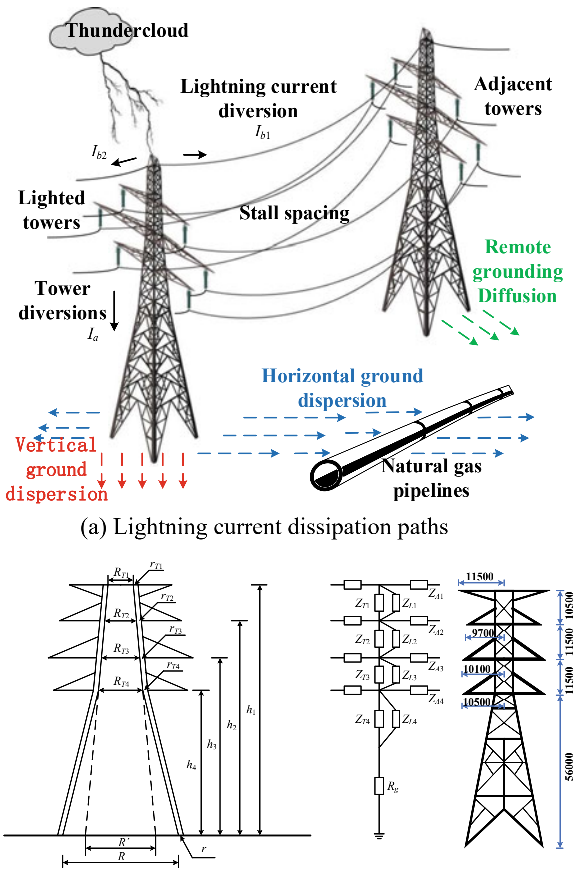
Power lines adjacent to the natural gas pipeline corrosion layer overvoltage protection in addition to the normal operation of the line coupling voltage, the main concern along the tower into the soil of lightning current on the impact of overvoltage potential. In order to quantitatively analyse the influence of direct lightning on the pipeline overvoltage of the neighbouring power line, the ATP-EMTP electromagnetic transient analysis software, which is commonly used in the power industry, is used to establish a simulation model of lightning overvoltage in the case of power lines and natural gas pipelines “two lines and one ground” crossed and adjacent to each other.

## 3 Simulation Models and Parameters

Considering that the grounding resistance of towers in the power industry is generally maintained within 10 Ω and the proportion of lightning line shunt is small, the study generally considers that the resistive coupling component in the case of lightning strikes is the main factor.

This paper uses COMSOL Multiphysics finite element simulation software to establish a model for calculating the lightning overvoltage in the case of a power line and a natural gas pipeline with "two lines and a ground" crossed and adjacent to each other as shown in Fig. 2. The finite element simulation can calculate the potential, current and electric field components at any point in the soil medium, and can solve for the withstand voltage on the pipeline grid and the insulation and corrosion layer. In the simulation model, the distance between the tower and the gas pipeline is taken as $d_{\mathrm{pg1}} = 40$ m, and the vertical distance between the extension end of the Φ12 mm galvanised steel grounding grid and the pipeline is $d_{\mathrm{pg2}}$. The standard lightning current waveform with a wavefront and half-wave duration of 2.6/50 μs recommended by the power industry test regulations is used, and the standard lightning current double exponential function waveform is created in COMSOL

**Fig. 1** Power line lightning dispersion with calculated parameters




(b) ATP-EMTP tower calculation model and parameters

Multiphysics software as follows

$$i(t) = 1.0474 I_{\mathrm{m}} \left( e^{-14790.18t} - e^{-1877833t} \right) \tag{1}$$

In addition, according to the general construction specification of electric power and natural gas pipeline, the simulation set pole tower galvanized steel grounding conductor and the burial depth of the pipeline are taken as 0.8 m and 1.5 m respectively, the edge and extension of the grounding grid are taken as $l_{\mathrm{g1}} = 16$ m, $l_{\mathrm{g2}} = 20$ m, respectively. The length of the pipe $l_{\mathrm{p}}$ is 500 m, the outer diameter Φ530 mm, the wall thickness of the pipe 13 mm. The pipe anticorrosion layer is 3 layers of polyethylene material (3LPE), the thickness of the insulation anticorrosion layer is taken as 3 mm, the surface resistivity $\rho_{\mathrm{F}}$ is $10^5$ Ω-m. The potential distribution characteristics of the adjacent natural gas pipeline and the influence law can be obtained through simulation calculation.

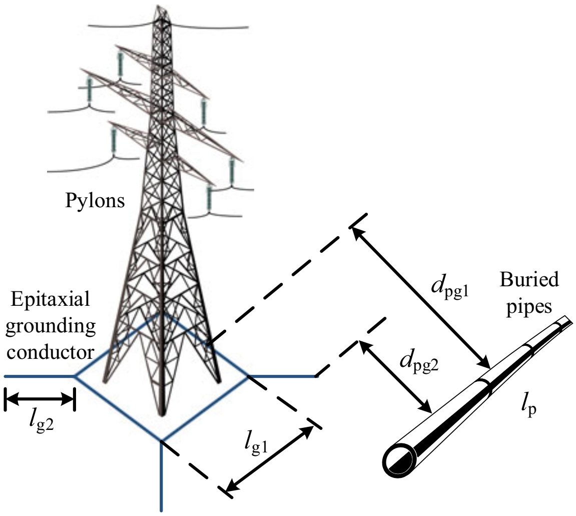
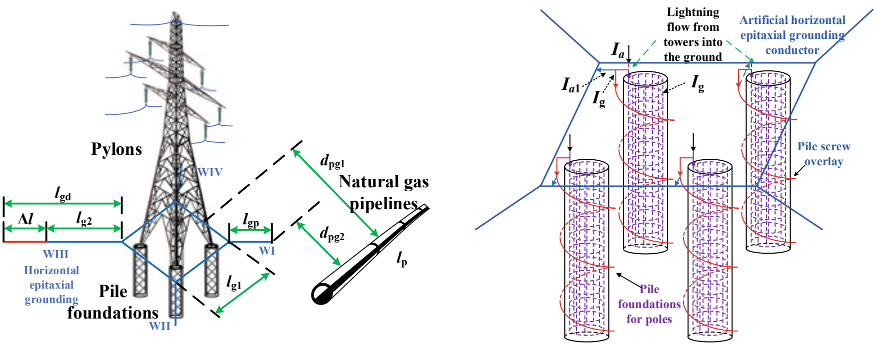



**Fig. 2** Finite element calculation model for "two lines and a ground"

# 4 Soil Vertical Dispersion Optimization

In this paper, we propose a method to optimise the grounding and dispersion structure of the spiral pile base, to ensure that the effective grounding and dispersion of the tower and the grounding resistance of the tower do not exceed the limit, to significantly reduce the dispersion of the natural gas pipeline side, and to reduce the withstand voltage value of the pipeline body and the anti-corrosion layer, the basic structure of which is shown in Fig. 3.

The horizontal structure of the pole tower earthing network in Fig. 3a is the same as in Fig. 2, with the difference being the addition of a spiral earthing structure




(a) Horizontal and vertical grounding grid simulation parameters

(b) Horizontal and vertical grounded diffusion structures for towers

**Fig. 3** Schematic diagram of the epitaxial grounding grid renewal on the outside of the concrete pile base of the pole tower, which can be made of conventional galvanised steel, copper-clad steel metal material or flexible graphite composite earthing material, of which the latter is easier to spiral lay due to its flexible material properties. The purpose of using a spiral structure is to increase the effective current dispersion volume of the earthing grid in the vertical dimension, with the steel skeleton within the pile base encapsulated in the concrete medium acting as a lesser grounding dispersion. The lightning current $I_a$ in Fig. 8 is dispersed to the soil medium by the grounding grid at three locations: the horizontal component of the boxed extended ray grounding grid $I_{a1}$ in the horizontal dimension, the component of the reinforcement skeleton $I_t$ in the vertical dimension and the component of the external spiral grounding grid $I_g$ in the vertical dimension. The "diversion" effect on the adjacent gas pipeline varies accordingly. It is envisaged that increasing the $I_t$ and $I_g$ components in the vertical dimension will reduce the amplitude of the lightning current on the adjacent gas pipeline.

In order to analyse the effect and influence factors of the external material of the concrete pile foundation of the pole tower, consistent with Fig. 2 and the horizontal grounding dispersion calculation model, the incoming mine current component amplitude is 60 kA, the length of the box grounding grid $l_{g1} = 15$ m, the length of the external grounding grid $l_{g2}$ is 10 m. In the four pile pits of the pole tower are single column pile foundation, the height of a single pile foundation is 15 m, the radius is 0.6 m, the concrete resistivity is $1 \times 10^4$ Ω-m. Simulations were carried out for the full pile foundation, the upper 2/3 of the pile foundation and the upper 1/3 of the pile foundation in turn, and compared with the case without external application. The effect of the external application area of the spiral vertical grounding grid on the current density in the vertical dimension of the soil for a soil resistivity $\rho$ of 500 Ω-m is shown in Fig. 4.

By the current density distribution can be seen, pile foundation external grounding grid current density is much higher than the concrete pile foundation reinforcement skeleton dissipation density, and with the increase of external material, spiral grounding grid dissipation effect is more obvious, external spiral grounding grid can effectively solve the concrete resistivity is too high, steel can not through the concrete

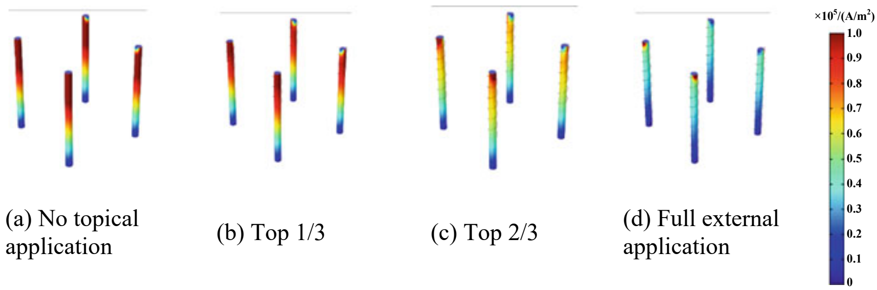



**Fig. 4** Effect of external area on current density distribution

medium dissipation problem, which for reducing the lightning current component on the adjacent natural gas pipeline play a better This is a good "shunting" effect.

# 5 Conclusion

The main findings of the study on the formation mechanism and protection strategies for lightning overvoltages in natural gas pipelines adjacent to power lines include: (1) pipe adjacent to the tower lightning strike through the tower tower and double side lightning line dispersion, the smaller the tower gear distance and grounding resistance shunt coefficient is greater.

natural gas pipeline adjacent to the tower pile steel conductor is limited by the concrete resistivity and small dissipation density, the use of pile spiral external grounding structure can increase the vertical dimension of the dissipation density, reduce the power line in the pipeline side of the lightning strike dissipation component, can take into account the power line lightning trip and pipeline overvoltage impact potential over the limit, reduce the amount of land acquisition and construction work.

The findings of this paper can provide a reference for the design, selection of materials and safe and protective operation of power lines and natural gas pipelines.

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