Lightning Protection for Gas-Pipelines installed under the Ground

HITOSHI KIJIMA, KENJI TAKATO, KAZUO MURAKAWA

Electrical Department
Polytechnic University
4-1-1 Sagamihara Kanagawa 229-1196 JAPAN
hkijima@uitec.ac.jp

Abstract: - Lightning protection for buried gas-pipelines has not yet being studid. Gas-pipes made of steel are covered with polyethylene sheath. When there is a high structure nearby the gas pipelines, the polyethylene's insulation may be destroyed by lightning surge. In this study, we have evaluated the possibilities of insulatin breakdown of polyethlene sheath using a finite element method.

As there is no rule on countermeasures in the world, we have to investigate the phenomenon when a lightning strikes the pipelines. Even the gas company normally use aditional sheath pipe or griddles to protect the gas pipelines from lightning surge , the effectiveness of these counter measure methods have not yet been evaluated. In addition to these methods, we have also investigated on the effectiveness of buried shielding wire normaly used for burial telecommunications lines.

In this study, we have simulated various lightning protection measures such as a sheath pipe, griddles and buried shielding wire by using finite element method so that called JMAG.

Key-Words: - gas-pipeline, dielectric breakdown, sheath pipe, protection griddle, counterpoise, JMAG

1 Introduction

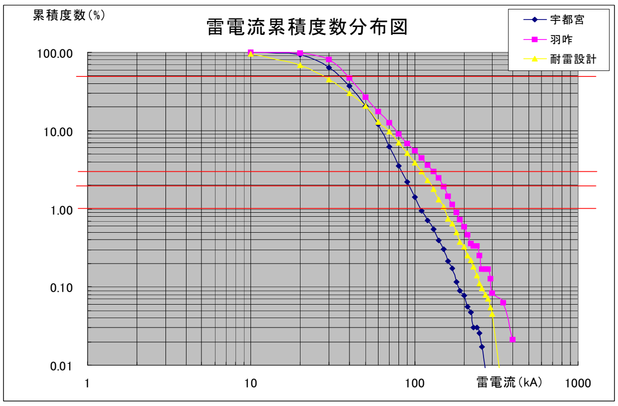
Lightning protection for power installations and telecommunications installations have being studied [1]-[13]. However, it was not yet investigated on the lighting protection of burial gas-pipelines.

Gas-pipes are made of steel. And polyethylene sheath is widely adopted as the gas- pipeline's outside corrosive protection material. When a high structure such as a power transmission tower is installed near the gas-pipeline route, dielectric breakdown of polyethylene occurs caused by a direct lightning strike. As there is no rule on countermeasures in the world, we have to investigate the phenomenon when a lightning strikes the pipelines. Even the gas company normally use aditional sheath pipe or griddles to protect gas pipeliness, the effectiveness of these counter measure methods have not yet been evaluated. In addition to these methods, we have also investigated the effectiveness of buried shielding wire normaly used for burial telecommunications lines. In this research we used JMAG which is 3 dimentinal electro-magnetic-field analysis software applying the 3 dimentinal finite element method[14].

2 Problem of Gas-pipelines when a lightning strikes

Fig.1 shows direct lightning strikes in Japan. Fig.2 shows a cumulative distribution of peak lightning surge current in Japan. The data was obtained by five year observations at several sites [8]. The maximum peak lightning surge current observed was 400kA. The occurrence probability of 100kA peak value is 3 % per one thunder storm day. The average frequency of direct lightning strikes at the sites is 35 days a year. Therefore 100kA peak current occured once a year. According to this data, we used 100kA peak lightning surge current for the simulation.

Fig.1 Direct lightning strikes in Japan



(a) Horizontal axis shows peak lightning surge current (kA)
(b) Vertical axis shows occurence probability (%)

Fig.2 Cumulative distribution of peak lightning surge current in Japan

Fig.3 shows gas-pipelines installed nearby a power transmission-tower. When a direct lighting strikes the tower, earth potential rise occurs as shown in Fig.4 (a), (b). The current flows through the soil under the ground. Due to this current, electric field strength as a function of depth are generated. The voltage was obtained by the integral of the electric feield strength from the ground surface to the burial point. Because gas-piplines are earthed at the far point, if this voltage exceed the breakdown voltage of the polyethylene sheath , gas-leak may occur.

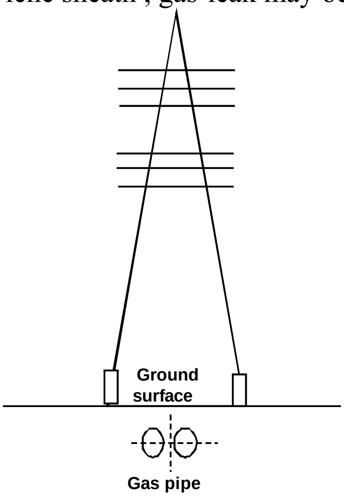


Fig.3 Gas-pipelines installed under the ground nearby a power transmission-tower

Fig. 4 (a) shows an earth potential rise caused by a direct lightning strike. When a surge current I flows at O as shown in Fig.4(a), current density J and electric field strength E at radius r in the soil are given as follows:

$$J(r) = \frac{I}{2\pi r^2} \qquad (1)$$

$$E(r) = \frac{\rho I}{2\pi r^2} \qquad (2)$$

As shown in Eq.(2), electric field strength E is a function of radius r, therefore electric field strength E near the direct lightning striking point is high.
Therefore the potential voltage at R is obtained by the integral of the E(r) as follows:

$$V(R) = -\int_{\infty}^{R} E(x)dx = \frac{\rho I}{2\pi R} \qquad (3)$$

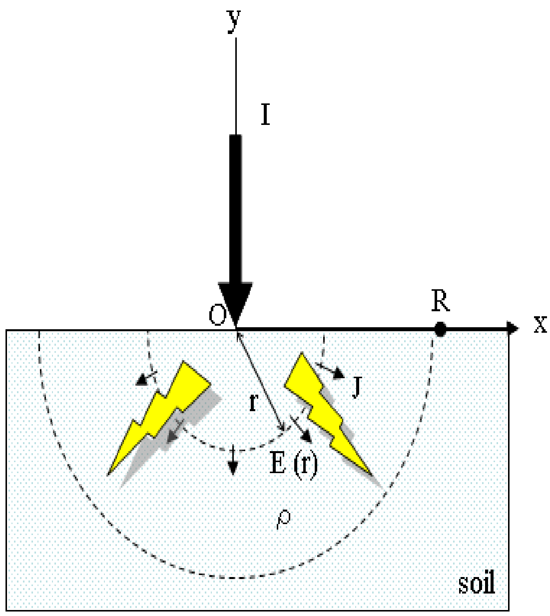
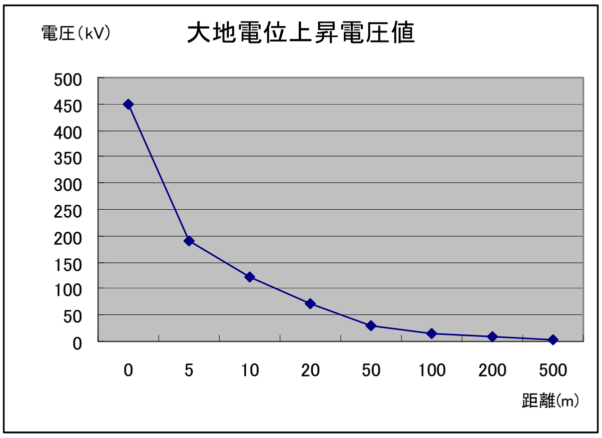


Fig. 4 (a) Earth potential rise caused by lightning strike

Fig.4 (b) shows earth potential rise when a direct lightning strike (100kA, ρ =100Ω･m).



(a) Horizontal axis shows distance from the tower (m)
(b) Vertical axis shows earth potential rise (kV)

Fig.4 (b) Erath potential rise when a direct lightning strike (100kA, ρ =100Ω･m)

3 Specifications of gas-pipelines

Gas-pipes are made of steel. And polyethylene sheath is widely adopted as a pipeline's outside corrosive protection material.

(1) The pipeline's burial depth d_1 is 1.5m under the ground.
(2) Soil resistivity ρ is 30～1000Ω･m
(3) Gas-pipelines are made of steel

Inner diameter	D_{i1}	387.4×10^{-3}m
Outer diameter	D_{O1}	406.4×10^{-3}m
Thickness	t_1	9.5×10-3m
Resistivity		1.5×10^{-7}Ω･m
Relative permeability		280

(4) Polyethylene sheath

Outer diameter	Do_{12}	411.4×10^{-3}m
Thickness	t_{12}	2.5×10^{-3}m
Resistivity		1.0×10^{14}Ω･m
Deelectric constant		2.3

4 Several lightning protection measures

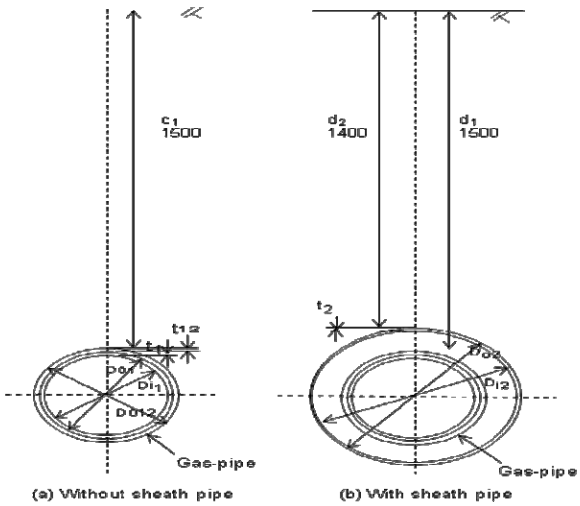
There are three protection measures against lightnig damage as listed in Table 1. The gas company normally use a sheath pipe or griddles to protect the gas pipelines from lightning surge current. In addition to these methods, we have also investigated on the effectiveness of a counterpoise normaly used for burial telecommunications lines.

Table 1 Lightning protection measures

Measures	View
Nothing	A gas-pipline is buried under the ground
(1) A sheath pipe	A gas-pipline is covered with a sheath pipe.
(2) Griddles	Griddles are instaled both upper part and side part of a gas-pipeline
(3)A counterpoise	A counterpoise is laid 30cm above a gas-pipeline

4 .1 Protection using a sheath pipe

Fig. 5 (a) shows a gas-pipe without any lightning protection measures. Fig 5(b) shows a protection measure using a sheath pipe. First of all, the sheath pipe is installed . Then the gas-pipe is inserted into the sheath pipe. The inner diameter D_{i2} of the sheath pipe is 589.0×10^{-3} m. As the outer diameter D_{o1} of the gas-pipe is 406.4×10^{-3} m, the clearance between the sheath pipe and the gas pipe is about 200 $\times10^{-3}$ m. Therefore the gas-pipe is to be able to insert into the sheath pipe easy.



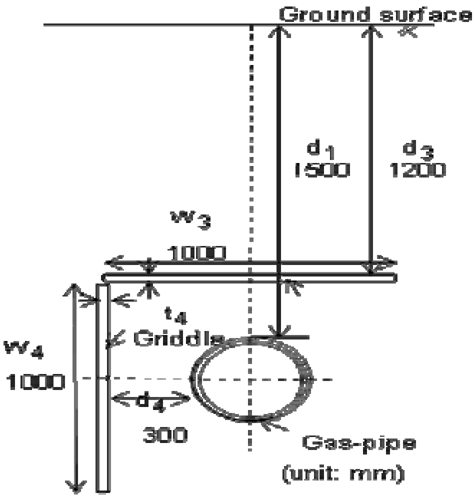
(1) A sheathe pipe's burial depth d_2 is 1.4m
(2) A Sheath pipe is made of steel

Inner diameter	D_{i2}	589.0×10^{-3}m
Outer diameter	D_{O2}	609.6×10^{-3}m
Thickness	t_2	10.3×10^{-3}m
Resistivity		1.5×10^{-7}Ω･m
Relative permeability		280

Fig.5 Lightning Protection measure using a sheath pipe

4 .2 Protection using griddles

Fig. 6 shows a protection measure using griddles. Griddle is metallic plate made of steel. We used two metallic plates installed upper part and side part of the gas pipe-line.

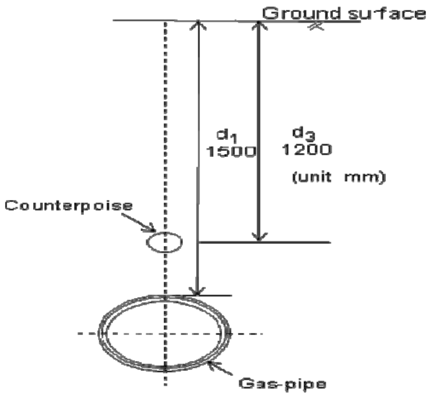


(1)A griddle's burial depth d_3 is 1.2m
(2)Upper part protection griddle width W_3 is 1.0m
(3)Side part protection griddle width W_4 is 1.0m
(4) Thickness t_4 6.0×10^{-3}m
(5) Distance d_4 0.3m

Fig. 6 Protection measure using griddles.

4 .3 Protection using a counterpoise

Fig. 7 shows a protection measure using a counterpoise. The counterpose is metallic thin wire made of steel. A counterpoise is laid 30cm above the gas-pipeline as a shielding wire.



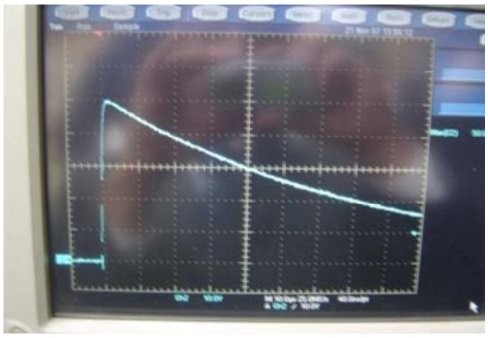
(1) A counterpose's burial depth d_3 is 1.2m
(2) Radius of counterpoise 1.0×10^{-2}m
(3) Resistivity $1.5\times10^{-7}\Omega\cdot$m
(4) Relative permeability 280

Fig.7 Protection measure using a counterpoise

5 Experimental results on dielectric breakdown voltage of the polyethylene sheath

5 .1 Applying lightning surge waveform

In order to claryfy the dielectric breakdown voltage of the polyethylene sheath, we tested them as shown in Fig.8, Fig.9 and Fig.10. Fig.8 shows one of lightning surge waveforms used in experiments. In this figure, the peak voltage value is 100kV, the rise time is 1us and the mean time to half value is 50 us. We denoted this lightning surge waveform 100kV(1/50us).

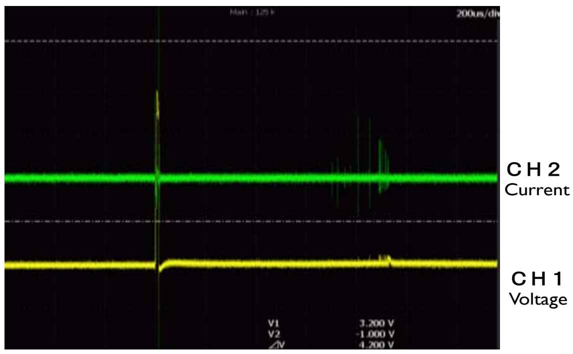


(a)Horizontal axis shows time (10 us/div)
(b)Vertical axis shows voltage(20kV/div)

Fig.8 Lightning surge waveform 100kV(1/50us) used in experiments

5 .2 Voltage and current when the dielectric breakdown of the polyethylene sheath occured

We increased the peak voltage value up to 200kV until the dielectric breakdown of polyethylene sheath occured. Fig.9 shows lightning surge waveform when the dielectric breakdown of the polyethylene sheath occured. Due to the dielectric breakdown of the polyethylene sheath, only several kVwas observed.



(a) Horizontal axis shows time (10 us/div)

(b) CH2: vertical axis shows current (10A/div)
(c) CH1: vertical axis shows voltage (1000V/div)

Fig.9 Voltage and curent when the dielectric breakdown of polyethylene sheath occured

5.3 Dielectric breakdown voltages of the polyethylene sheath as a function of thickness

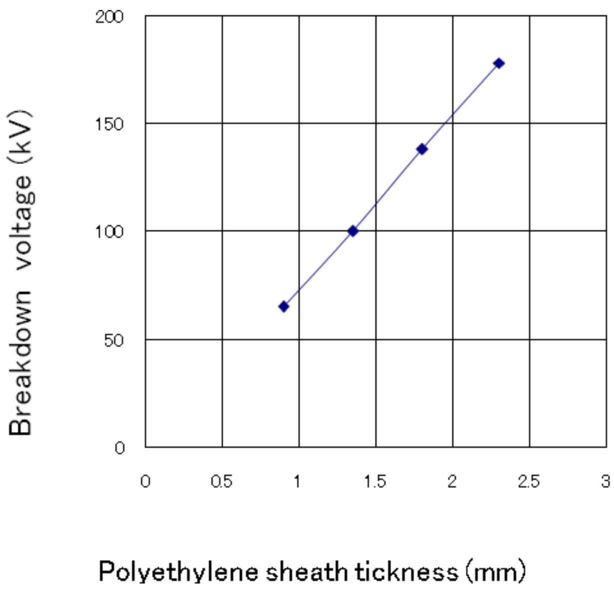


Fig.10 Voltages in which the polyethylene sheath caused dielectric breakdowns as a function of thickness

Since the thickness of the polyethylene sheath was set to 2.5×10^{-3}m in this model, Fig.10 shows that the dielectric breakdown voltage of the polyethylene sheath is 200kV(2.0E+5V). This value is compared with the value computed by the simulation.

6 Simulation method

6.1 Finite element method

In this study, we have simulated various lightning protection measures such as a sheath pipe, griddles and a counterpoise by using computer software so that called JMAG which is 3 dimentional electro-magnetic field analysis software applying the finite element method[14] .

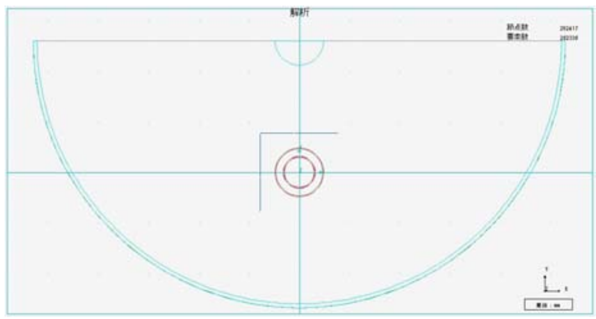
The electric fields up to 1.5m under the ground were calculated in the case with and without lightning protection measures. Then the voltages were calculated by the integral of the electric feield strength from the ground surface to the burial point .

6.2 Conditions for the simulation

Fig.11 shows cross section of the model view.

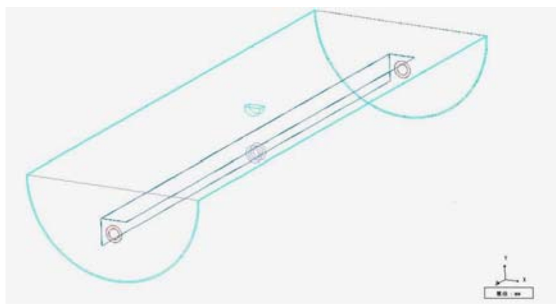
Fig.12 shows cubic model view.

In order to examine the screening effect by the difference in soil resistance, soil resistivity was set into 30, 100 and 1,000 Ω･m.



(a) A direct lightning surge peak current is 100kA.
(b) A pipeline's burial depth is 1.5 m under the ground.
(c) Model radius is 3 m.

Fig.11 Cross section of the model view



(d) Model total length is 40 m (left side 20m, right side 20m)

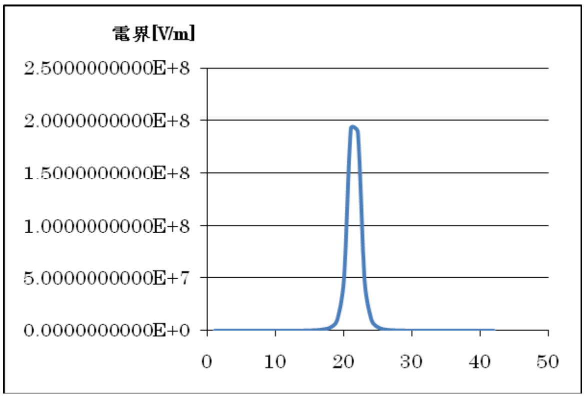
Current density, electric field strength and voltage were calculated at the center point

Fig.12 Cubic model view

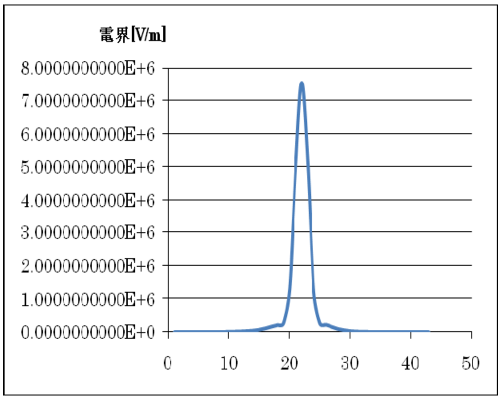
7 Simulation results

7.1 Simulation results on electric field strength

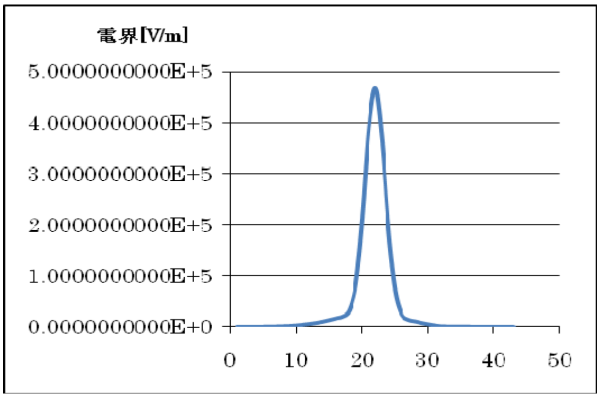
One example of the analyzed results of electric field strength in the case of without any protection measures are shown in Fig. 13(a), (b) and (c). The electric field strength was degraded as the depth increased. The voltage was obtained by the integral of these electric feield strength from the ground surface to the burial point.



(a) At the ground surface 0[m]



(b) At the depth 0.5[m]



(c) At the depth of 1.0[m]

Fig. 13 Analyzed results of electric field strength in the case of without any protection measures

7.2 Simulation results on current density and voltage

As a matter of fact that gas-piplines are earthed at the far point, if this voltage obtained by the integral of the electric feield strength exceeds the breakdown voltage of the polyethylene sheath, gas-leak may occur.

7.2.1 without measures

The current density in the case of without any lightning protection measures is shown in Fig.14.

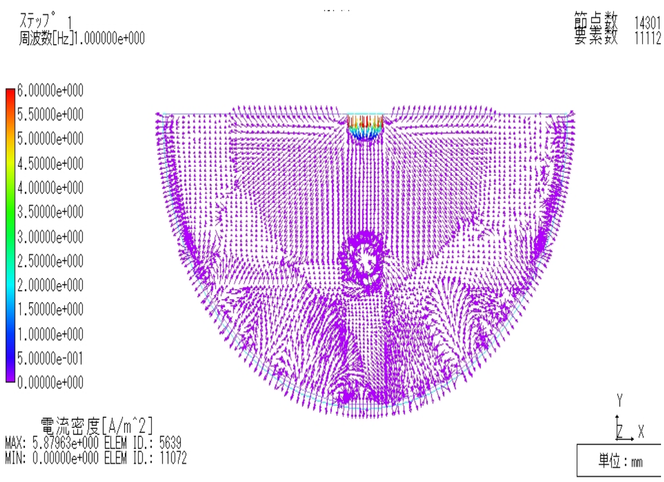


Fig.14 Flow of the current in the case of without any lightning protection measures

Next, it takes into consideration about the dielectric breakdown of the polyethylene sheath.
The voltages were obtained as folows.

$$
\begin{array}{lll}
2.17E+8\ V \gg & 2.0E+5V & (30\Omega\cdot m) \\
2.64E+7\ V \gg & 2.0E+5V & (100\Omega\cdot m) \\
6.60E+6\ V \gg & 2.0E+5V & (1000\Omega\cdot m)
\end{array} \quad (4)
$$

It became clear from the results of (4) that the voltages exceed the breakdown voltage value of the polyethylene sheath. It turned out that the polyethylene sheath will cause a dielectric breakdown in the case of without measures.

7.2.2 Cover using a sheath pipe (whole part)

The gas company normally uses aditional sheath steel pipe (whole part) to protect the gas pipelines from lightning surge. The current density in the case of using the sheath pipe (whole part) is shown in Fig.15.

The simulation results of electric field strength at the gas pipe burial position are listed in Table 2.

When the sheath pipe (whole part) is used, compared with the case where there is no measure, electric field strength has fallen sharply.

It turned out that the current from all the direction was able to be covered by the sheath pipe (whole part).

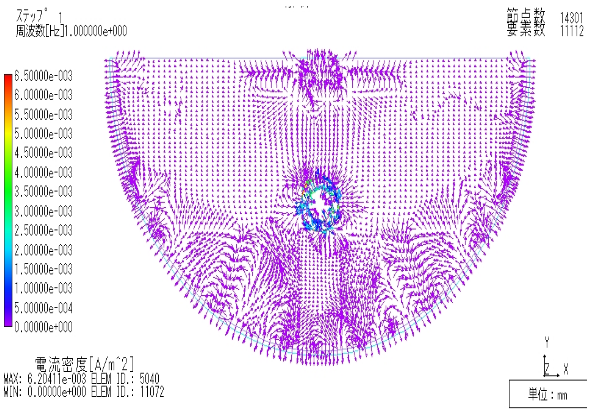


Fig.15 Flow of the current when using the sheath pipe (whole part)

Table 2 Field strength at the gas pipe burial position

Electric field [V/m] (30Ω･m)	2.116E-4
Electric field [V/m] (100Ω･m)	1.602E-5
Electric field [V/m] (1000Ω･m)	4.422E-8

The voltages were obtained as folows by the integral of the electric feield strength from the ground surface to the burial point.

1.95E+4 V≪ 2.0E+5V (30Ω･m)
1.90E+3V≪ 2.0E+5V (100Ω･m)
5.85E+2V≪ 2.0E+5V (1000Ω･m)

(5)

The results of (5) showed that they were less than the breakdown voltage value of the polyethylene sheath. It is thought that it can become a protection measure very effective when the sheath pipe (whole part) is used.

7.2.3 Cover using a sheath pipe (only upper part)

Even the gas company has not yet used sheath steel pipe having only upper part, we investigated this model.

The current density in the case of using the sheath pipe (only upper part) is shown in Fig.16.

The simulation results of electric field strength at the gas pipe burial position are listed in Table 3.

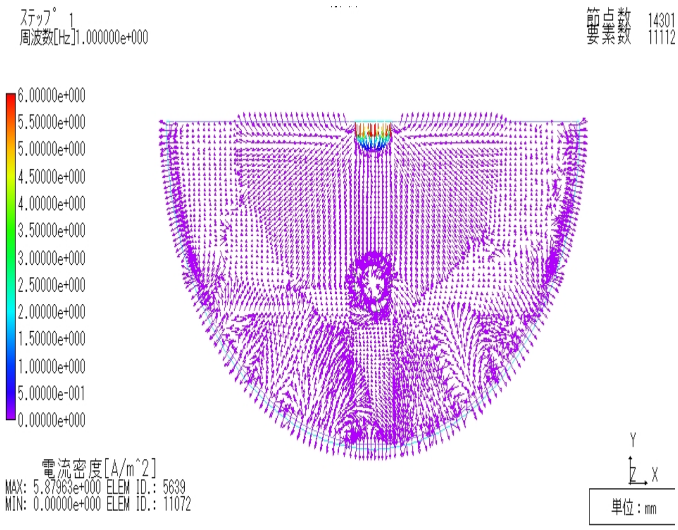


Fig.16 Flow of current when using the sheath pipe (Only upper part)

Table 3 Field strength at the gas pipe burial position

Electric field [V/m] (30Ω･m)	5.130E-3
Electric field [V/m] (100Ω･m)	3.518E-4
Electric field [V/m] (1000Ω･m)	3.282E-5

It turned out that the electric field strength has fallen sharply compared with the case where there has no measure even when the sheath pipe (upper part) is used.

The voltages were obtained as folows by the integral of the electric feield strength from the ground surface to the burial point.

1.95E+4 V≪ 2.0E+5V (ρ=30Ω･m)
5.84E+3V ≪ 2.0E+5V (ρ=100Ω･m)
5.84E+2V ≪ 2.0E+5V (ρ=1000Ω･m)
(6)

The results of (6) showed that they were less than the breakdown voltage value of the polyethylene sheath. By this, even the sheath pipe (upper part) is used; it is thought that effectiveness is still valid.

7.2.4 Cover using protection griddles

The gas company normally use griddles to protect the gas pipelines from lightning surge. The current density in the case of using protection griddles is shown in Fi.17.

The simulation results of electric field strength at the gas pipe burial position are listed in Table 4.

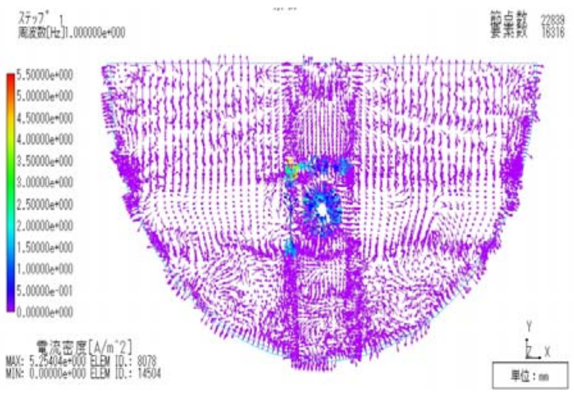


Fig.17 Flow of the current protection when using the griddles

Table 4 Field strength at the gas pipe burial position

Electric field [V/m] (30Ω・m)	3.266E-2
Electric field [V/m] (100Ω・m)	1.032E-1
Electric field [V/m] (1000Ω・m)	6.026E-1

It turned out that the electric field strength has fallen compared with the case where there has no measure. The protective barrier of the upper part and left-hand side shows intercepting current. However, since the pipeline's whole surface is not enclosed like the sheath pipe (whole), it is assumed that the current from a right-hand side and a lower part side without a protective barrier was not able to be covered. The voltages were obtained as folows by the integral of the electric feield strength from the ground surface to the burial point.

2.22E+5V ≫ 2.0E+5V (30Ω・m)
4.01E+4V ≪ 2.0E+5V (100Ω・m)
1.70E+4V ≪ 2.0E+5V (1000Ω・m)
(7)

The results of (7) showed that they were less than the breakdown voltage value of the polyethylene sheath in the case of 100Ω・m and 1000Ω・m. However, in the case of 30Ω・m, the voltage exceeds the breakdown voltage value of the polyethylene sheath.

Therefore even using griddles in the case of 30Ω・m, the dielectric breakdown of the polyethylene sheath may occur.

7.2.5 Cover using counterpoise (whole part)

Even the gas company des not use a counterpoise, we have investigated on the effectiveness of the counterpoise normaly used for burial telecom. lines.

The counterpoise is metaric thin wire made of steel. The current density in the case of using the counterpoise (whole part) is shown in Fig.18.

The simulation results of electric field strength at the gas pipe burial position are listed in Table 5.

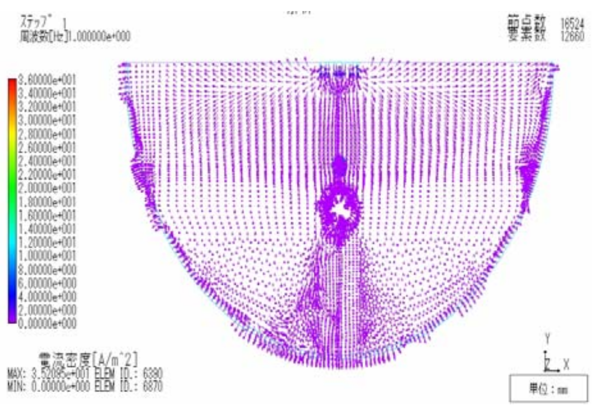


Fig.18 Flow of the current at the time of covering with a counterpoise (whole part)

Table 5 Field strength at the gas pipe burial position

Electric field [V/m] (30Ω・m)	1.112E-2
Electric field [V/m] (100Ω・m)	9.142E-4
Electric field [V/m] (1000Ω・m)	1.089E-4

It turned out that compared with the case where there has no measure electric field strength has fallen extremely. The voltages were obtained as folows by the integral of the electric feield strength from the ground surface to the burial point.

1.04E+4 V≪ 2.0E+5V (30Ω・m)
3.31E+3V ≪ 2.0E+5V (100Ω・m)
3.13E+2V ≪ 2.0E+5V (1000Ω・m)
(8)

The results of (8) showed that they were much less than the breakdown voltage value of the polyethylene sheath. The screening effect was excellent as a measure.

7.2.6 Cover using counterpoise (1m interval having 10cm space)

Even the telecom. company has not yet used a counterpoise (1 m interval having 10 cm space) , we investigated this model. The current density in the case of using the counterpoise (1 m interval having 10 cm space l) is shown in Fig.19.

The simulation results of electric field strength at the gas pipe burial position are listed in Table 6.

Even if using the counterpoise (1 m interval having 10 cm space), it is thought that effectiveness is still valid.

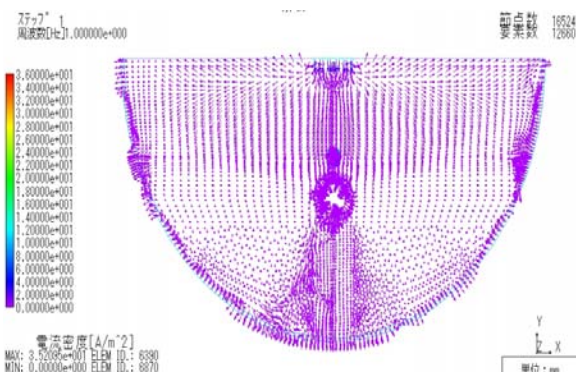


Fig.19 Flow of the current at the time of covering with a counterpoise (1m interval)

Table 6 Field strength at the gas pipe burial position

Electric field [V/m] (30Ω･m)	5.413E+0
Electric field [V/m] (100Ω･m)	1.660E+0
Electric field [V/m] (1000Ω･m)	1.631E-1

The voltages were obtained as folows by the integral of the electric feield strength from the ground surface to the burial point.

$$1.84E+4\ V \ll 2.0E+5V \quad (30\Omega\cdot m)$$
$$3.56E+3V \ll 2.0E+5V \quad (100\Omega\cdot m)$$
$$5.53E+2V \ll 2.0E+5V \quad (1000\Omega\cdot m) \quad (9)$$

The results of (9) showed that it was much less than the breakdown voltage value of the polyethylene sheath.

8 Comparisons

The analyzed results of the voltages are listed in Table 7.

As the dielectric breakdown voltage of the polyethylene sheath is 200kV(2.0E+5V), voltages in the case of without measures exceed this breakdown voltage value. Because gas-piplines are earthed at the far point, if the voltages exceed the breakdown voltage of the polyethylene sheath, gas-leak may occur. Therefore evaluation results in the case of without measures became bad (×).

On the other hand, all measures except protection using griddles at 30Ω･m are effective to protect the gas pipelines aginst lightning surge.

As the resistivity of the soil increased voltages decreased because almost all current flow through the metallic part of the measures.

Table 7 Voltages evaluation of various measures

Measures	Voltage (30Ω･m)	Voltage (100Ω･m)	Voltage (1000Ω･m)
Nothing	2.17E+8 ×	2.64E+7 ×	6.60E+6 ×
Sheath pipe protection (whole)	1.95E+4 △	1.90E+3 ○	5.85E+2 ◎
Sheath pipe protection (upper part)	1.95E+4 △	5.84E+3 ○	5.84E+2 ◎
Protection griddle	2.22E+5 ×	4.01E+4 △	1.70E+4 △
Counterpoise (whole)	1.04E+4 △	3.31 E+3 ○	3.13E+2 ◎
Counterpoise (1m interval)	1.84E+4 △	3.56E+3 ○	5.53E+2 ◎

◎very good, ○good, △so-so, ×bad

9 Conclusion

We have simulated various lightning protection measures such as a sheath pipe, griddles and a counterpoise using 3D electro-magnetic field analysis software applying the finite element method.

The following results were obtained by analyzing current density, electric field strength and voltage when the lightning surge current flows into a soil nearby gas-pipelines.

(1) In the case of without measures, the voltage exceed the breakdown voltage value of the polyethylene sheath. Thereby, a gas leak may be caused.

(2) By enclosing a gas-pipeline using a sheath pipe, the current from all the direction can be shielded. It is thought that a sheath pipe is very effective measure.

The construction expense and time using a sheath pipe is high.

(3) Even using griddles in the case of 30Ω･m, the dielectric breakdown of the polyethylene sheath may occur because the voltage exceeds the breakdown voltage value of the polyethylene sheath.

The construction expense and time using griddles is high.

(4)By laying a counterpoise above a pipeline as a shielding wire, most current concentrates on this counterpoise. As a result a very effective screening effect is acquired.

The construction expense and time using a counterpoise is low.

Table 8 lists comprehensive evaluations for various measures taking into account the evaluation results mentioned above.

Table 8 Comprehensive evaluations for various measures

	Shielding effect	Construction expense and time	Total Evaluation
With no cover	×		×
Sheath pipe protection (whole)	○	×	△
Sheath pipe protection (upper part)	○	△	○
Protection griddle	△	×	△
Counterpoise (whole)	○	△	○
Counterpoise (1m interval)	○	○	◎

◎very good, ○good, △so-so, ×bad

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