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Validation of Some Protection Guidelines for Neighboring Pipelines against Fault Currents from Power Transmission Tower

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Fault current can be discharged from power transmission tower due to lightning or inadvertent contact of crane, etc. Pipelines in proximity to either the source of the ground fault or the substation grounding grid may provide convenient conductive path for the fault current to travel. Inappropriate measures to the neighboring pipelines against the fault current may cause severe damages to the pipes such as coating breakdown, arc burn, puncture, loss in wall thickness, or brittle heat-affected zone. Like inductive and conductive AC coupling, steadily induced fault current right after the coating breakdown can lead to corrosion of the pipeline. In this work, some protection guidelines against fault currents used in the field have been validated through the simulation and analytical method.

***Keywords** : fault current, pipeline, AC coupling, power transmission, shielding.*

1. Introduction

AC power transmission line along pipeline may affect the stability of the pipeline in three manners such as resistive, inductive and capacitive coupling modes. Especially the fault current from the AC power transmission tower is a typical interference by resistive coupling mode and may often cause the vital damage to the underground pipeline. It is well known that it may cause the breakdown of coating, arc burn, puncture or loss in thickness of pipe as well as personal safety as a result of induced voltage through soil path. Thus it requires the optimum countermeasures against the fault current from AC transmission tower. Fig. 1 shows some examples for the damage of underground pipeline by the fault current.

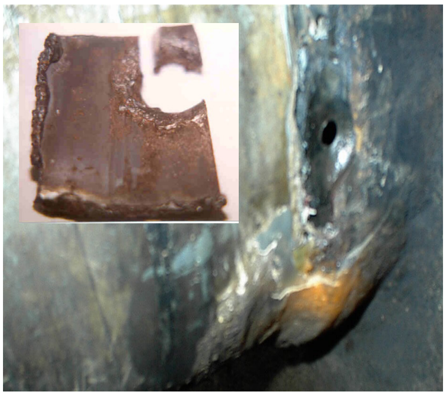
This study has been carried out to validate some interference criteria and countermeasures to the fault current by experimental simulation, theoretical review on voltage distribution around anode, and commercial simulation packages using analytical method.

2. Background

2.1 Separation distance

In order to protect the pipeline against voltage rise in

(a)



(b)

Fig. 1. Case histories on pipe failure by AC fault current; (a) thickness loss of more than 50% at transmission line by 154 kV, (b) puncture at distribution pipe by 22.9 kV.

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the earth due to fault current, a variety of criteria are found to be proposed from literature. For instances, Canadian standard[1)] recommends separation more than 10 m over 35 kV, and German document[2)] encourages the separation of 3 m below 100 kV and 10 m over 110 kV. W. Baeckmann[3)] mentions 2 m and Canadian Electrical Association report[4)] insists the separation distance of 11 m at 138 kV, 18 m at 230 kV and 41 m at 500 kV. Osaka Gas (OGC)[5)] uses the separation distance of 2 m at 154 kV and 10 m at 345 kV whereas Gaz de France (GDF)[6)] takes least separation distance 2 m. In the light of above facts, it is inferred that the criterion might be dependent of the different theoretical background and their elegant cultural experience.

2.2 Mitigation practice for voltage induced by fault current

GDF accepts the tolerable voltage of 5 kV and practices grounding through diode for mitigation in case of over the threshold level.[6)] The CEA report[4)] suggests the mitigation of screening electrode (distributed Mg anode) and Gasunie of Netherlands[7)] obeys that 30 m separation is enough, and recommends mitigation when exceeds 1.5 kV. Osaka Gas[5)] proposes some concrete methods to reduce the risk of AC shock such as grounding plate without contacting with pipeline for the mitigation based upon the tolerable voltage of 5 kV. It is relatively easy to take it as the mitigation; however, it requires too long length when soil resistivity is high. Thus it is necessary to estimate the effectiveness of the mitigation. Table 1 summarizes the practices.

Fig. 2 shows Method C, that is, how to calculate the length l. To calculate the length l, one can use following Eqs. 1, 2 for horizontal anode;

$$R = \frac{\rho}{2\pi l} \ln \frac{\frac{l}{2} + \sqrt{(\frac{l}{2})^2 + d^2 + h^2}}{-\frac{l}{2} + \sqrt{(\frac{l}{2})^2 + d^2 + h^2}} \qquad (1)$$

$$R = \frac{\rho}{2\pi l} \ln \frac{l}{d} \quad \text{in case of} \quad \frac{l}{2} >> d >> h \qquad (2)$$

where R is defined as V_b/I_g, where V_b is breakdown voltage of coating (V_b: 5,000 V),
I_g is grounding current (I_g: 10,000 A),
$l/2$ is required protection length from the nearest foot of electric tower [m],
$\rho$is soil resistivity [Ωm],
d is clearance between pipeline and the nearest foot of electric tower [m] and
h is buried depth of steel protection plate [m].

Table 1. The Countermeasure around Power Transmission Tower practiced at OGC

Transmission voltage [kV]	Clearance between pipeline and the nearest foot of electric tower		Protecting Method
	Prohibited [m]	Protected [m]	
77	none	< 5	A
154	< 2	2 ≤~≤ 6	B
275 or 345	< 10	10 ≤~≤ 50	C

* A: "Π"- form shielding toward both ends within 5 m from tower pole
* B: Method A + "steel plate" of 15 m for portion 5 m away
* C: "steel plate" of required protection length

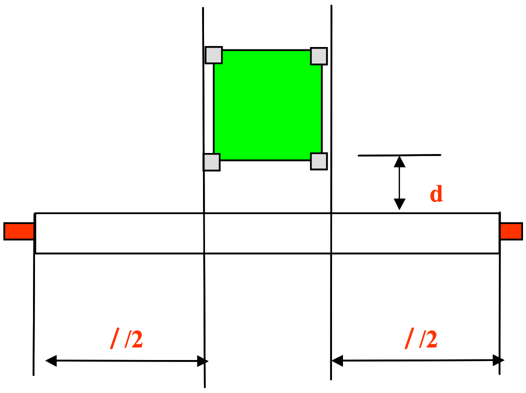


Fig. 2. Steel plate length in Method C of Table 1

3. Approaches to validation

3.1 Visual arc test

In order to visualize the necessity of shielding by steel to reduce the risk of arcing, simple arc tests were made for simulated environments and ground resistance using a pinhole tester with a full capacity of 30 kV.

3.2 Simulation of mitigation with commercial package

The voltage rise in the earth by fault current was calculated by using typical parameter values listed in Table 2. In this calculation the results from a hemisphere anode were compared with those obtained from the OGC's guidelines. Simulation using commercial package program to get appropriate designing factors (length, shape, and coating) was also made. In this study the CatPro from Elsyca has been utilized. Like most literature, the tolerable voltage which physically means the coating breakdown voltage is taken as 5 kV in this study.

Table 2. Typical Parameter Values for Calculation of Voltage Rise in the Earth

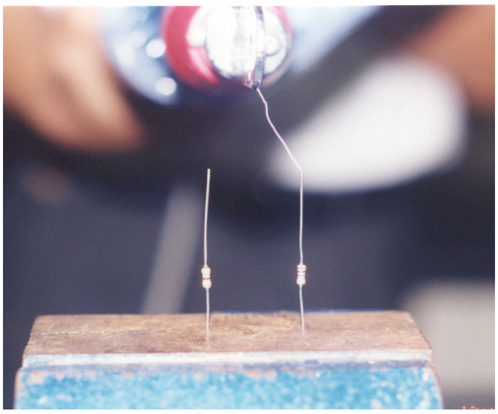
Parameters	Typical Value
Tower leg condition	15 m depth, rectangular 4 legs, 20 m between legs
Distance from tower leg	10 m
Fault current	10 kA (constant)
Mitigation	copper wire of 10 cm Φ

4. Results and interpretation

4.1 Visual arc test

Fig. 3 shows that arcing occurs easier at a path with lower ground resistance, and thus the bare steel shielding can have a good protective material to reduce the risk of arcing at pipeline with higher ground resistance due to protective coating.

(a)



(b)

Fig. 3. Arcing tests showing (a) steel shielding effect (b) ground resistance effect: left 100 kΩ, right 1 kΩ

4.2 Calculation of voltage rise

When a fault occurs, enormous current discharged from tower forms potential gradient at soil, whereas buried long pipeline with numerous coating defects is generally well earthed. Consequently, voltage difference between pipeline and soil is induced.

The hemispherical model ignores the shape of tower and gives the calculated voltage with distance when the current enters into the nearest position of pipeline from the center of the hemisphere. Thus the model results in a very conservative analysis. Under a simple hemispherical anode, the equation for voltage difference with distance is,

$$V_x = \rho \frac{I}{2\pi x} \tag{3}$$

where ρis soil resistivity, I, fault current, and x, distance.

Fig. 3 shows the calculation comparisons among the horizontal models (Eqs. 1, 2) and hemispheric model. In the figures the voltage distributions according to Eq. 1 and hemispherical Eq. 3 behave similarly at initial distance and show ever-decreasing, whereas that from Eq. 2 shows a sharp increase at initial stage and then a gradual decrease with the distance. It can be seen that Eq. 1 and Eq. 2 give us a more overestimated results than Eq. 3 over the distance. Based upon the breakdown voltage of coating, 5 kV, the protection length can be taken at an intercept by the voltage. Table 3 summarizes the protection length required to cover the voltage over 5 kV at fault current of 10 kA under the combination of soil resistivity and separation distance considered in the calculations.

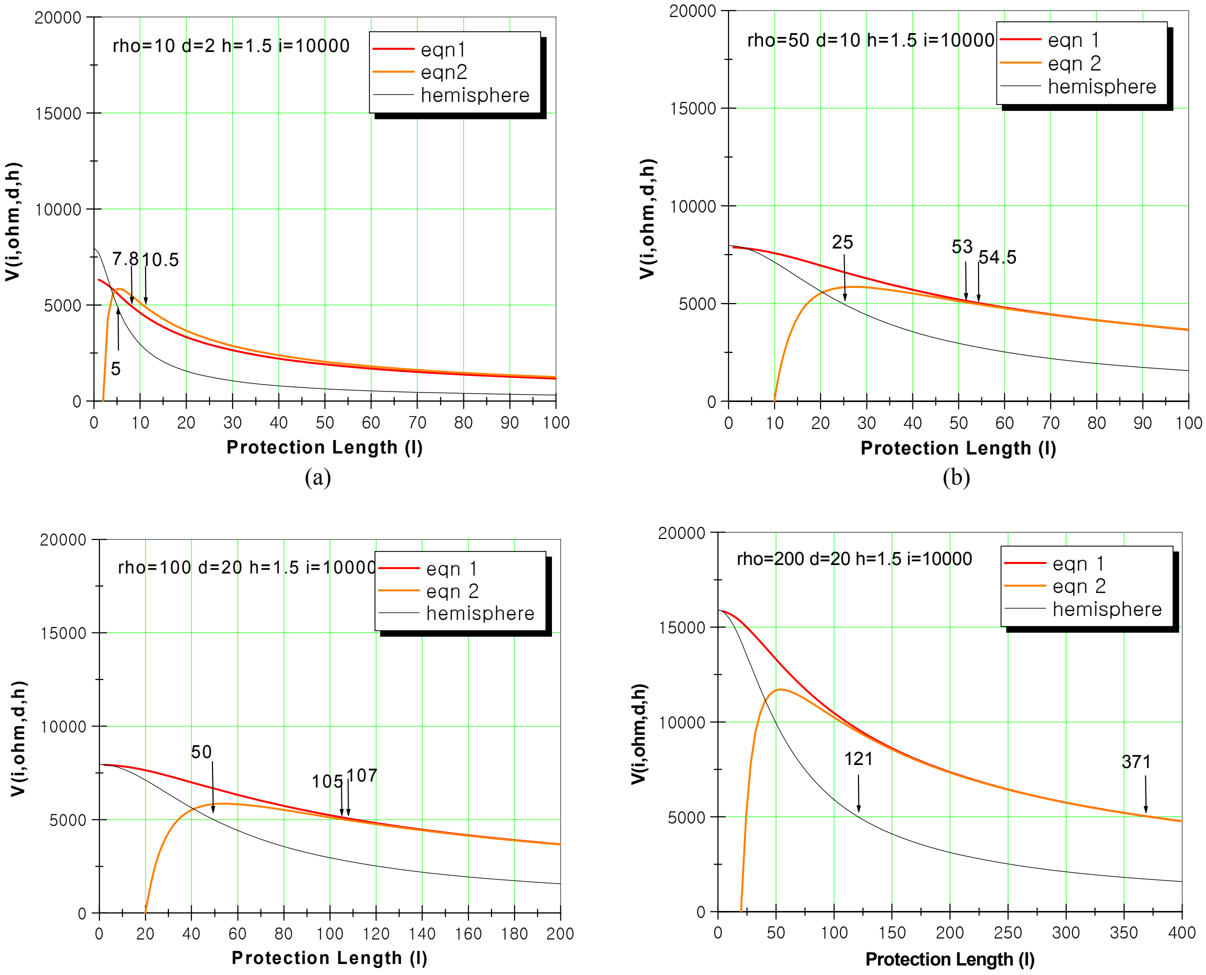
On the other hand, in the '40s E.D. Sunde suggested the flash-over distance under lightning depending on the soil resistivity in his work[8] as followings

$$r(m) = 0.08\sqrt{\rho I} \quad \text{where } \rho < 100\ \Omega\text{m and I (kA)} \tag{4}$$

$$r(m) = 0.047\sqrt{\rho I} \quad \text{where } \rho > 1000\ \Omega\text{m and I (kA)} \tag{5}$$

Table 3. Calculated Protection Lengths at the Fault Current of 10 kA.

Soil Resistivity [Ωm]	Separation Distance [m]	Radius within 5 kV at Hemispherical model [m]	Protection Length [m]		
			Eq. 1	Eq. 2	Hemi-sphere Eq. 3
10	2	3.2	7.8	10.5	5
50	10	15.8	54.5	53	25
100	20	31.8	107	105	50
200	20	63.6	371	371	121



(a) (b)

(c) (d)

Fig. 3. Calculated voltage distributions to determine steel plate length in 1.5 m depth at fault current of 10 kA under (a) ρ=10 Ωm, d=2 m (b) ρ=50 Ωm, d=10 m (c) ρ=100 Ωm, d=20 m and (d) ρ=200 Ωm, d=20 m

Sunde's equations. tell us arc distance can be few meters at ordinary fault current, however a lightning is sustained in a very short time such as few microseconds compared to few milliseconds of fault current. In this case the break voltage through soil under lightning can be also higher than that of normal fault current.[9] Thus Sunde's equations are not applicable for the consideration of fault current mitigation.

4.3 Simulation for the effectiveness of shielding steel plate

Fig. 5 shows the schematic diagram for the simulation of pipeline and tower, etc using computer analysis program. It was assumed that 1 km pipeline is vertically located from the origin and AC interfering source is located at 10 m away from the pipeline. The current out of the source is assumed to return into far another sink on the upper-right of the figure.

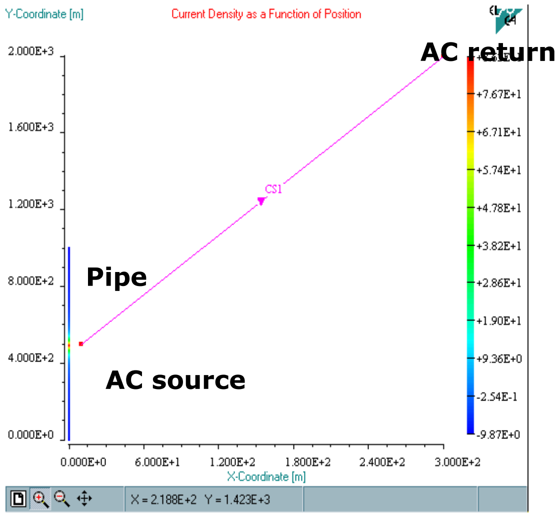
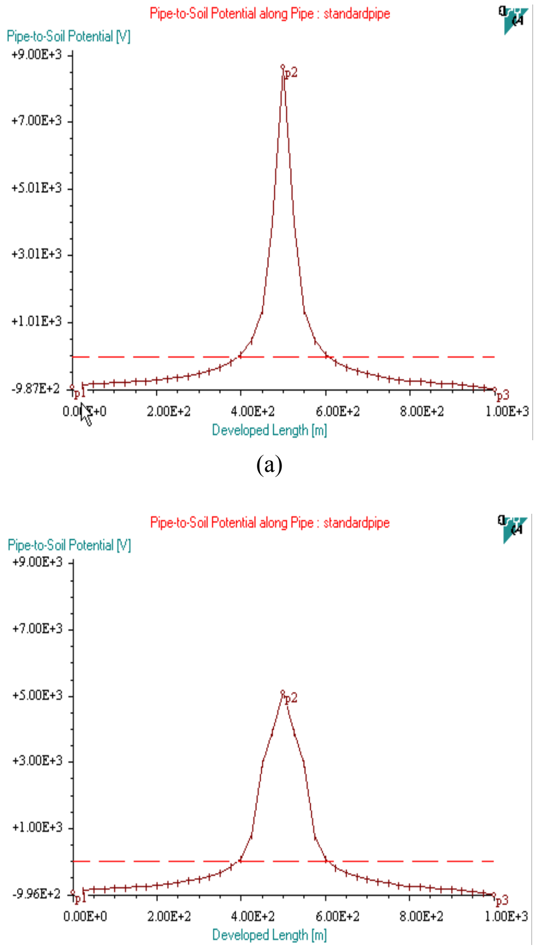


Fig. 5. Schematics of Structure Dimensions used for Simulation



(a)

(b)

Fig. 6. Potential distributions (a) before and (b) after mitigation

Fig. 6(a) explains the potential distribution of pipeline interfered by AC source. In this simulation an arbitrary condition was used to show the peak voltage of 9,000 V although the voltage rise is generally dependent of soil condition and magnitude of interfering AC current. Fig. 6(b) shows the change of potential distribution after installment of 100 m bare pipe at the peak voltage by parallel to 10 cm away from pipeline. The use of pipe form instead of plate as shielding material was a result due to a limitation of commercial package program; however, it is not so unreasonable to do approximation to see the effect of mitigation.

From the results it is apparent that the peak voltage is reduced at a half magnitude and the peak shows a more broadness. This means that the bare steel can reduce the peak voltage and the interference at the peak moves toward the periphery resulting in an increase of intensity. Thus it requires an allowance when protection length is determined if the potential distribution behavior is considered. From these results it is recommended that the mitigation should be done base on the detailed design by using an exact simulation considering soil resistivity and candidate installment.

5. Conclusions

In this study the mitigation by non-contacting grounding plate was found to be effective with simple visual tests and computer simulation. By comparisons with horizontal anode and hemispheric anode, the widely-practiced horizontal equations are shown to result in more conservative than those at hemispheric model. However, the practical length taken should be more than the calculation due to the transition of interference after installment, and an analytical simulation is highly recommended in the mitigation design.

Acknowledgments

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