Analysis of Lightning Phenomena for Underground Petroleum Pipeline System

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Abstract

This article presents an analysis of lightning phenomena and guidelines for the protection of an underground oil pipeline system, considering the continuity of electric power after a lightning strike. The transient output is convolved using a mathematical program (ATP EMTP) to simulate a standard 10/350 microsecond waveform associated with multiple dimensions. In this study, physical properties are converted into electrical properties, such as pipe metal, pipe insulation, corrosion protection circuit wires, and grounding as analysis parameters. As a result of this simulation, it was found that the transient voltage increases higher when the length is longer and greater than the safety limit of the pipe corrosion protection devices. Appropriate characteristics of lightning protection devices were used in this study to limit this overvoltage. Based on the simulation result and the corresponding characteristics of the lightning protection devices, the transient voltage was limited according to BS 60950. The result showed that the correct lightning protection devices help to reduce the damage caused by lightning to the assets of the oil transportation industry.

Keywords: Pipeline; Lightning; Impedance; Transient; Induced voltage

Introduction

Pipeline Petroleum transportation is the fastest, convenience and safety. Its energy per unit cost is lowest when compare to other transportations. Normally underground petroleum pipeline will be laid at approximately 1.5 meter depth from soil surface and parallel to railway or high voltage transmission line.

From the record found corrosion protection devices which connect to pipeline always damage from lightning [1].

The previous studies on the effect of lightning to pipeline and how to protect pipeline coating, was on natural gas pipeline which laid nearby high structure and used finite element method [2] and CDEGS [3] program not only to study in electrical induction through pipeline which laid above soil and underground but also the possibility of underground cable damage from lightning at 132 kV [4]. Those studies did not consider about the combined of pipeline impedance and corrosion protection device cable impedance.

Nomenclature

$x_{(t)}$	Power function
$y_{(t)}$	Exponential Function
$i_{(t)}$	lightning current
I_0	peak current
h	coefficient to correct peak current
t	time
τ_1	front time constant
τ_2	tail time constant
n	slope factor.
ΔV	step voltage
ρ	specific soil resistance
I	lightning current
s	step distance
d	distance away from lightning first reach ground
R	soil resistance per meter
I_s	step current
V_{Pipe}	induced voltage at pipeline
L_{Pipe}	induction coefficient per 1 meter length
di/dt	the rate of change of lightning appeared at pipe per time

This article presents lightning phenomenon analysis for underground petroleum pipeline and its protection methodology by using program which used to simulate transient state in power system by considering both petroleum pipeline impedance and corrosion protection device cable impedance.

Therefore, the rest of this paper is organized as follows: Section 2 presents the lightning phenomenon analysis. 1.Electrical characteristic of soil, pipeline insulation and pipeline is presented in Section 3. Section 4 expresses the underground pipeline model and simulation results. Finally, the conclusion and discussion is given in Section 5.

1. Lightning phenomenon analysis

From standard IEC 61312 1, the maximum lightning current is 200 kA with 10 / 350 micro second waveform. As shown in figure 1, when lightning struck to construction, 50% of lightning power will be dissipated to earth, the left will be dissipated to other systems in the building that can be interfered such as power system, telephone cable or communication system. From statistical number of lightning magnitude in Thailand at 20 kA [5], the dissipation to earth current will be dissipated to underground petroleum pipeline

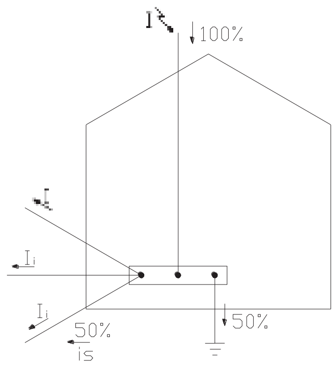

Fig. 1. Distribution of lightning current

Lightning waveform function

Lightning current is the most important factor in lightning phenomenon analysis for underground petroleum pipeline. Current function is a time domain function which can use Heidler's mathematic function to analyze its waveform [6] as following equation (1) – (4) which comply to IEC-61312-1

$$i_{(t)} = I_0 . x_{(t)} . y_{(t)} \tag{1}$$

where $x_{(t)}$ is Power function , $y_{(t)}$ is Exponential Function

$$x_{(t)} = \frac{K_s^n}{\left(1+K_s^n\right)} \quad ; K_s = t / \tau_1 \tag{2}$$

$$y_{(t)} = exp\left(-t / \tau_2\right) \tag{3}$$

$$i_{(t)} = \frac{I_0}{h} . \frac{\left(t / \tau_1\right)^n}{1+\left(t / \tau_2\right)^n} . exp\left(\frac{t}{\tau_2}\right) \tag{4}$$

where $i_{(t)}$ is lightning current, I_0 is peak current, h is coefficient to correct peak current, t is time, τ_1 is front time constant, τ_2 is tail time constant, n is slope factor.

Lightning waveform

From IEC 61312-1 standard as shown in figure 2, the lightning waveform which T1 is front wave time constant and T2 is tail wave time constant. T2 is considered at 50% peak current. The ratio of current to time is called steepness. (di/dt), its unit is kA/uS

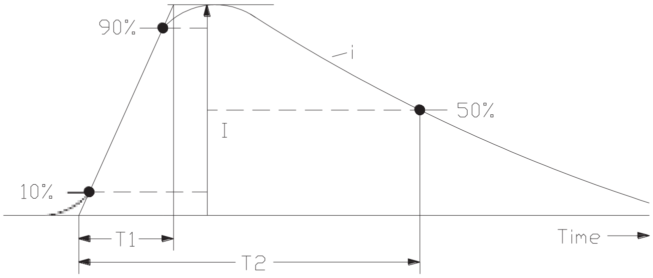

Fig. 2. Lightning current waveform

Pipeline system impedance

This analysis does not concern about lightning frequency so pipeline impedance per unit is calculated by using Laplace Transform by *Resistance = R*, *Inductance = sL, Capacitance = 1/sC*

Step voltage

As shown in figure 3, after lightning current reach the ground this position will contain maximum intensity of electrical field. This will cause lightning current and potential dissipate along soil surface in circular. The distance between each circular is approximately the same length as human step. We call this electrical circular as step voltage. In case petroleum pipeline and corrosion protection device cable are in the way of lightning current dissipation and step voltage, by through soil resistance through pipeline insulation and to pipeline metal, petroleum pipeline will get an effect by lightning current and step voltage too. The calculation of lightning current and potential are shown in equation (5)-(6)

$$\Delta V = \frac{I\rho}{2\pi} \cdot \left(\frac{s}{d(d+s)} \right) \quad (5)$$

$$I_s = \Delta V / R \quad (6)$$

where ΔV is step voltage, ρ is specific soil resistance, I is lightning current, s is step distance, d is distance away from lightning first reach ground, R is soil resistance per meter, I_s is step current.

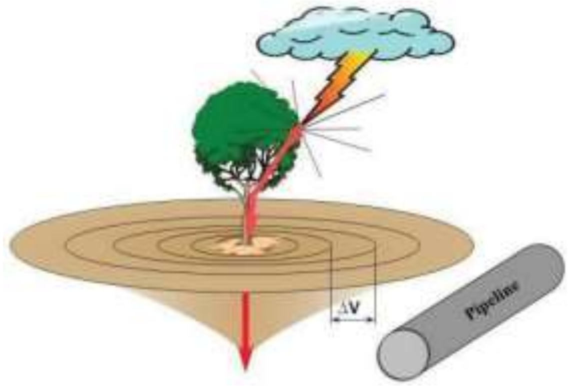

Fig. 3. Underground pipeline in the radius of step voltage

The distance away from lightning point to pipeline through step voltage for 5 meters, its current and potential will decrease. The lightning current at pipeline surface can be calculated as in equation (6) this current will be used as a parameter for lightning current sourcing in program ATP-EMTP.

Induced voltage from pipeline induction

When lightning current reach the ground, the electrical continuity which includes soil, pipeline insulation, pipeline metal and electrical cable will cause induced voltage along pipeline which is shown as in equation (7)

$$V_{Pipe} = L_{Pipe} \cdot \frac{di}{dt} \tag{7}$$

V_{Pipe} is induced voltage at pipeline, L_{Pipe} is induction coefficient per 1 meter length, di/dt is the rate of change of lightning appeared at pipe per time which can be calculated from equation (8) which is derived from equation (4)

$$\frac{di}{dt} = \frac{I_0}{h} \cdot \left\{ \left(\frac{(t/\tau_1)^{10}}{1+(t/\tau_1)^{10}} \right) . exp^{(-t/\tau_2)} . \left(-1/\tau_2\right) + exp^{(-t/\tau_2)} . \left\{ \frac{10.(t^9/t_1^{10})}{1+(t/t_1)^{10}} - \frac{10.(t^{19}/t_1^{20})}{\left[1+(t/t_1)^{10}\right]^2} \right\} \right\} \tag{8}$$

2. Electrical characteristic of soil, pipeline insulation and pipeline

Electrical characteristic of soil

Many researches have stated about electrical characteristic of soil because it has both direct and indirect contact to pipeline system on its electrical continuity. From figure 4, when consider electrical characteristic of soil there are compose with resistance (R) 1000 Ohm/m and capacitance (C) 221.35 pF/m as shown its equivalence circuit

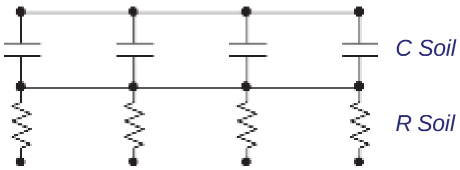

Fig. 4. Soil equivalent circuit

Electrical characteristic of pipeline insulation

External coating by using Fusion Bonded Epoxy (FBE) to protect directly contact between pipelines and soil, this will help to protect corrosion by its characteristic that withstand corrosion via acid or base and other corrode solutions and also has a very high resistance. When considering its characteristic it compose with resistance and capacitance by its resistance (R) 3.3^{17} Ω/m as follow ASTM-D257 and its average capacitance (C) 10.42 pF/cm² from field measurement.

Electrical characteristic of underground pipeline

Petroleum pipeline material comes from metal so when we consider its electrical characteristic it will compose with resistance per length (R) and its induction per length (L) as well. Normally its resistance is around 56.941 941 μΩ/m [8] and its average induction is around 0.495 H/m. Those values come from field measurement on 14" diameter pipeline.

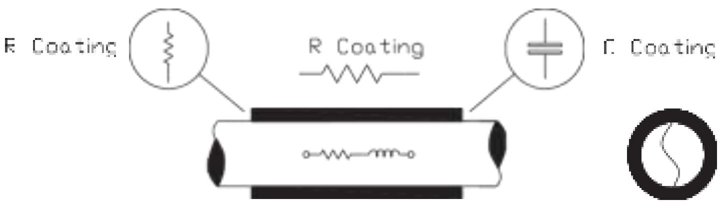

Fig. 5. Electrical element of pipeline

Surge protection

Metal oxide surge protection normally has a very high resistance and inverse to potential. Its current and potential characteristic are as in table 1 and its approximately calculation value as equation (9)

Table 1. V/I characteristic of arrestor

V	275	300	450	520	600	680	780	950	1.5k
I	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}

$$I = kV^{\alpha} \quad (9)$$

I is current pass through surge protection device, k is constant value depend on type of surge device, V is potential over surge device, α is power number which can be derived from equation (10)

$$a = \frac{\log I_2 - \log I_1}{\log V_2 - \log V_1} \quad (10)$$

3. Underground pipeline model and simulation results

Lightning current parameters which difference from [9] can be considered from first stroke where τ_1 equals to 19 micro second, τ_2 equals to 485 micro second, n equals to 10 as follow IEC 61312-1. Its simulation can be considered in 3 categories, 1) consider only pipeline impedance 2) consider impedance from both pipeline and corrosion protection cable and 3) protection for category 2. All categories simulate on pipe length at 500 and 1,000 meters by record instantaneous state at every 100 meters.

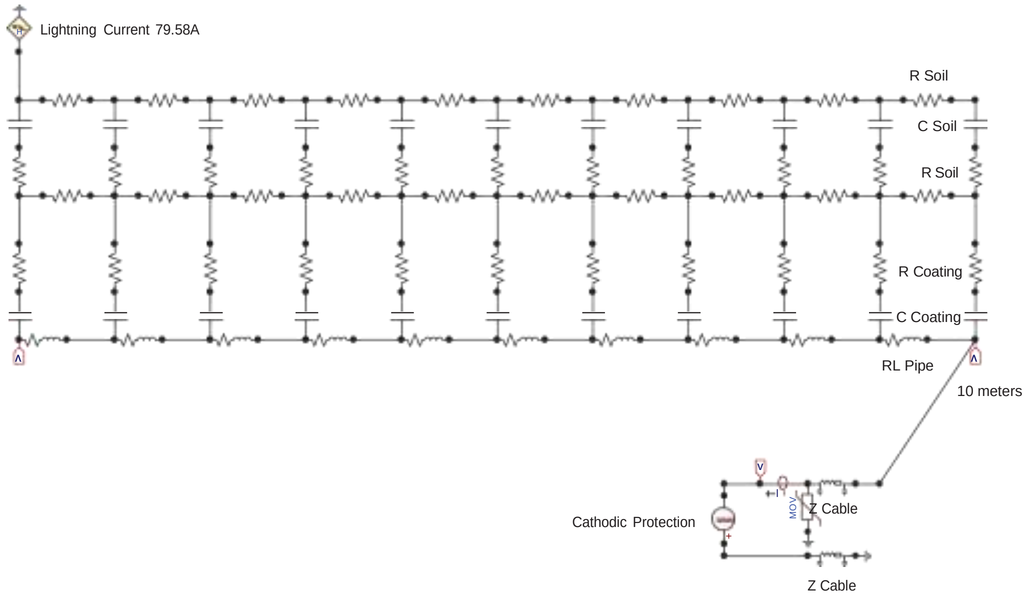

Fig. 6. Pipeline equivalent model

Table 2. Transient state on pipeline

Distances of record (Meters)	Appeared voltages (Kilovolts)		Appeared currents (Ampere)	
	Length of pipeline			
	500 m	1000 m	500 m	1000 m
initial (0)	4.124	4.124	0.158	0.079
100	4.857	4.902	0.158	0.079
200	5.497	5.681	0.158	0.079
300	5.956	6.369	0.158	0.079
400	6.231	6.964	0.158	0.079
500	6.323	7.468	0.158	0.079
600	-	7.881	-	0.079
700	-	8.202	-	0.079
800	-	8.431	-	0.079
900	-	8.569	-	0.079
1,000	-	8.615	-	0.079

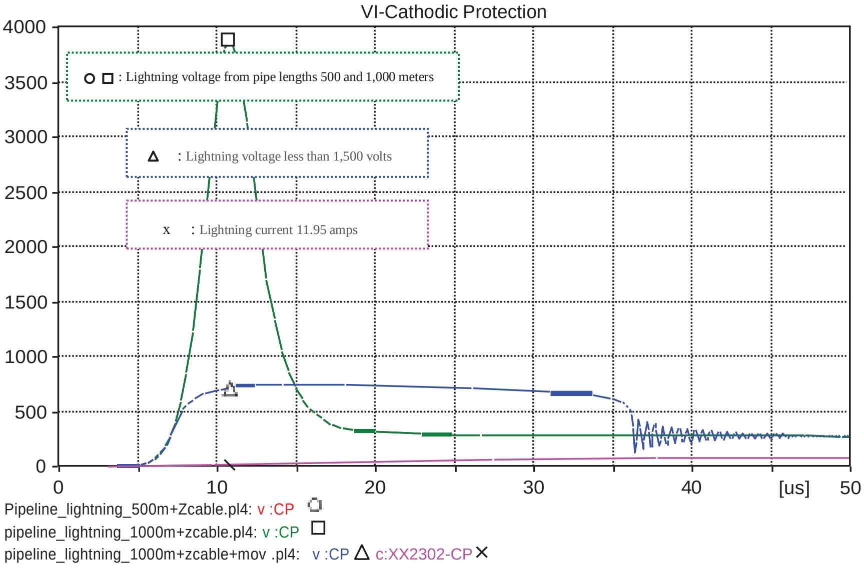

Fig. 7. lightning current and voltage to appears at cathodic protection

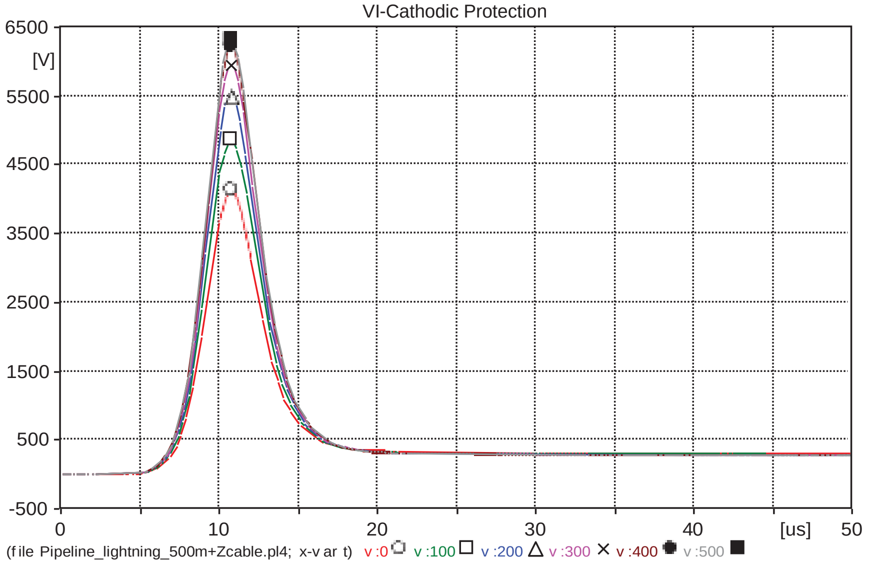

Fig. 8. Lightning current and voltage to appears pipeline from pipe length 500 meters

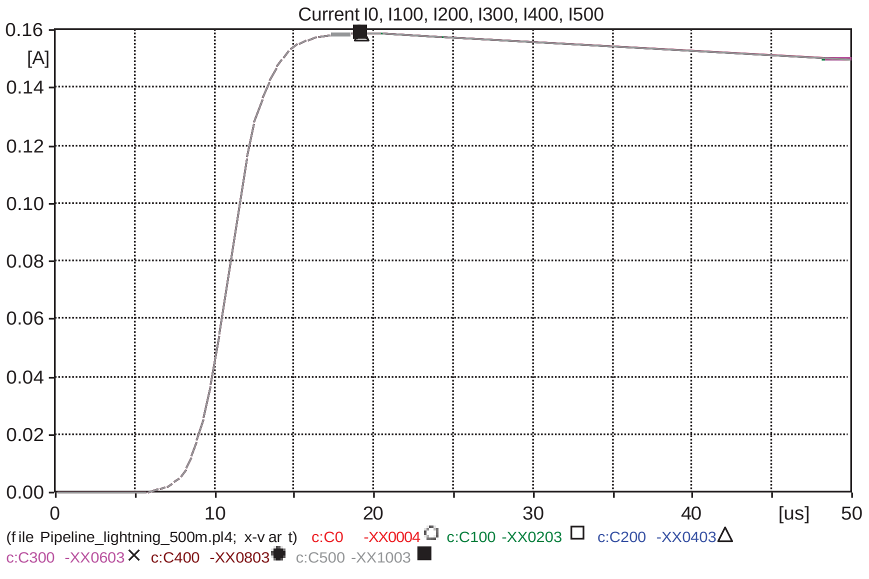

Fig. 9. Lightning current to appears pipeline from pipe length 500 meters

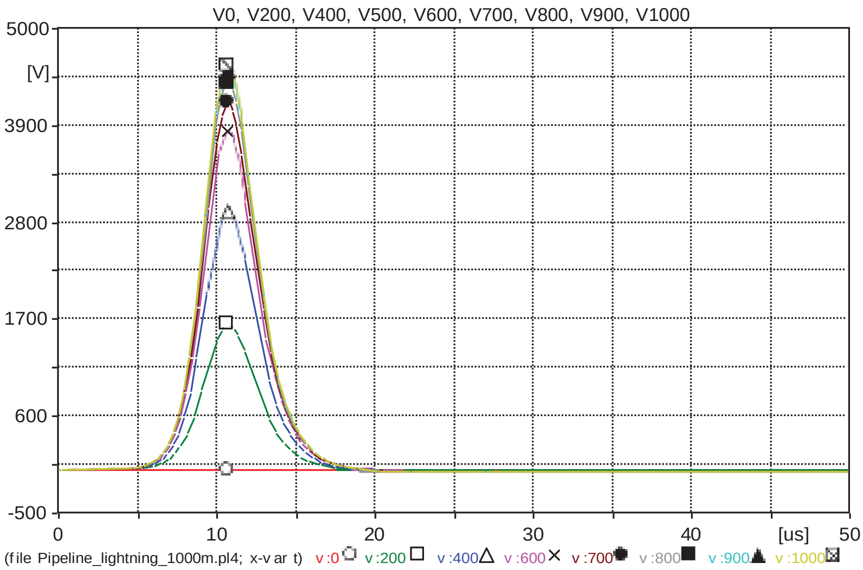

Fig. 9. Lightning voltage to appears pipeline from pipe length 1,000 meters

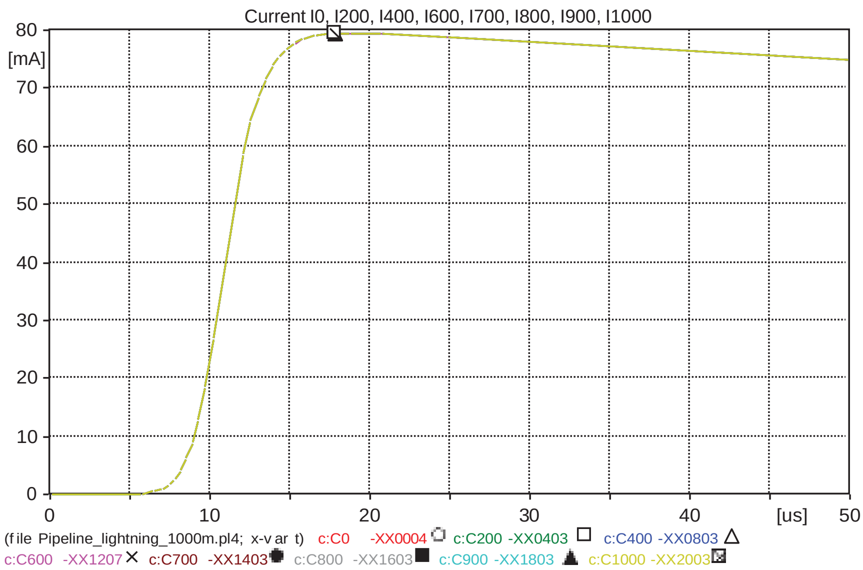

Fig. 10. Lightning current to appears pipeline from pipe length 1,000 meters

4. Conclusion

The analysis of the lightning phenomenon proposed for the underground oil pipeline and its protection included in this document and the result of its simulation showed that the instantaneous potential of lightning from a distance along the pipeline increases as the length of the pipeline increases. increases, its inductance varies directly according to its length as shown in equation (7) , and it was also found that the instantaneous current tends to decrease when its length increases, as shown in Table 2. Considering the impedance of the pipeline and corrosion. protective circuit cable, according to this analysis, both the instantaneous potential as well as a current greater than the safety value of the device, which is sufficient to damage the corrosion protection device. The protection simulation result showed that it can limit the instantaneous potential below 1500 volts according to BS60950 as shown in Figure 7, so it can be used to control the potential generated in the tube.

References

[1] Thai Petroleum Pipeline Co., LTD.,Department of Electrical Engineering. 2/8 Moo 11 Lumlukka Rd., Ladsawai, Lumlukka, Pathumthani 12150, Order No. 11028267

[2] Hitoshi Kijima, Kenji Takato, Kazuo Murakwa, "Lightning Protection for Gas-Pipelines installed under the Ground", *International Journal of systems Applications, Engineering & Development*, Issue 1, Volume 5, 2011

[3] Konstantinos Kopsidas, Ian Cotton, "Induced Voltages on Long Aerial and Buried Pipelines Due to Transmission Line Transients", *IEEE Transactions on Power Delivery*, Vol. 23, No. 3, July 2008

[4] Nor Emyliah binti husin, "Simulation Study on Lightning Effects to 132 kV Underground Cable Universittei Knotogmi Ataysa, 2011

[5] Nattaya Klairuang, Witchuda Sopho, and Pisarn Densungnern, Lightning Performance Improvement of 22 kV Distribution Line, Department of Electrical Engineering, Faculty of Engineering at Sriracha, Kasetsart University Sriracha Campus

[6] Nattaya Klairuang, Effect of Electric Fields Generated by Direct Lightning Strikes on Ground to Underground Cables, 2005, ISBN 974-9842-48-0

[7] Jin Shijiu, Li Jim, Chen Shili, Xiao Kun, Song Shizhe, "The Study of Detection Technology and Instrument of Buried Pipeline-Coating Defaults", *Proceedings of the 4* World Congress on Intelligent Control and Automation* lune 10-14, 2002

[8] A.W. Peabody, "Control of Pipeline Corrosion", *Second Edition 2001 by NACE International*, .pp. 30

[9] Boonlerd Topradith, Krischonme Bhumkittipich and Thanapong Suwanasri, *In 4th Electrical Engineering Network 2012*. Nong Khai, Thailand, April 3-5, pp.184-187